Andréia Bolzan de Paula

AVALIAÇÃO DA ADAPTAÇÃO MARGINAL E RESISTÊNCIA COMPRESSIVA DE RESTAURAÇÕES ESTÉTICAS TIPO ONLAY E DA DUREZA KNOOP DE UM CIMENTO RESINOSO DUAL

Dissertação apresentada à Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, para obtenção do título de Mestre em Materiais Dentários.

Orientadora: Profa. Dra. Regina Maria Puppin Rontani

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Dedico este trabalho

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RESUMO

O avanço da Odontologia Estética tem sido impulsionado pela introdução de novos compósitos resinosos e técnicas restauradoras. Para amenizar as falhas associadas à contração de polimerização, a técnica indireta tem se tornado uma alternativa na restauração de dentes com preparos extensos. Entretanto, a polimerização incompleta do agente cimentante pode ocasionar redução do desempenho físico e mecânico da restauração. Dessa forma, os objetivos desta dissertação foram: (1) avaliar o efeito da técnica restauradora e do tratamento termo/mecânico na adaptação marginal e resistência compressiva de restaurações estéticas tipo *onlay* fixadas com cimento resinoso e (2) a influência de diferentes espessuras de compósito resinoso e distâncias da ponta ativa do aparelho fotoativador na dureza Knoop do agente cimentante Rely-X ARC utilizado nas restaurações indiretas. No estudo 1, preparos tipo *onlay* foram realizados em 50 terceiros molares hígidos e restaurados com compósito resinoso Z-250. Os dentes foram separados em grupos de acordo com a técnica restauradora (direta/indireta) e a ciclagem termo/mecânica. Para a análise da adaptação marginal foi aplicada uma solução corante nas margens da restauração e as áreas coradas foram consideradas como presença de fendas marginais, as quais foram mensuradas através do software Image Tool 3.0. Todos os espécimes foram submetidos ao teste de resistência à compressão. No estudo 2 foi utilizado um incisivo bovino incluído em resina de poliestireno. A face vestibular foi planificada e sobre ela aplicada uma película de PVC e uma matriz de borracha, dentro da qual foi inserido o cimento resinoso Rely-X ARC e uma nova película de PVC. Discos de compósito resinoso, de espessuras diferentes, foram confeccionados e inseridos individualmente sobre este conjunto e fotoativados por 40 segundos, variando a distância da ponta ativa do fotoativador. Após armazenagem por 24h a 37°C, as amostras foram seccionadas longitudinalmente ao meio e polidas para mensuração da dureza Knoop em 3 profundidades do cimento. No estudo 1, não houve diferença estatisticamente significativa entre as técnicas restauradoras quanto à presença de fendas, entretanto, o tratamento termo/mecânico influenciou significativamente o aumento de fendas marginais. Na resistência à compressão não houve diferença estatística significativa entre as técnicas restauradoras empregadas e o tratamento termo/mecânico também não influenciou significativamente à resistência à compressão (RC). No estudo 2, a distância da ponta ativa do fotoativador assim como diferentes espessuras do disco de resina composta, resultou em valores de dureza Knoop estatisticamente distintos, nas profundidades. O aumento da espessura do disco de compósito resinoso ocasionou diminuição dos valores de dureza do cimento. Foi observado diminuição dos valores de dureza apenas quando foi utilizada a distância da ponta do fotoativador de 1mm. As regiões de base e centro apresentaram, respectivamente, os menores e maiores valores de dureza Knoop. Com base nos resultados obtidos pode-se concluir que as técnicas direta e indireta para restauração tipo *onlay* apresentaram similar resistência à fratura por compressão. A adaptação marginal foi influenciada pelo tratamento termo/mecânico; com o aumento da espessura do compósito restaurador e da distância do fotoativador, houve redução dos valores de dureza do cimento resinoso.

Palavras-chave: Materiais dentários, cimentos de resina, resinas compostas, adaptação marginal, resistência compressiva, dureza.

ABSTRACT

Esthetic Dentistry has advanced increasingly with the introduction of new resin composites and restorative techniques. To reduce failures associated with polymerization contraction, indirect technique has become an alternative to restoration of teeth with extensive preparations. However, the incomplete polymerization of luting agent can cause a decrease in the physical/mechanical performance of restorations. The objectives of this dissertation were to evaluate: (1) the effect of restorative technique and thermo/mechanical cycling on the marginal adaptation and compressive strength of onlay esthetic restorations bonded with luting resin agent and (2) the influence of different thickness of resin composite discs and the distances of tip of curing unit on Knoop hardness of luting agent Rely-X ARC used in indirect restorations. In the study 1, onlay cavity preparations were performed in 50 sound third molars that were restored with resin composites Z-250. The teeth were divided in groups according to the restorative technique (direct/indirect) and the thermal/mechanical cycling. To analyze the marginal adaptation, a dye solution was applied on the restoration margins and the dyed areas were considered as marginal gaps and measured by means of Image Tool 3.0 software. All specimens were submitted to mechanical test of compressive strength. In the study 2, a bovine incisor was embedded in a polystyrene resin. The buccal surface was ground flatted and over it was applied a PVC pellicle and a rubber mold. The luting cement Rely-X ARC was inserted into the mold and a new PVC pellicle was applied. Resin composite discs, with different thickness, were performed and placed individually over this set (tooth/luting cement) and polymerized for 40 seconds, modifying the distance of tip of light curing. After storing at 37^{o} C for 24 hours, specimens were longitudinally sectioned in two equal parts and polished to measure the Knoop hardness in three depth of cement. In the study 1, there was no statistically difference between the restorative techniques in relation to marginal gaps; however, thermal/mechanical cycling exerted significant influence on the increase of marginal gaps. About the compressive strength, any statistically difference was observed among the restorative techniques, independent of the thermal/mechanical cycling. In the study 2, the distance of tip of curing unit and distinct thickness of composite resin discs resulted in statistically different Knoop values when deepness was analyzed. The increase of resin disc thickness causes reduction on the hardness values of cement. Reductions on hardness values were observed only with 1mm tip curing unit distance. The base showed the lowest means while the center showed the highest. Based in the results obtained it could be concluded that direct and indirect techniques to onlay restoration had similar compressive strength. Marginal adaptation was influenced by thermal/mechanical cycling; increasing of resin composite thickness and distance of active tip of light curing unit, there was a reduction of hardness values of resin cement.

Keywords: Dental materials, luting cement, composite resin, marginal adaptation, compressive strength, hardness.

SUMÁRIO

INTRODUÇÃO

Compósitos resinosos têm sido utilizados como material restaurador em dentes posteriores desde a década de 60. No entanto, a primeira geração destes materiais apresentava grande alteração de cor e baixa resistência ao desgaste (Christensen & Buonocore, 1997). No decorrer dos anos, essas desvantagens têm sido minimizadas devido à melhora das propriedades mecânicas e estéticas desses materiais, além de permitir a confecção de preparos que preservam maior quantidade de estrutura dentária, quando comparados a outros materiais. Portanto, as restaurações adesivas realizadas com compósitos têm sido o tratamento de escolha para dentes posteriores (Leirskar, *et al.*, 2003; Spreafico, *et al.,* 2005; Peutzfeldt, 2001; Dietschi & Spreafico, 1997).

A maior parte das falhas causadas em restaurações de resina composta pode ser atribuída à contração durante o processo de polimerização. A reação química desencadeada na fase orgânica da resina produz a conversão dos monômeros em polímeros, resultando na aproximação das moléculas e conseqüente contração (Van Noort, 1994). No decorrer desse processo, essa tensão gerada no compósito se concentra na interface adesiva entre o dente e o material restaurador (Ferracane & Mitchem, 2003), comprometendo a integridade da união dessa região, podendo acarretar defeitos marginais, formação de fendas, deflexão de cúspides e sensibilidade pós-operatória (Soares *et al.,* 2005; Leirskar, *et al.*, 2003; Carvalho, *et al.,* 1996; Roulet, *et al.*, 1991; Retief, 1994). Frente a esse fato, é necessário que haja criteriosa seleção do material restaurador e da técnica adesiva, além da importância da configuração do preparo cavitário (Peutzfeldt & Asmussem, 2004), considerados fatores críticos no controle das conseqüências da tensão causada pela contração de polimerização (Burrow, *et al.*, 1994; Lutz, *et al.*, 1986).

Compósitos para *onlays* têm sido desenvolvidos tanto para técnica direta como para indireta (Kugel, 2000; Peutzfeldt, 2001) devido às propriedades físico-mecânicas melhoradas desses materiais. Atualmente, a técnica restauradora direta com resina composta tem sido a mais utilizada para a confecção de restaurações estéticas (Mondelli, *et al*., 2004), quando realizada diretamente no dente preparado, proporcionando menor número de visitas do paciente ao dentista, além de custo acessível (D'alpino, *et al*., 2002). Entretanto, a perda de união entre o compósito resinoso e a parede cavitária é devido à contração desse material durante a polimerização, sendo considerado o maior problema de significância clínica dessa técnica (Kakaboura, *et al*., 2006; Leirskar, *et al*.,2003). Além do risco de contaminação por saliva, quando o isolamento do meio bucal não é ideal (Forss & Widstrom, 2003) existe a dificuldade de restabelecer a forma anatômica e os contatos e contornos proximais (Soares *et al*., 2005).

Na tentativa de amenizar alguns dos problemas associados à técnica direta, a técnica indireta tem sido proposta (Von Mormann, *et al*. 1982). A maior vantagem desta técnica é a diminuição da tensão causada pela contração de polimerização (D'alpino, *et al*., 2002; Dijken & Horstedt, 1996; Dijken & Ludin, 1988; Shortall, *et al*., 1989), considerando que a restauração é confeccionada sobre um modelo de gesso e a contração do compósito ocorre fora do dente preparado (Peutzfeldt & Asmussen, 2004). Dessa forma, objetiva-se apenas a contração da fina camada de cimento resinoso (Gemalmaz & Kukrer, 2006; Iada, *et al*., 2003) utilizado durante o processo de fixação da peça protética, o que promoveria melhor selamento e adaptação marginal, quando comparada à técnica direta (Spreafico, *et al*., 2003; Ziskind, *et al*., 1998; Dijken & Horstedt, 1995). Entretanto, a polimerização do agente cimentante desenvolve tensões, as quais podem ocasionar o rompimento da união entre a restauração e o dente, gerando infiltração marginal (Hasanrisoglu, *et al*., 1996; Van Diikjen & Horstedt, 1996). Erros nas fases de moldagem, de obtenção de modelo e de delimitação na confecção da peça também podem interferir na ocorrência de fendas marginais (Peutzfeldt & Asmussen, 1990). Portanto, ambas as técnicas, direta e indireta, exibem vantagens e desvantagens próprias.

Além da influência destas técnicas restauradoras e materiais adesivos, outros parâmetros têm sido considerados para estimar o potencial dos danos causados pela contração de polimerização. Dentre esses parâmetros, podemos considerar o tamanho da cavidade, a presença ou ausência de esmalte ao redor das margens da cavidade e a qualidade, localização e morfologia da dentina (Peutzfeldt & Asmussen, 2004; Perdigão & Swift, 1994; Shono, *et al.*, 1999). Estudos têm demonstrado que restaurações diretas e indiretas exibem menor formação de fendas quando o término das margens do preparo cavitário está localizado em esmalte ao invés de dentina (Millengig, 1992; Dietchi, *et al.*, 1995). Isto pode ser explicado pelo fato da dentina ser um substrato complexo, heterogêneo e biologicamente hidratado e que torna o processo de adesão menos confiável, mesmo com o surgimento de novos materiais adesivos tentando minimizar esses efeitos (Linden, *et al.*,1995). Portanto, a qualidade marginal de restaurações adesivas posteriores pode ser otimizada com o término das margens do preparo cavitário em esmalte (Diestschi, *et al.*, 1995), uma vez que a adesão e a adaptação do material restaurador ao esmalte é mais eficiente. A adaptação da restauração insatisfatória é responsável por acelerar o processo da infiltração marginal e a deterioração da restauração (Alani & Tho, 1997; Miazaki, *et al.*, 1998). Porém, nem sempre o término em esmalte é possível, principalmente em se tratando de restaurações tipo Classe II e V, cuja margem cervical encontra-se em dentina.

Um fator muito importante relacionado à eficiente adaptação marginal e conseqüente longevidade da restauração é o cimento utilizado na fixação de restaurações indiretas. Além do preparo, as propriedades físicas e químicas desse material são consideradas essenciais para o sucesso clínico de coroas e próteses parciais fixas (Kumbuloglu, *et al.*,2004) uma vez que a resistência e durabilidade da união são promovidas pela retenção oferecida pelo cimento (El-Mowafy,1991). Tal retenção poderá garantir melhor selamento marginal, diminuindo a microinfiltração (Sorensen *et al.,* 1991) e aumentando a resistência à fratura dos dentes restaurados e da restauração (Jensen *et al.,* 1989).

A aplicação dos cimentos resinosos tem sido consideravelmente requerida nestes últimos anos, sendo o material de escolha para a cimentação de restaurações indiretas de compósito, de cerâmica e para cimentação de pinos (El-Mowafy *et al*., 1999). Os cimentos resinosos possuem composição e características similares as do compósito restaurador (Markus *et al.,* 2003). Eles podem ser classificados de acordo com o método ativação da polimerização dentro de três categorias: ativados quimicamente, por luz ou ainda por dupla ativação. Os cimentos de dupla ativação foram desenvolvidos na tentativa de combinar as propriedades desejáveis dos cimentos ativados química e fisicamente pela luz (El-Mowafy *et al*., 1999), o que promoveria, adequada polimerização em áreas profundas e maior controle do tempo de presa (Peutzfeldet, 1995), além de apresentarem baixa solubilidade, boa resistência à fratura e propriedades ópticas (Qualtrough & Hale, 1998).

Alguns trabalhos sobre cimentos de dupla ativação demonstraram que o emprego da fotoativação tem a capacidade de melhorar as propriedades mecânicas de tais materiais quando comparados com os mesmos ativados apenas pelo modo químico (el-Mowafy *et al*., 1999; Hofmann *et al*., 2001; Foxton *et al*., 2003). Quando a fotoativação do cimento resinoso é realizada indiretamente, alguns aspectos devem ser levados em consideração. À medida que a espessura do material restaurador aumenta, a dispersão de luz incidida é maior, reduzindo dessa maneira a quantidade de energia que atinge a camada de cimento. Tal redução, também é observada quando a distância da ponta ativa da unidade fotoativadora em relação à superfície do compósito é aumentada, uma vez que o contato direto entre ambos não é possível em todas as situações clínicas (Correr-Sobrinho *et al.,* 2000). Assim ocorreria menor grau de conversão do cimento, o qual é dependente da energia fornecida durante a fotoativação (Rueggeberg *et al*.,1994; Halvorson *et al*., 2003). Esse fato acarretaria na polimerização inadequada e subseqüente alteração das propriedades físicas e mecânicas deste material (Chang & Boyer, 1989; Blackman *et al*., 1990), além da possível dissolução do cimento e ingresso de bactérias (Leirskar *et al.,* 1999).

Uma forma indireta de se estimar o grau de conversão de um material é o ensaio de dureza, por ser um método simples e confiável (Darr & Jacobsen, 1995). Correr-Sobrinho *et al.,* (2000), verificaram a influência da distância da ponta ativa da unidade fotoativadora, sobre a dureza Knoop em diferentes profundidades dos compósitos Z100 e Silux Plus e constataram menores valores de dureza para ambos compósitos quando tal distância foi aumentada, atribuindo tais resultados à diminuição da intensidade de luz emitida, acarretando em menor grau de conversão do compósito, que refletiria na diminuição das propriedades físicas e mecânicas do material, e portanto, comprometeria o seu desempenho.

Tensões químicas, térmicas e mecânicas (Abdalla & Davidson, 1996; da Cunha Mello, *et al*., 1997) quando associadas a um menor grau de conversão do material podem contribuir para a deterioração das restaurações. Devido à evolução rápida e constante dos materiais adesivos e à dificuldade de acompanhamento clínico em longo prazo, metodologias simulando os diferentes tipos de estresses presentes na cavidade bucal têm sido realizadas (Bedran & Pereira, 2004), tornando mais confiáveis os resultados obtidos nas pesquisas *in vitro*.

O desempenho das técnicas restauradoras em dentes permanentes em relação à adaptação marginal e resistência compressiva, quando tais dentes são submetidos ao tratamento termo-mecânico e o grau de conversão do material utilizado na cimentação das restaurações indiretas, são tópicos importantes para mensurar a longevidade das restaurações.

Assim sendo, os objetivos desta dissertação[1], dividida em 2 capítulos, foram: 1. Avaliar a influência da técnica restauradora (direta e indireta) e do tratamento termo/mecânico na adaptação marginal e na resistência compressiva em restaurações estéticas tipo *onlay*; 2. Avaliar a influência de diferentes distâncias de fotoativação e espessuras de restaurações tipo *onlay* em compósito resinoso na dureza de um cimento resinoso de dupla ativação.

[1] Este trabalho foi realizado no formato alternativo, com base na deliberação da Comissão Central de Pós-Graduação (CCPG) da Universidade Estadual de Campinas (UNICAMP) nº001/98.

CAPÍTULO 1

Effect of restorative technique and thermal/mechanical treatment on marginal adaptation and compressive strength of esthetic restorations

CLINICAL RELEVANCE

The direct technique can be indicated to restore posterior teeth with composite resin due to some advantages over the indirect technique, such as the shorter clinical time and low cost. However, it has taken in account that in case of failure, the direct restorations showed the worst kind of fractures, as catastrophic ones.

Paper submitted for consideration of publication by Operative Dentistry

ABSTRACT

Objectives: The purpose of this study was to evaluate the compressive strength and marginal adaptation of composite onlay, using indirect and direct techniques, after thermal and mechanical cycling.

Material and methods: Onlay standardized cavities were prepared in fifty permanent molars and restored with Z-250 composite resin using indirect (IRT) or direct (DRT) restorative techniques and submitted or not to thermal (500 cycles, 5 to 55º C) and mechanical cycling (50,000 cycles, 70N). The teeth were distributed into five groups (n=10): G1- IRT/cycling; G2- IRT/ no cycling; G3 – DRT/cycling; G4 – DRT/no cycling and G5 (control group) – sound teeth. All prepared teeth were stored in 100% relative humidity at 37o C during 24 hours followed by finishing with Sof-lex discs. A Caries Detector solution was applied on the tooth-restoration interface of all teeth for 5 seconds, followed by washing and drying. Four digital photographs were taken of each dental surface. The extension of gaps was measured using a standard software (Image Tool 3.0). All groups were submitted to compression test in a universal testing machine INSTRON at a crosshead speed of 1mm/min. The compressive strength (CS) and marginal adaptation data were submitted to ANOVA and Tukey test ($p<0.05$).

Results: For both evaluation criteria (compressive strength and marginal adaptation), there was no statistically difference among the restorative techniques used in this study. Thermal/mechanical cycling did not exert significant influence on CS. However, the experimental groups had lower compressive strength ($p<0.05$) when compared to the control group.

Conclusions: Onlay restorations prepared with both indirect and direct techniques had similar compressive strength and marginal adaptation; only the marginal adaptation was influenced by thermal / mechanical treatment.

Key words: marginal adaptation, composite resins, compressive strength, thermal cycling, polymerization techniques.

INTRODUCTION

Esthetic restorations in posterior teeth with composite resins have been markedly required in dental offices, since they are considered less expensive than other esthetic materials (Rada, 1994). Although the composite materials have reached great development since their introduction, with modern formulations that promoted improvements in the biomechanical and esthetic properties (De Gee, Feilzer & Davidson, 1993), composite shrinkage during polymerization is the main cause of failures of composite resin restorations (Van Noort, 1994); it affects the integrity of the tooth/restoration bonding interface, originating marginal defects, gaps, secondary caries, cusp deflection and postoperative sensitivity (Soares & others, 2005; Leirskar & others, 2003).

The direct technique is commonly applied in esthetic restorations because of its low cost and decrease in number of clinical sections (D'alpino & others, 2002). However, resin shrinkage during polymerization is considered a significant clinical problem of this technique (Leirskar & others, 2003); besides the difficulty to achieve contact points, correct anatomical contour and accessibility to the proximal surface during light-curing (Karakaya, Rahiotis & Ozer, 2005). For these reasons, restorative techniques that promote polymerization of composite resin outside the mouth have been investigated (Soares & others, 2004).

Accomplishment of resin restorations using the indirect technique has some advantages when compared to the direct technique, such as restriction of polymerization shrinkage to a thin layer of luting cement used for cementation of the restoration, besides maintenance of adhesive interface, improvement of bond strength (Braga et al., 2000) and better finishing and polishing (Borges et al, 2006), promoting a positive influence on the marginal adaptation of these restorations (Diestchi et al., 2002). Although the polymerization shrinkage can be reduced, rupture between the luting agent and tooth structure may still occur (Fabianelli & others, 2005); thus, complete elimination of marginal gaps using the indirect technique is not possible so far (Peutzfeldt & Asmussen, 1990).

Besides the restorative technique, selection of the restorative material and the configuration of cavity preparation may be associated with the deleterious effects of polymerization shrinkage (Peutzfeldt & Asmussem, 2004) and may influence the marginal adaptation and compressive strength of restored teeth (Soares & others, 2004).

Extensive cavity preparations lead to tooth weakness (De Freitas & others, 2002) and utilization of composite resins can reinforce the tooth structure. Because of this, compressive strength assays have been applied to evaluate the maximum load supported by restored teeth, considering the rigidity, modulus of elasticity associated with the coefficient of thermal expansion and bond strength of the restorative material. These factors contribute to increase the ability of absorption of compressive forces by the restored tooth (D'alpino & others, 2002), allowing comparative analysis of resistance among the different restorative procedures (Soares & Martins, 2004).

Methodologies simulating thermal and mechanical stresses that normally occur in the oral cavity have been applied *in vitro* studies to measure the longevity of restored teeth (Bedran-de-Castro, Pereira & Pimenta, 2004). Studies evaluating the microleakage of dental materials have shown contradictory results considering the effectiveness of thermal and mechanical stress (Hakimeh & others, 2000; Chan & Glyn-Jones, 1994). The same was verified for the bond strength between tooth structure and restoration, although few studies on bond strength have applied these types of stress simultaneously (Nikaido & others, 2002a, Nikaido & others, 2002b).

The null hypothesis in this study was that the restorative technique and thermal / mechanical cycling not influence the compressive strength and marginal adaptation of onlay preparations in permanent teeth.

METHODS AND MATERIALS

This study was approved by Research Ethics Committee of the School of Dentistry of Piracicaba – State University of Campinas (Approval n. 099/2005), according to the recommendations of the National Health Council – Ministry of Health of Brazil for researching in human subjects. Fifty freshly extracted permanent third molars with similar dimension and anatomy as mandibular first molars or maxillary second molars were selected. The teeth were cleaned, disinfected and frozen-stored until utilization. The teeth were distributed into five groups (n=10) according to the treatment (Table 1). Each group comprised five third molars anatomically similar to the mandibular first molars and maxillary second molars.

Each tooth was embedded in PVC cylinders (18-mm diameter and 25-mm height) using polystyrene resin (Piraglass Ltda., Piracicaba, SP. Brazil). The crows were positioned at 1mm below the cementoenamel junction and totally out of the resin. Onlay cavity preparations were performed in a machine in order to standardize the dimensions of the cavity, using diamond tapered burs # 4137 with 6º inclination related to wall cavities (KG Sorensen, São Paulo, SP, Brazil), positioned parallel to the tooth long axis, at high-speed with thorough abundant irrigation. Forty teeth were prepared and ten sound teeth comprised the control group. The diamond burs were always replaced after preparation of five cavities. The teeth were prepared with the following characteristics:

Occlusal Box: the isthmus width was approximately one third the buccal-lingual distance without cavosurface grinding; the depth of the pulpal wall was 2 mm in relation to central fissures on the occlusal surface.

Proximal Box: the depth was based on half of the distance between the pulpal wall and cementoenamel junction, due to variations in cervical-occlusal height. The diameter of the active tip of the bur was used as the parameter for the mesial-distal width of the gingival wall. The inner angles of prepared teeth were rounded.

All teeth received additional grinding of the functional cusp up to the depth of the pulpal wall. The following cusps were removed: palatal cusp of teeth anatomically similar to the maxillary second molars, and mesiobuccal cusp of teeth similar to mandibular first molars.

Indirect technique

Impressions from the preparations were taken using putty and light polisiloxane (Flexitime® Trial Kit -Heraeus Kulzer Hanau, Germany) using a PVC cylinder (12.5 mm) fixed to a metallic handle as tray impression. After 1 hour, the casts were poured in stone (Durone IV, Dentsply, Petropolis, RJ, Brazil) and removed after one hour. Indirect restorations (groups G1 and G2) were made in the stone, previously isolated with Isolacril (Asfer, São Paulo, SP, Brazil), using a hybrid composite (Filtek Z-250, C4 shade, 3M/ESPE - Table 2), by the incremental technique, beginning by the proximal box followed by the occlusal box. Each increment was light-cured for 40 s using the Elipar Triligth curing unit (ESPE, Germany; Norristow, AMERICA INC.).

The bonding procedure of restorations on the tooth surfaces was made according to the manufacture's instructions, using the adhesive system Single Bond 2 (3M/ESPE, St. Paul, MN, USA – Table 2) and dual-cured resin luting agents Rely-X ARC (3M-ESPE, St. Paul, MN, USA – Table 2), which were inserted on the inner surface of onlays after cleaning with phosphoric acid etching (Scotchbond ® - 3M/ESPE. Paul, MN, USA – Table 2). The onlay was fixed by finger pressure, simulating a clinical situation, and the excess luting cement was removed with a cutting instrument. Then, each surface (buccal, lingual, mesial and distal) was light-cured with Elipar Trilight light curing unit (power density: 800 mw/cm^2, 3M/ESPE, St. Paul, MN, U.S.A.) for 40s (. After that, the restoration/tooth set was stored in 100% relative humidity at 37°C during 24h followed by finishing with diamond bur 3139F (KG Sorensen Ind. Com. Ltda., Barueri, S.P., Brazil) and Soflex (3M, St. Paul, MN USA) discs.

Direct technique

Direct restorations (groups G3 and G4) were made using a hybrid composite (Filtek Z-250, C4 shade, 3M/ESPE- Table 2), by the incremental technique, and bonded to the teeth with the system Single Bond 2, according to the manufacture's instructions. The restoration/tooth set was stored in 100% relative humidity at 37°C during 24h followed by finishing following the same protocol used for indirect restorations.

Marginal adaptation test

After storage, an acid red solution in propylene glycol (Caries Detector – Kuraray Co., Japan) was applied on the restoration margins of groups G2 and G4 during 5s, rinsed in cooled water and dried with absorbent paper. Two mark points were drawn on all tooth surfaces (buccal, palatal/lingual, mesial and distal) with a pen using a digital caliper rule, with a 2-mm distance between them. Next, using a digital camera (Mavica FD 97, Tokyo, Japan), color photographs were taken of each tooth surface (buccal, palatal / lingual, mesial and distal) at the same distance, magnification and light using a tripod.

Then, each digital photograph of each surface was evaluated in the Image Tool 3.0 software (Periodontology Department, University of Texas, Health Science Center at San Antonio, TX, USA). A calibrated examiner performed all measurements after application of a confidence test using 25% of the total sample. The statistical correlation results (Pearson Correlation Test) showed 97% of confidence (R^2 = 0,9538); p=0.00. The two points drawn on the tooth surfaces were used to calibrate the spatial measurement. Then, a line was drawn on all tooth/restoration margins, and the total of 4 surface lengths was determined as total tooth/restoration interface length.

The gaps of tooth/restoration were determined. The dyed lengths of each surface were measured and recorded, and the total dyed length of four surfaces was determined as total gap length. The data of each specimen were transformed to gap percentage related to the total margin using the formula gap:

$$\%GAP = \frac{l}{l_T} \times 100$$

where l is the dyed length; l_T is the total margin length. Data were submitted to two-way ANOVA at a significance level of 95%; and the mean were compared by the Tukey test (p<0.05).

Thermal Cycling and Mechanical Load Cycling Procedure

After storage, specimens of the G1 and G3 groups were submitted to mechanical load cycling. The apparatus used for the cycling load belonged to Restorative Dentistry of Piracicaba Dental School – UNICAMP, Brazil, consisted of five stainless steel pistons with cylindrical tips and spherical ends, with 2 mm of diameter. These tips were placed in contact with the center of the occlusal surface of restorations. The loading device delivered an intermittent axial force of 70N at the frequency of 2.5Hz, adding up to 50,000 cycles. Next, the specimens were subjected to 500 cycles in a thermal cycling apparatus, belonged to the same department, with two baths at 5 to ±2°C and 55 to ±2°C each with dwell time of 30 seconds and a transfer time of seven seconds between each bath. After cycling, the marginal adaptation was measured.

Compression test

All groups were submitted to compression test in a universal testing machine (model 4411, INSTRON Corp., Canton, MA). The specimens were inserted in a metallic matrix that acted as a supporting base and reinforced the PVC cylinder. A 5-mm stainless steel sphere was placed on the occlusal surface of molars and loaded at a crosshead speed of 1mm/min until the specimen is fractured. Data were obtained in Kgf and specimens were stored in distilled water for posterior analysis of the fracture pattern of each specimen. Data were analyzed by the two-way ANOVA ($p<0.05$), and Dunn test to compare with control group ($p<0.05$).

Analysis of fracture types

After the compression test, the set (tooth/fractured restoration) was observed by visual inspection and classified according to the failure: catastrophic type (when the fracture occurred until the root) and non catastrophic type (when the fracture was limited to coronal portion of the tooth).

RESULTS

The means of compressive test values and the frequency of catastrophic fracture sites are displayed in Table 3, Table 4 and Figure 1, respectively. The ANOVA test showed that there were no significant differences in compressive strength (CS) between the restorative techniques evaluated in this study. Thermal/mechanical cycling did not have a significant influence on CS. However, the experimental groups had lower compressive strength values ($p<0.05$) compared to the control group. The frequency of marginal gaps is listed in Table 5 and Figure 2. The results indicated that there was no statistically difference among the percentage of gaps obtained in direct restorations when compared with the indirect technique. However, after the thermal/mechanical treatment, both types of restorations had a significant increase in the marginal gaps values.

DISCUSSION

The loss of dental hard tissues resulting from the caries process or even cavity preparation weakens the tooth structure (De Freitas & others, 2002), especially when this preparation is a mesial-occlusal-distal cavity (MOD) because the proximal boxes increase the possibility of tooth fracture (Mondelli & others, 1980).

The choice of restorative materials with suitable physical and mechanical properties similar to sound teeth, especially fracture strength, is an important decision taken by the dentist during dental attendance. For many years, acid etching has been used in bonding procedures and several studies demonstrated that it strengthens the remaining tooth structure (Santos & Bezerra, 2005). However, many researches have demonstrated that teeth with occlusal-proximal cavities did not recover the same fracture strength of sound teeth after restoration with composite resin (Geurtsen & Garcia-Godoy, 1999). This study demonstrated that specimens of groups G1, G2 G3 and G4, regardless of the treatment and restorative technique used, did not recover the compressive resistance compared to sound teeth (Group 5). These results are similar to those obtained by Watts & others (1995) and Geurtsen & Garcia-Godoy (1999), who observed the partial reinforcement of teeth restored with composite resin when compared to sound teeth.

However, the teeth restoration with composite resin reinforces the dental structure when compared with no restored and prepared teeth. Blaser & others (1993) and Bakke & others (1985) have determined compressive test values between 51% and 64% to large MOD preparations with occlusal box presenting the isthmus width with one-third of inter-cusp distance and approximate depth of 3 mm (without restoration) when compared to sound teeth. In this present study, the compressive strength recovery of restored and prepared teeth reached values between 61% and 76% in relation to the control group, without statistically significant difference among the study groups.

Considering the restorative technique, G1 and G2 groups with teeth restored with indirect technique had similar compressive strength (CS) as G3 and G4 groups with teeth restored using the direct technique, suggesting that both techniques had the same clinical performance. Scientific evidences have shown that the direct restorative technique generates higher stress at the tooth/restoration interface when compared to the indirect technique, and such tension could be influenced by the configuration and extent of cavity preparation and caused by polymerization shrinkage of composites (Versluis & others, 2004). Some investigators have demonstrated that large MOD restorations with additional grinding of a cusp show lower stress on the restoration and tooth/restoration interface, but increase the stress on the tooth structure, resulting in a reduction of compressive strength of restored teeth. Although no statistically significant difference was observed among the CS values of teeth treated by both restorative techniques, in the analysis of fracture sites, the catastrophic ones were observed for the direct technique restoration, especially when associated with thermal/mechanical cycling (G3).

The compressive strength values observed for restored teeth not submitted to cycling (G2/G4) compared to the control group (G5) disagreed with the findings obtained by D'alpino & others (2002), who reported there is no statistical difference in fracture resistance between sound and composite-restored teeth. This discrepancy among results can probably be attributed to different experimental conditions, such as the utilization of less conservative preparations in this study, in which the functional cusp was removed.

Thermal and mechanical cycling methods have been used to simulate the oral conditions and the stress caused by the chewing process (Bedran-de-Castro & others, 2004b). The frequency and number of cycles, restorative material and C factor seem to be the most divergent factors among studies (Hakimeh & others, 2000).

In the present study, the intermittent axial force of 70N and a total of 50.000 mechanical cycles were chosen to simulate a constant occlusal load distributed during chewing. These factors associated with thermal cycling proposed by the ISO guidelines did not influence the compressive recovery of specimens of G1 and G3 groups, restored by the indirect and direct techniques respectively, when compared with G2 and G4 groups (no cycling). Studies have demonstrated variability in the influence of thermal/mechanical cycling on the performance of tooth structure/restoration bonding, indicating that different strength tests may indicate different material behaviors (Bedran-de Castro, Pereira & Pimenta, 2004a; Bedran-de-Castro & others, 2004b).

The thermal/mechanical cycling may have more influence on the bond strength of the material to the tooth substrate (Nikaido & others, 2002a; Nikaido & others, 2002b; Bedran-de-Castro, Pereira & Pimenta, 2004a) than the compressive recovery of restored teeth. In bonding strength tests, such as microtensile and shear tests, the force is concentrated in small areas (Sano & others, 1994) and in compressive strength tests, the applied force is absorbed and dissipated in a greater area.

The marginal integrity is the most important factor in the evaluation of clinical success of the tooth restorations and depends on several factors, especially marginal adaptation (Kournetas & others, 2004). The formation of marginal gaps is associated with some factors, such as the dental material (composite resin and bonding system), restorative technique (Peutzfeldt & Asmussen 2004), cavity preparation and bonding substrate. Regarding the standardization of cavity preparation and restorative materials, this study emphasized the parameters related to the restorative technique and thermal/mechanical treatment for analysis of marginal adaptation and compressive strength.

Considering the marginal adaptation of onlay restorations, in this study, the specimens directly restored and submitted to thermal/mechanical cycling (G3/G4) were not statistically different from indirectly restored teeth (G1/ G2) concerning the percentage of gaps. These results are similar to those found by Alani & Kianimanesh (2002) and Soares & others (2005), who observed similar effectiveness of both restorative techniques when the marginal integrity was evaluated. Conversely, the marginal sealing promoted by resin composites has been pointed as deficient (Braga, Ferracane & Condon, 2002), although improved bond strength to the tooth structure (enamel and dentin) has been observed by some investigators (D'alpino & others, 2002; Montes & others, 2000). In spite of the presence of marginal gap does not necessarily correspond to microleakage, the detection of gaps in enamel margins can cause microleakage in both enamel and dentin (Dietschi & Herzfel, 1998; Prati & others, 2004).

The most significant clinical problem of the direct restorative technique is the stress of polymerization shrinkage (Leirskar & others, 2003), which can lead to rupture of the composite resin/cavity wall bonding. Several studies have shown better performance of the indirect technique compared to the direct technique considering the marginal adaptation (Censi & others, 2005; Dietschi, Scampa & Holz, 1995), due to the decrease in polymerization stress. However, in this study, there was no statistical difference in relation the presence of marginal gaps for both restorative techniques. This finding may have occurred because the incremental technique used in direct restorations. This technique has been used to limit stress development and maintain the satisfactory marginal adaptation (Kreijci &

Stavvridaki, 2000) The reduced thickness of cured resin improves the stress release by draining of the material through the free surfaces, besides the greater uniformity and distribution of curing energy inside each increment (Davidson & Gee, 1984). For the indirect restorative technique), the polymerization stress is controlled by a thin layer of resin cement (Shortall & others, 1989; Gemalmaz & Kukrer, 2006) interposed between the restoration and dental substrate.

The resin cement used in this study contains bifunctional monomers such as Bis-GMA that assign high viscosity to the material, which is reduced by the inclusion of monomer's diluents (TEGDMA) to yield a polymeric network. However, significant polymerization shrinkage occurs in this reaction and even a thin layer of resin cement could cause sufficient stress to generate bonding failures, as observed in the present study. It is possible that the problems related to polymerization shrinkage might not be eliminated only by utilization of the indirect technique. Besides, the inappropriate execution of any step of this technique could compromise the marginal integrity of restoration and consequently originate interface gaps (Alavi & Kianimanesh, 2002; Peutzfeldt & Asmussen, 1990).

In this study, it was observed that thermal/mechanical cycling negatively influenced the marginal adaptation, regardless of the restorative technique used, with significant increase in the percentage of marginal gaps, especially at the cervical areas. This finding can be assigned to occlusal stresses generated at the tooth/restoration interface (Van Meerbeek & others, 1998). Besides, temperature cycling also induces repetitive shrinkage and expansion stress on the tooth/restorative material interface (Galé & Darvell, 1999). These stresses can cause fissures that propagate through the entire bonding interface and create a continuous flow of oral fluids, in a process called percolation (Irie & Suzuki, 2001). Then, it could be suggested that thermal/mechanical cycling of restored teeth results in significant stress between tooth and dental material and the frequency/number of cycles used in this study was sufficient to increase the percentage of marginal gaps in G1 and G3 specimens when compared to G2 and

G4, whose teeth were not submitted to cycling, regardless of the restorative technique used.

Considering the compressive strength and marginal adaptation, no influence of the restorative technique was observed on the restoration performance. Based on these results, the direct technique can be indicated to restore posterior teeth with composite resin due to some advantages over the indirect technique, such as the shorter clinical time and low cost. However, in case of failure, the direct restorations showed the worst kind of fractures, catastrophic ones.

Despite acceptance of the tested hypothesis that the restorative technique and thermal/mechanical cycling do recovery not the compressive strength, the hypothesis that thermal/mechanical cycling does not influence the marginal adaptation of onlay restorations was rejected.

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Table 1 – Distribution of groups according to the restorative techniques and treatment used in this study.

Groups	Restorative technique		Thermal/Mechanical
	Direct	Indirect	Treatment
G1		X	X
G2		X	
G3	X		X
G4	X		
G5	Sound teeth		

Table 2 – Description of the restorative materials and luting cements used in this study.

Materials	Composition*	Manufacturer Batch n.
Scotchbond Etching®	37% phosphoric acid	(3M/ESPE, St Paul, MN EUA);
Filtek Z250 (C4)	Bis-GMA, Bis-EMA; UDMA; zirconia/silica filler (82w%)	3M/ESPE, St. Paul, MN, USA-5LT
Rely-X (A3)	Bis-GMA; TEGDMA zirconia/silica filler (67.5w%) dimethacrylate monomers	3M/ESPE, St. Paul, MN, USA-FBFM
Single Bond 2	HEMA; Bis-GMA; water, ethanol photoinitiators, silica	3M/ESPE, St. Paul, MN, USA-4KF

Table 3 – Compressive strength means (Kgf) and standard deviation (SD) compared with control group of percentage specimens with catastrophic fractures.

Indirect restoration		Direct restoration		Control group
Cycling (G1)	No Cycling (G2)	Cycling (G3)	No Cycling (G4)	(G5)
203.435 ± 77.94a	222.66 ± 51.63a	181.131 ± 61.62a	206.08 ± 66.77a	298.51 ± 79.93b
30%	30%	70%	20%	

Means followed by different lower case letters are statistically different ($p > 0.05$). The percentage refers to specimens without possibility of restoration.

Table 4 - Compressive strength means (Kgf) and standard deviation (SD).

Treatment	Indirect restoration	Direct restoration
Cycling	203.435 ± 77.94aA	181.131 ± 61.62aA
No Cycling	222.66 ± 51.63aA	206.08 ± 66.77aA

Means followed by different lower (lines) and upper (columns) case letters are statistically different ($p < 0.05$).

Figure 1 – Compressive strength means and standard deviations, obtained by different treatments.

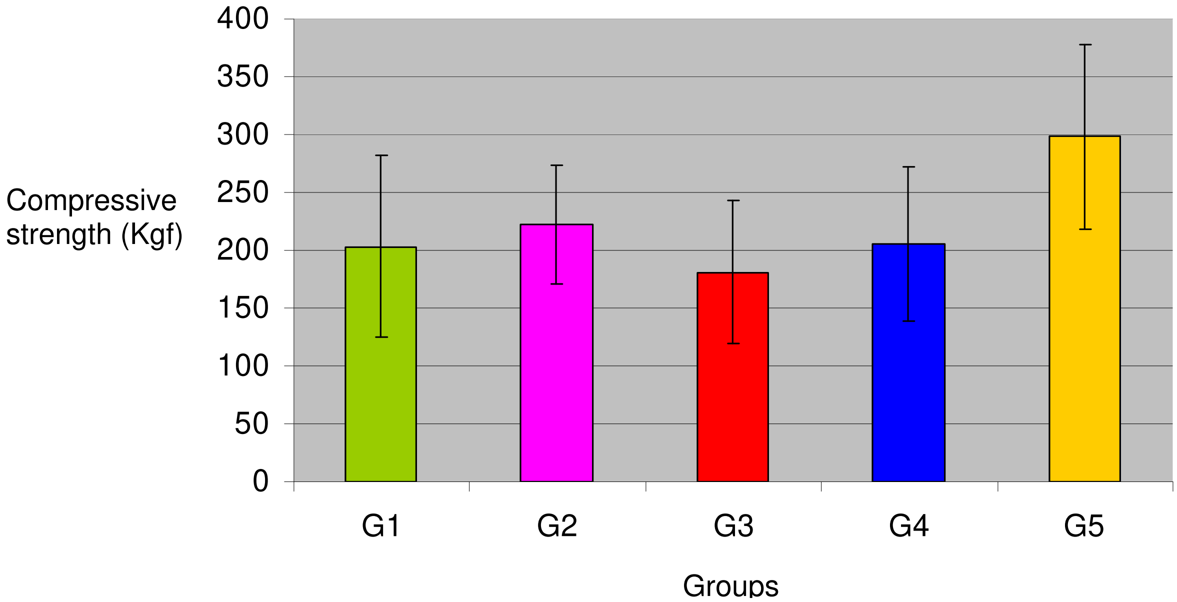
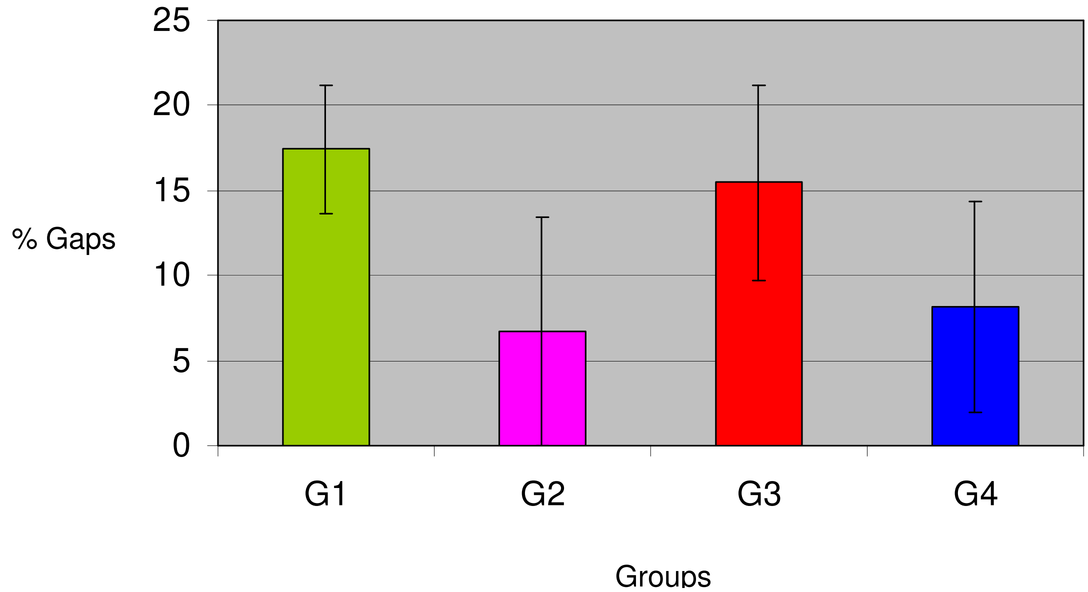


Table 5 - Marginal gap means (mm) and standard deviations (SD).

Treatment	Indirect restoration	Direct restoration
Cycling	17.42 ± 3.79aA	15.48 ± 5.72aA
No Cycling	8.69 ± 6.73aB	8.19 ± 6.22aB

Means followed by different lower (lines) and upper (columns) case letters are statistically different ($p < 0.05$).

Figure 2. Percentage means and standard deviations of gaps obtained for experimental groups.



The effect of thickness of indirect restoration and distance from the light-curing unit tip on the hardness of a dual-cured resin cement

ABSTRACT

Objective: This study evaluated Knoop hardness and polymerization depth of Rely-X ARC dual-cured resin cement light-activated through different thicknesses of pre-cured resin composite discs when the light-curing unit tip was positioned at different distances.

Material and methods: One bovine incisor was embedded in polystyrene resin and its buccal surface was flattened to simulate light reflection properties of dentin. Dentin was covered with PVC film and a rubber mold (0.8 mm in thickness and 5 mm in diameter) was placed and filled with resin cement, which was covered with another PVC film. Light curing was carried out through pre-cured resin composite discs (2, 3, 4 or 5 mm in thickness) with Elipar Trilight (800 mW/cm^2). The light curing unit tip was positioned 0, 1, 2 or 3 mm from the resin surface and the resin cement was light-activated for 40s. The specimens (n=5) were stored for 24 h at 37º C and were sectioned and Knoop hardness was measured on top, center and bottom of the resin cement layer using a Microhardness tester under 50gf for 15s. Data were submitted to split-plot ANOVA and Tukey's post-hoc test (α=0.05). Results: the polymerization depth of the resin cement was influenced by the distance of the light curing unit tip and by resin disc thickness as well. The increase in resin disc thickness decreased in cement hardness. The increase in distance of the light curing unit tip decreased hardness only at the top of the resin cement layer. Specimens showed the lowest hardness at the bottom, while the center presented the highest values.

Conclusion: resin cement hardness was influenced by the thickness of the indirect restoration and by the distance between the light curing unit tip and the resin cement surface.

Keywords: Hardness; Dental Materials; Resin Cements; Resin Composite; Indirect composite Restoration

INTRODUCTION

The success of indirect esthetic restorations depends mainly on the luting agent, which should guarantee an effective bonding between the restoration and the dental substrate, preserving the marginal seal [1]. Despite the variety of commercially available cements, there is no ideal cement for all clinical situations [2]. Therefore, the choice of the luting agent must rely on the physical, biological properties and manipulation characteristics of this material [3,4,5] associated with the characteristics of the prosthetic restoration.

In an attempt to combine the desirable properties of self- and light-activated resin cements, dual-cured cement was developed to allow the clinician to control the polymerization time and for proper polymerization at deep areas where light is strongly attenuated due to the distance from the curing-unit tip [1,6-11]. However, in some clinical situations, some factors such as light intensity, exposure time, thickness, composition, shade and opacity of the indirect restorative material can affect the amount of energy reaching the cement [7,11].

Studies have demonstrated that the distance from the top of the highest cusp to the cavity floor can reach 8 mm at deep cavities [12,13], so the light intensity reaching the deepest region can be strongly attenuated. As a consequence, lower degree of conversion is expected from resin cements when the energy is lower than that required for a proper resin cement polymerization, leading to postoperative sensitivity, staining, marginal breaking, poor adhesion between the tooth and the indirect restoration [14-15], microleakage, secondary caries [16], and changes in some cement mechanical properties [17]. The degree of conversion depends on the energy supplied during light activation, and can be characterized as the product of light intensity and exposure time [18-19]. The hardness test is a simple and reliable method commonly used as indicative of the degree of conversion of resin cements [20]. High degree of conversion is associated with improved physical and mechanical properties of resin materials [21] and provides durability to indirect restorations [22].

Studies have shown that an increase in the thickness of indirect restorative materials can decrease the hardness of the luting agent [23-26]. El-Badrawy and El-Mowafy [27] evaluated the effect of ceramic and resin composite thickness on hardness of 7 dual-cured resin cements for indirect restorations and observed a similar and gradual trend to a reduction of cement Knoop hardness with increase in the thickness of the restorative material. These results were attributed to the light attenuation caused by the increase in opacity and thickness.

The distance between the light curing unit tip and the unpolymerized resinous material can be another factor affecting the monomer conversion and mechanical properties of resin composites. Caldas et al. [28] evaluated the influence of the distance between the light curing unit tip and the resin composite Z250 on Knoop hardness using 3 different light curing units. The authors observed that the increase in such distance leads to a decrease in resin hardness and they attributed this result to the lower degree of conversion due to poor light intensity delivered to the composite.

Thus**,** the null hypotheses of this study were that different thicknesses of indirect composite restorations do not affect Knoop hardness of Rely-X ARC dual-cured resin cement values, and that different distances between the light curing unit tip and the resin cement do not interfere on resin cement polymerization depth.

MATERIAL AND METHODS

Resin Discs Preparation

Four pre-cured discs of resin composite Z-250, shade C4 (3M/ESPE, St. Paul, MN, U.S.A.) with 2 mm, 3 mm, 4 mm and 5 mm in thickness and 8 mm in diameter were created to simulate composite indirect restorations with different thicknesses. A rubber mold was filled with Filtek Z250 over a polyester strip (Polidental Ind. and Com., São Paulo, Brazil) and a glass slab with 4 mm in thickness. Light curing was carried out for each 2-mm thick increment with Elipar Trilight light curing unit (power density: 800 mw/cm^2, 3M/ESPE, St. Paul, MN, U.S.A.) for 40s. The light intensity was measured before light curing with a digital handheld radiometer (Dental Hilux Curing Light Meter, Dental Benlioglu Incorporation, Turkey). Prior to light curing of the last increment of each disc, the resin composite was covered with a polyester strip, originating flat surfaces without resin excesses. The polymerized discs were stored dry at room temperature until the moment of their use.

Substrate Preparation

To simulate the cementation of indirect restoration, a bovine tooth had its root sectioned and the incisal and proximal surfaces of the crown were ground sequentially under water cooling, in a polishing machine (APL-4, Arotec, Cotia, Brazil) with #120 and #200 grit Silicon Carbide sandpapers (Carborundum, Saint-Gobain, Recife, Pernambuco, Brazil). This tooth was inserted in a PVC mold and embedded in polystyrene resin (Piraglass, Piracicaba, Brazil). After resin polymerization, the buccal surface was wet-ground flat sequentially with # 200, #400 and #600 grit SiC sandpaper.

Specimen Preparation

The material used in the specimen preparation was the dual-cured resin cement Rely-X ARC (3M-ESPE)-Table 1. A conventional quartz tungsten halogen light curing unit Elipar Trilight with light intensity of 800mW/cm^2 was used to light-activate the specimens for 40s each. A was checked after each five sets.

Rubber molds with 5mm in diameter and 0.8 mm in thickness were used as matrix for resin cement specimens. These molds were positioned on the prepared bovine tooth previously covered with a PVC film (Filme de PVC, Goodyear do Brasil Produtos de borracha Ltda, São Paulo, Brazil). After manipulation according to the manufacturer's instructions, the cement was inserted in the mold and was covered with another PVC film. The pre-cured composite discs with different thicknesses were then seated and the resin cement was light-activated through the indirect resin restoration using 4 different distances obtained with standardized resin acrylic spacers (8mm in diameter): 0 (direct contact with composite surface), 1mm, 2mm and, 3mm from the composite surface (Figure 1).

Tested groups were determined by the combination of different thicknesses of resin composite discs and the distance between the light curing unit tip and the surface to be irradiated (*n=5)* - Table 2.

After light curing, specimens were stored dry at 37°C for 24 h [29]. For Knoop hardness measurements, the specimens were longitudinally sectioned in two equal parts under water cooling with diamond saw (Extec model 12205, Extec corp., Enfield, U.S.A.). The exposed surfaces exhibiting the adhesive interface were sequentially polished under water cooling with #400, 600 and 1200 grit Silicon Carbide sandpapers for 15s, 30s and 60s, respectively, in a universal polishing machine model APL-4.

Knoop Hardness measurements

Indentation and microhardness measurements were performed in a Microhardness Tester model HMV-2 Shimadzu (Shimadzu, Tokyo, Japan). Three sequences of 3 indentations each (50 Kgf during 15 s) were performed to obtain 3 hardness values for each depth: 50 µm, 400 µm and 750 µm from the interface between pre-cured resin disc and resin cement (Figure 2).

A hardness mean value was obtained for each depth in each specimen and the values were submitted to Split-plot 3-way ANOVA (factors “resin composite disc thickness”, and “light curing unit tip”, and “polymerization depth” as the dependent variable. It was considered as factorial scheme the composite disk thickness and distance of light curing unit tip as parcel and the depth as sub parcel. Tukey’s post-hoc test for multiple comparisons was applied for comparison among groups. Significance was 95% (a=0.05) for both tests and statistical analyses were performed using SAS/lab software.

RESULTS

The polymerization depth presented significant interaction with factors "composite disc thickness" and "light curing unit distance"($p<0.05$). The interaction between light curing unit tip distance and composite disc thickness was not significant ($p>0.05$). There was no significant interaction among the three factors.

There was a significant decrease in hardness at the top of the resin cement layer with the increase in composite disc thickness when groups having 4-mm and 5-mm thick pre-cured resin discs were compared to the direct light curing groups and groups with 2-mm and 3-mm thick pre-cured resin discs. Specimens with indirect light-activation showed lower hardness when compared to the direct light curing groups at the center and bottom of the resin cement layer, regardless of the resin disc thickness (Figure 3).

The bottom of the resin cement layer presented the lower hardness with the increase in thickness of the pre-cured resin disc. Higher hardness was observed at the center when compared to the values observed at the top, regardless of the thickness of the pre-cured resin composite disc (Figure 4).

No decrease in hardness was observed when the distance between the light curing unit tip and the composite surface was increased, except at the top of the resin cement layer, which presented the highest hardness value with direct light curing and the lowest with light curing unit tip 1 mm distant from the resin surface. The hardness values obtained with the distance of 2 mm and 3 mm between the light-curing unit tip and the resin surface were similar to those obtained with direct light curing and when the light-curing unit tip was 1 mm distant (Figure 5).

Regardless of the distance between the light curing unit tip and the resin cement, the bottom of the resin cement layer presented the lowest hardness values when compared to the center and top regions, and the highest values were observed at the center. The same was observed in all tested groups (Figure 6).

DISCUSSION

An adequate polymerization is essential to ensure the best performance of resin cements [29-31], which is directly associated with the clinical success of materials. In addition, some factors can reduce the power density delivered to the luting agent during the cementation of indirect resin composite restoration. Among these factors, the influence of cavity depth and the distance between the light curing unit tip and the resin cement surface were evaluated in this study.

The results of this study showed statistical significant differences in hardness at the top, center and bottom regions of resin cement layers light cured through different thickness of pre-cured resin composite discs (Figure 3). A decrease in hardness was observed at the top of the resin cement layer specifically when groups having 4-mm and 5-mm thick pre-cured resin composite discs were compared to those with direct light curing and with 2-mm and 3-mm composite discs. Moreover, hardness decreased at the center and bottom of the resin cement layer regardless of the resin disc thickness.

According to Moon et al. [32], the resin composite polymerization is inversely proportional to the power density of the light reaching the resin surface. As light intensity decreases exponentially in function of the restoration thickness [29], less light penetration is expected when thicker restorations are used and consequently lower degree of conversion is observed in resin cements beneath such restorations [28,33]. This fact results in negative effects on resin composite physical properties [23,34] and on resin cements, as observed by Rasetto et al. [35].

In this current study, hardness values were lower at the top, center and bottom of the resin cement layer with the increase in resin disc thickness between the light source and the resin cement during light curing. These results can be associated with the low energy supplied to the resin cement to sensibilize photoinitiators molecules, resulting in low degree of conversion and hardness [36]. It can be speculated that the light transmittance obtained using 4-mm and 5-mm thick resin composite discs was not adequate for suitable light activation of resin cement at the top of the resin cement layer and that chemical activation was responsible for the hardness values verified in these groups.

The hardness of the groups directly activated (0/0), (1/0), (2/0) and (3/0) was higher at the top of the resin cement layer than that of the groups having 4-mm and 5-mm pre-cured resin discs and higher than the hardness at the center and bottom of the resin cement layer of groups with 2-, 3-, 4-, and 5-mm thick pre-cured composite discs. These results corroborate with Warren [24], who observed higher hardness with direct light curing of resin cements when compared to the hardness obtained with indirect light curing. The author suggested that the exposure time of light should be increased for thicker restorations to promote similar hardness in comparison to that obtained with direct light curing. This longer light exposure could compensate for light attenuation by air, restoration opacity and thickness. It should be considered that the light exposure time recommended by manufacturers is optimum to obtain the proper hardness value of resin cement only with direct light curing [37].

Regarding resin cement polymerization depth, the top of the resin cement layer presented lower hardness values than the center regardless of the thickness of the resin disc or the distance between the curing unit tip and the resin cement layer (Figures 4 and 6). It is possible that the compression of the resin cement with resin composite disc during specimen preparation and light activation leads inorganic fillers to concentrate at the center of the resin cement layer since the resin monomer emerged to the top and bottom regions. According to Hofmann et al. [38], the percentage of unreacted C-C bonds is twice bigger at the surface in comparison to such percentage at the bulk of the resin material. Free radicals are three-dimensionally surrounded by reaction components in the bulk, while superficial free radicals react with others linearly at the composite surface.

The bottom region of the specimens obtained with indirect light activation presented the lowest hardness values compared to other regions. It is possible that the self-curing mechanism was not capable of inducing suitable polymerization at deep areas [39]. According to Rueggeberg et al. [18] and Pilo et al. [36], low degree of conversion and low hardness values can be attributed to poor light exposure, what can explain the influence of resin composite discs interposed between light curing unit tip and resin cement on resin cement hardness values. Probably, the power density supplied for resin cement during light curing was inadequate to excite photoinitiators at deep areas because of light absorption and scraping by superficial areas [40]. The reciprocity between exposure time and light intensity could be also applied to overcome the effects on polymerization depth, once such effects are related to energy supplied for activation [41].

The distance of the light curing unit tip from the surface to be irradiated is another limitation factor to be considered for light transmittance. No significant difference in hardness at the center and bottom of the resin cement layer was observed with the increase in the distance between light curing unit tip and the resin cement surface (Figure 5). However, the top of the resin cement layer showed lower hardness when the light curing unit tip was 1 mm distant from the resin cement layer. This finding corroborates with Sobrinho et al., who observed a decrease in hardness with an increase in the distance of the light curing unit tip from the resin surface [42]. In addition, the resin composite thickness had an important role in the results of the present study.

Some authors have indicated light curing units with a minimum light intensity of 300 mW/cm^2 for the light activation of resin restorative materials [43]. The ISO 4049 does not have any recommendation about the minimum light intensity for light activation, but recommends that manufacturers' instructions should be followed on researches. The light intensity of the light curing unit used in this study was 800mW/cm^2, which is higher than minimum indicated in earlier studies. According to Rahiotis et al. [44], light curing with high intensity during the initial 15 s can lead to a fast polymerization of the superficial layer, changing its optical properties, what could explain the high variation in hardness values at the top of the resin cement layer.

The null hypotheses that Z250 resin composite discs with different thicknesses do not decrease resin cement hardness values and that polymerization depth is not influenced by the distance of light curing unit tip from the surface to be irradiated were both rejected. In addition, based on the results of this study and considering its limitations, it can be concluded that resin cement polymerization depth can be affected by the thickness of indirect composite restorations and by the distance between the light curing unit tip and the surface to be irradiated as well. Clinically, an inadequate polymerization can lead to early degradation of the luting agent by hydrolysis compromising the adhesive interface. Gap formation should be considered as consequence, as well as low physical properties of luting agent and low longevity of the restoration [22].

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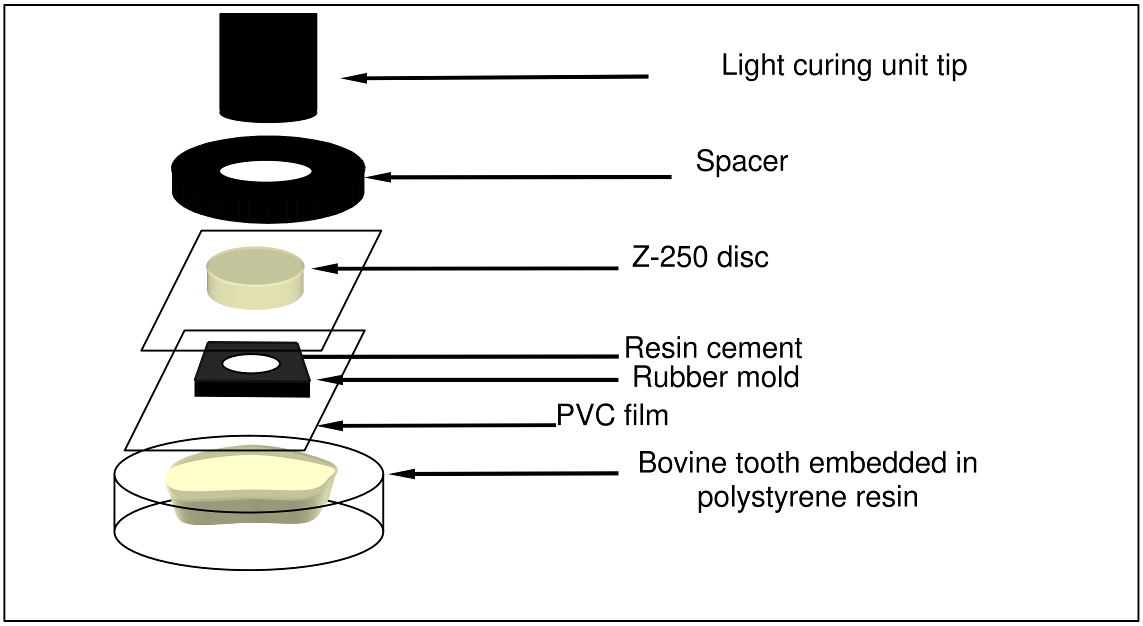
Table 1. Description of the restorative materials used in this study.

Materials	Composition*	Manufacturer Batch n.
Filtek Z250 (C4)	Bis-GMA, Bis-EMA; UDMA; zirconia/silica filler (82w%)	3M/ESPE, St. Paul, MN, USA-5LT
Rely-X (A3)	Bis-GMA; TEGDMA zirconia/silica filler (67.5w%) dimethacrylate monomers	3M/ESPE, St. Paul, MN, USA-FBFM

Table 2 – Distribution of groups according to resin composite disc thickness and light curing unit tip distance.

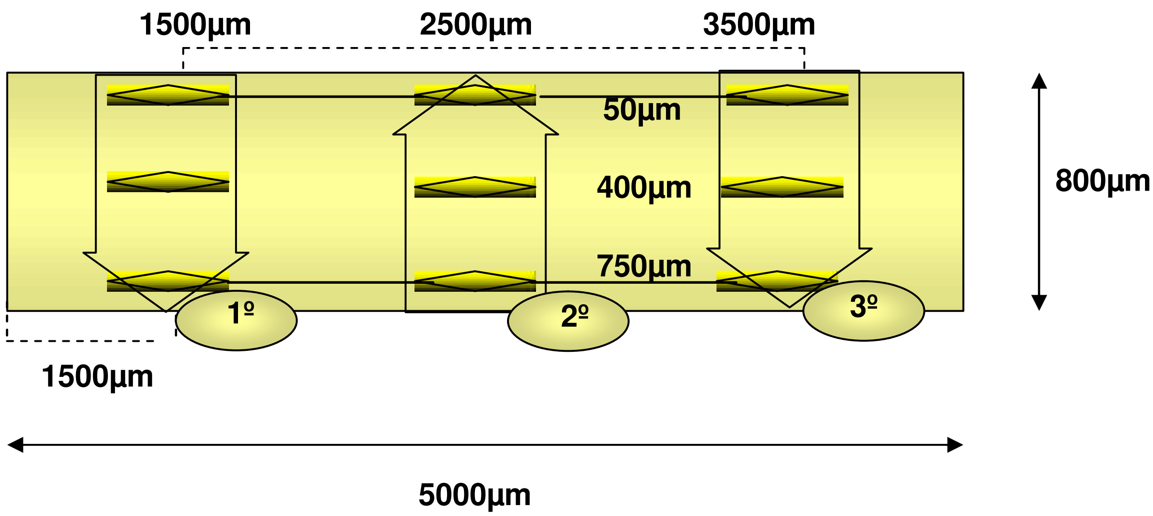
Disc thickness (mm)	Light curing unit tip distance (mm)			
	0	1	2	3
2	(0/2)	(1/2)	(2/2)	(3/2)
3	(0/3)	(1/3)	(2/3)	(3/3)
4	(0/4)	(1/4)	(2/4)	(3/4)
5	(0/5)	(1/5)	(2/5)	(3/5)
0	(0/0)	(1/0)	(2/0)	(3/0)

Figure 1. Schematic representation of specimen preparation.



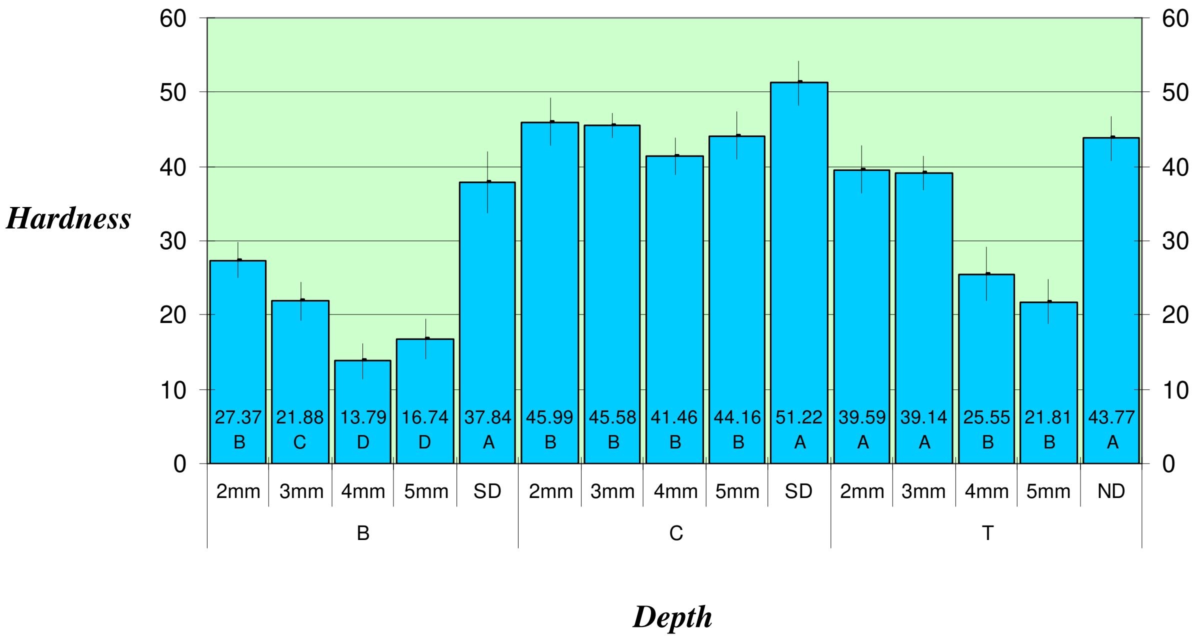
Adapted from Tango et al., 2006

Figure 2 - Schematic representation of indentation performed at the resin cement layer.



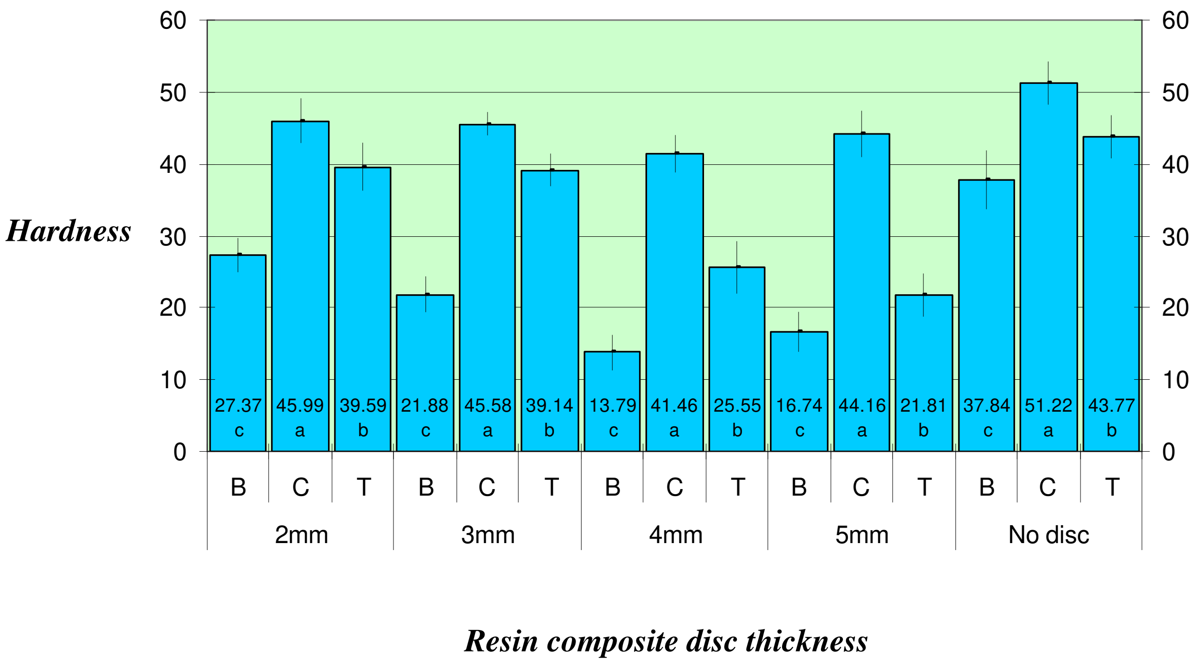
Adapted from Tango et al., 2006

Figure 3- Bar graph showing Knoop hardness means for different combinations of thickness of pre-cured resin disc and resin cement depth (top (T), center (C) e bottom (B)).



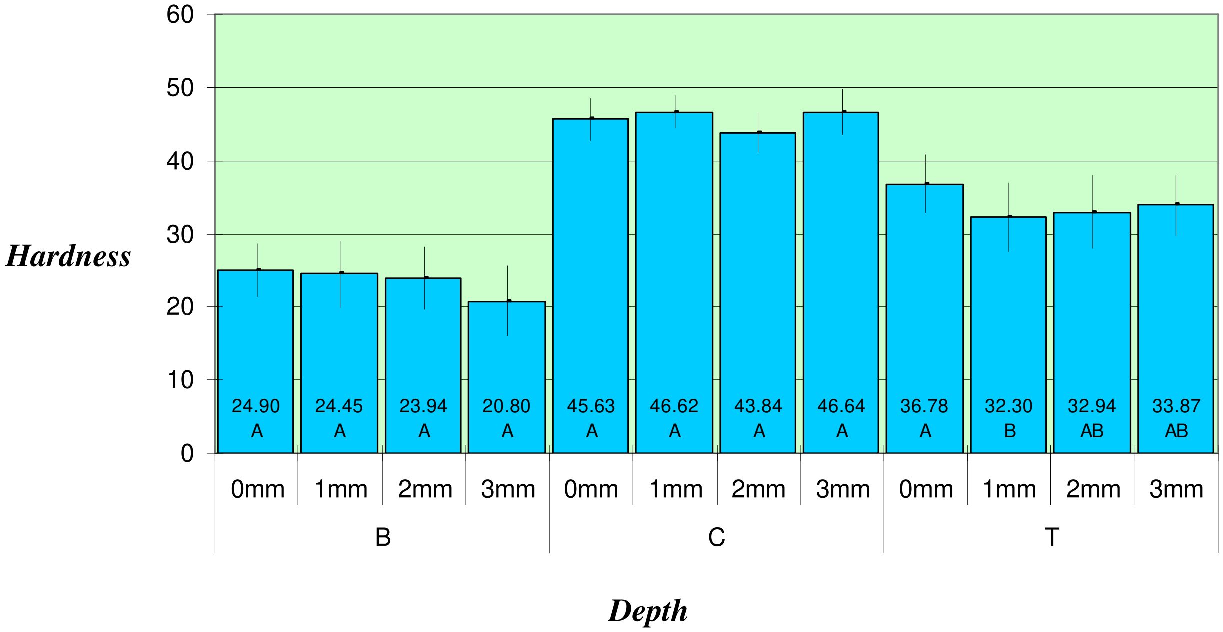
Bars with similar letter in each depth represent similar hardness values according to Tukey's test (a=0.05). ND – no composite disc

Figure 4- Bar graph exhibiting Knoop hardness means for different combinations of resin cement depth – (Top (T), center (C) and base (B)) and thickness of pre-cured resin disc.



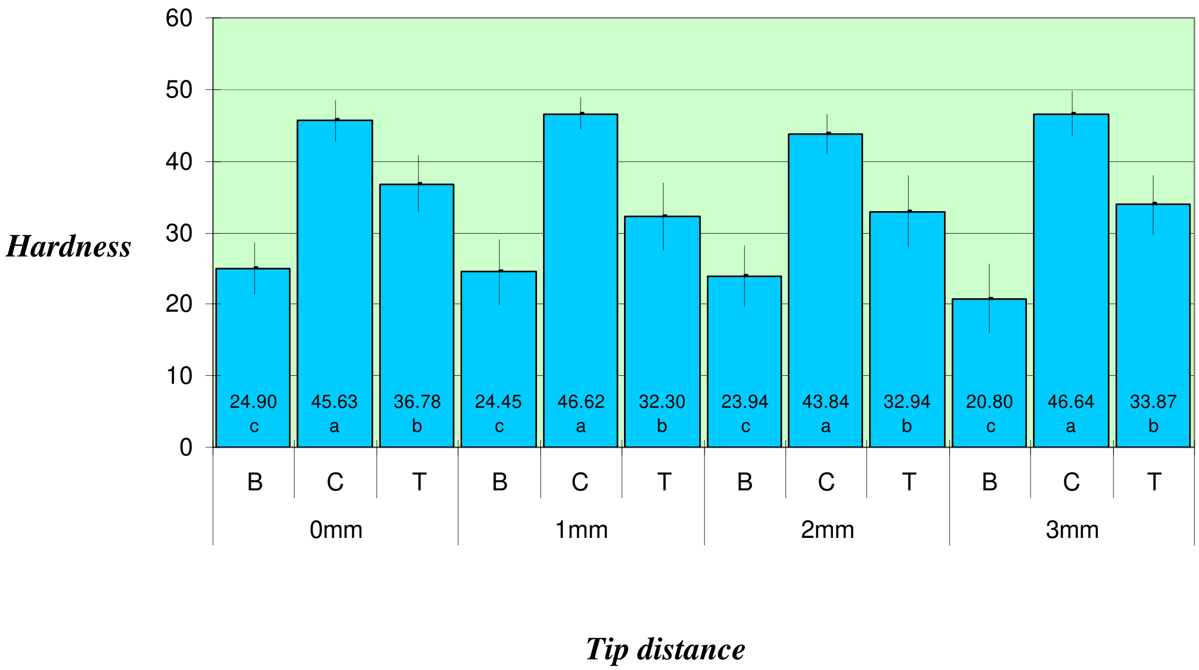
Bars with similar letter in each depth represent similar hardness values according to Tukey's test (a=0.05).

Figure 5 - Bar graph showing Knoop hardness means for different combinations of distance of light curing unit tip and depth of resin cement polymerization (top (T), center (C) e bottom (B)).



Bars with similar letter in each depth represent similar hardness values according to Tukey's test (a=0.05).

Figure 6 - Bar graph showing Knoop hardness means for different combinations of resin cement polymerization depth (top (T), center (C) e bottom (B)) and light curing unit tip distance.



Bars with similar letter in each depth represent similar hardness values according to Tukey's test (a=0.05).

CONCLUSÕES

Baseado nos resultados obtidos pôde-se concluir que:

1. As técnicas direta e indireta para restauração do tipo *onlay* apresentaram similar resistência à fratura por compressão. Entretanto, a adaptação marginal, foi influenciada significativamente pelo tratamento termo/mecânico. Porém, tanto a técnicas direta quanto a indireta não recuperaram a resistência compressiva dos dentes hígidos.

2. A polimerização, avaliada através da dureza Knoop, do agente cimentante é influenciada pela espessura de compósito resinoso a ser cimentado, assim como pela distância entre a superfície a ser irradiada e a ponta ativa da unidade fotoativadora.

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APÊNDICE

Pranchas de Figuras

Figura 1 - lustrações dos materiais de consumo utilizados na Dissertação.

A. Material de moldagem tipo silicona de adição Flexitime® Trial Kit (Heraeus kulzer, Hanau, Germany). Material pesado;

B. Material de moldagem tipo silicona de adição Flexitime® Trial Kit. Material leve;

C. Gesso Pedra tipo IV Durone IV(Dentsply, Petrópolis, RJ,Brasil);

D. Gel isolante para modelos de gesso Isolacril ®(ASFER, São Paulo, SP, Brasil);

E. Sistema de união Single Bond 2® (3M/ESPE, St Paul, MN EUA);

F. Ácido Fosfórico 37% - Scotchbond Etching® (3M/ESPE, St Paul, MN EUA);

G. Compósito restaurador Filtek Z250® cor C4 (3M/ESPE, St Paul, MN EUA), utilizado na confecção das restaurações diretas e indiretas;

H. Cimento resinoso Rely X® ARC (3M/ESPE, St Paul, MN EUA);


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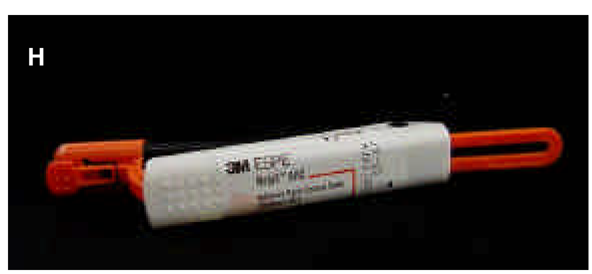
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Figura 2 - Seqüência de confecção dos espécimes do Capítulo 1.

A. Terceiros molares hígidos selecionados para o experimento;
B. Terceiro molar incluído em resina de poliestireno em tubos de PVC;
C. Máquina Padronizadora de preparo cavitário do Departamento de Odontologia Restauradora da Faculdade de Odontologia de Piracicaba – UNICAMP, Brasil
D. Fresa n°4137 (KG Sorensen Ind. Com. Ltda., Barueri, S.P., Brazil);
E. Preparo concluído.

Técnica Restauradora Direta

F. Condicionamento ácido do dente;
G. Aplicação do sistema de união sobre a superfície dental;
H. Restauração realizada pela técnica incremental;
I. Restauração finalizada;

Técnica Restauradora Indireta

J. Molde com os materiais pesado e leve, respectivamente, do kit do silicona de adição Flexitime® Trial Kit;
K. Modelo de gesso recebendo a aplicação do gel isolante para modelos;
L. Onlay confeccionada;
M. Condicionamento ácido da parte interna da peça;
N. Aplicação do agente de união na parte interna da peça;
O. Condicionamento ácido sobre a superfície dentária;
P. Aplicação do agente de união sobre a superfície dentária;
Q. Proporcionamento e manipulação do cimento;
R. Fixação da peça no dente pela técnica de pressão digital;
S. Remoção do excesso de cimento com instrumento cortante logo após a inserção da peça e antes da fotoativação;
T. Fotoativador Elipar Trilight® (ESPE, St. Paul, MN, EUA);
U. Restauração finalizada após a fotoativação na linha de cimentação durante quarenta segundos em cada face

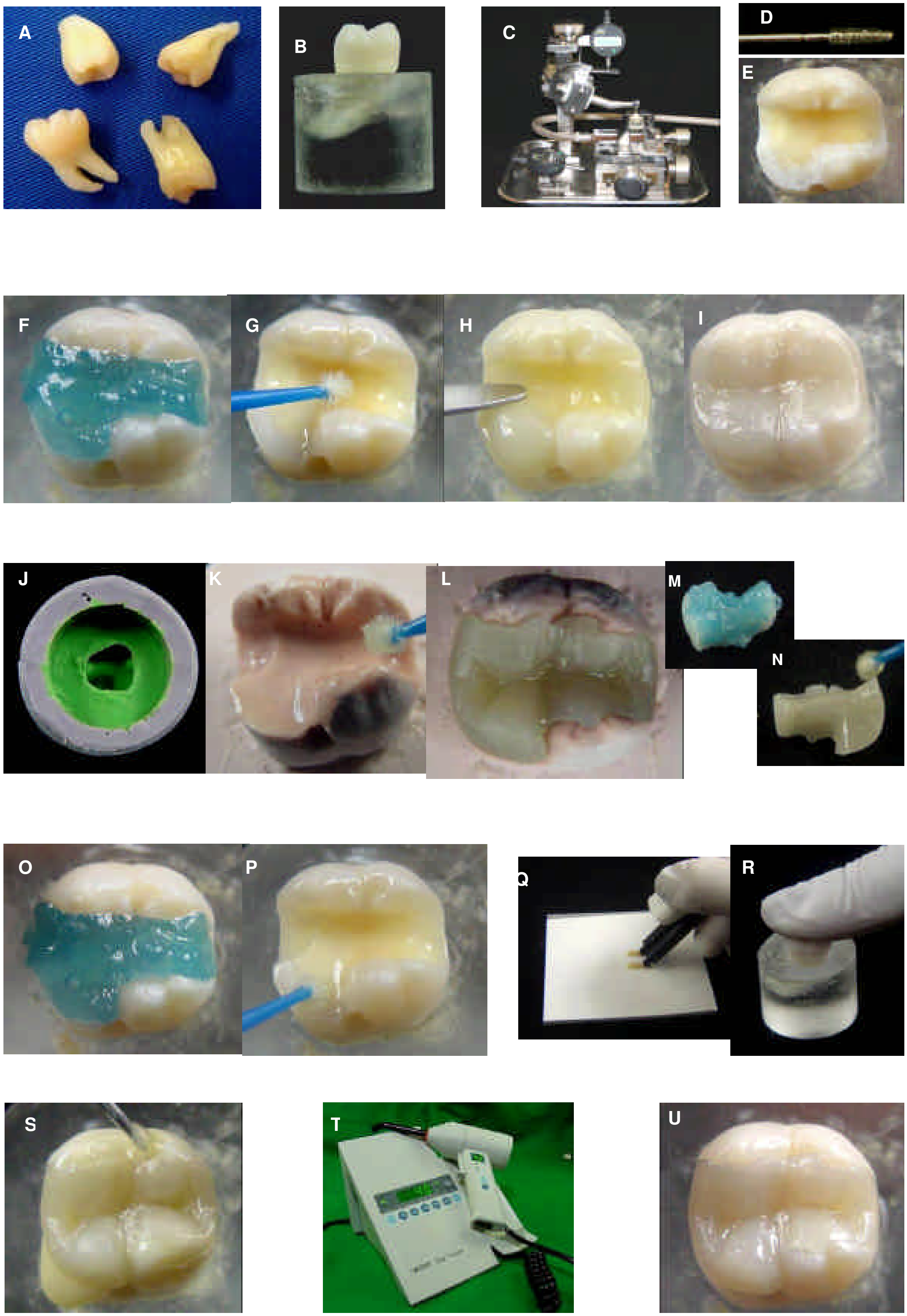
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Figura 3 -Testes de adaptação marginal e mecânico de compressão do Capítulo 1.

A. Kit para acabamento e polimento de restaurações de compósito Soflex® (3M/ESPE, St. Paul, MN, EUA) fresa diamantada 3139F(KG Sorensen;
B. Vista oclusal de um dente similar ao PMS com extensões de 2mm delimitadas por pontos em cada face do dente;
C. Paquímetro digital (Mitutoyo – Japan) utilizado para a delimitação entre os pontos;
D. Solução corante de propilenoglicol e ácido vermelho Caries Detector® (Kuraray Company Ltd. Osaka, Japan);
E. Aplicação da solução Caries Detector® em toda extensão da margem dente/restauração;
F. Área corada na porção cervical da restauração, considerada presença de fendas;
G. Área corada na superfície oclusal da restauração, considerada presença de fenda;
H. Software Image Tool 3.0 (Periodontology Departament University of Texas, Health Science Center at San Antonio, TX, USA), utilizado para mensurações lineares. As medidas foram transformadas em mm adicionando-se o comando de calibração de medidas lineares do Programa, onde os pontos pré-determinados foram utilizados como referência;
I. Uma linha foi desenhada unindo os pontos e após a seleção da unidade de medida mm, o número 2 foi digitado na caixa específica que pede o valor exato da medida utilizada como referência. A partir de então, qualquer medida feita foi automaticamente convertida em mm. Esse procedimento foi realizado para cada foto.
J. O comando distância foi acionado e uma linha foi desenhada sobre as margens da restauração, sendo que a soma dos comprimentos das margens das quatro fotos de cada dente resultava no comprimento total das

margens dente/restauração. O mesmo procedimento foi realizado para as áreas coradas e sua somatória resultava na quantidade da fenda presente.

K. Máquina de ciclagem térmica;

L. Máquina de ciclagem mecânica;

M. Máquina de ensaio universal Instron;

N. Fratura resultante do teste de compressão, no exemplo dente com fratura não severa;

O. Fratura resultante do teste de compressão, no exemplo dente fraturado com fratura severa.


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Figura 4 - Confecção dos espécimes do Capítulo 2.

Preparo do substrato

A. Seleção do dente bovino;
B. Corte da raiz;
C. Inclusão do dente bovino em resina de poliestireno;

Confecção das Amostras

D. Posicionamento da matriz de borracha sobre o substrato previamente protegido com película de PVC;
E. Proporcionamento do cimento resinoso Rely-X ARC;
F. O Cimento espatulado foi inserido em matriz de borracha com 5mm de diâmetro e 0,8mm de espessura, a qual foi assentada sobre o dente bovino preparado;
G. Discos de resina composta Filtek Z250 com diferentes espessuras (2, 3, 4, e 5mm);
H. Disco de resina colocado sobre a matriz contendo o cimento previamente protegido com uma película de PVC;
I. Espaçadores (1, 2 e 3mm) utilizados para padronizar a distância de fotoativação;
J. Espaçador colocado sobre o disco de resina;
K. Fotoativação do cimento;
L. Amostra confeccionada.

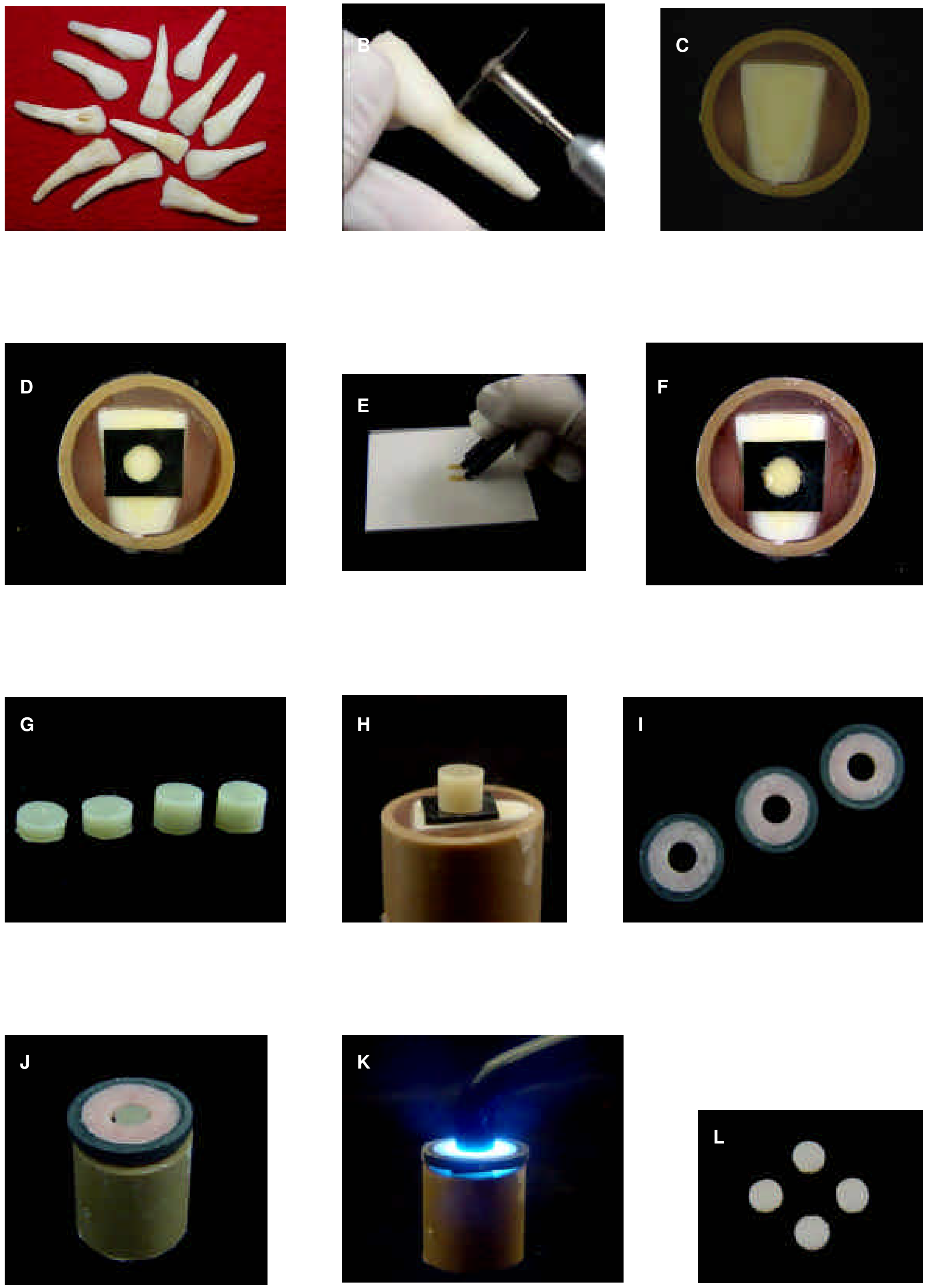
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Figura 5 - Teste de Dureza Knoop

A. Máquina utilizada para seccionar as amostras (Extec model 12205, Extec corp., Enfield, EUA);

B. Aparato confeccionado em resina acrílica para inclusão das amostras;

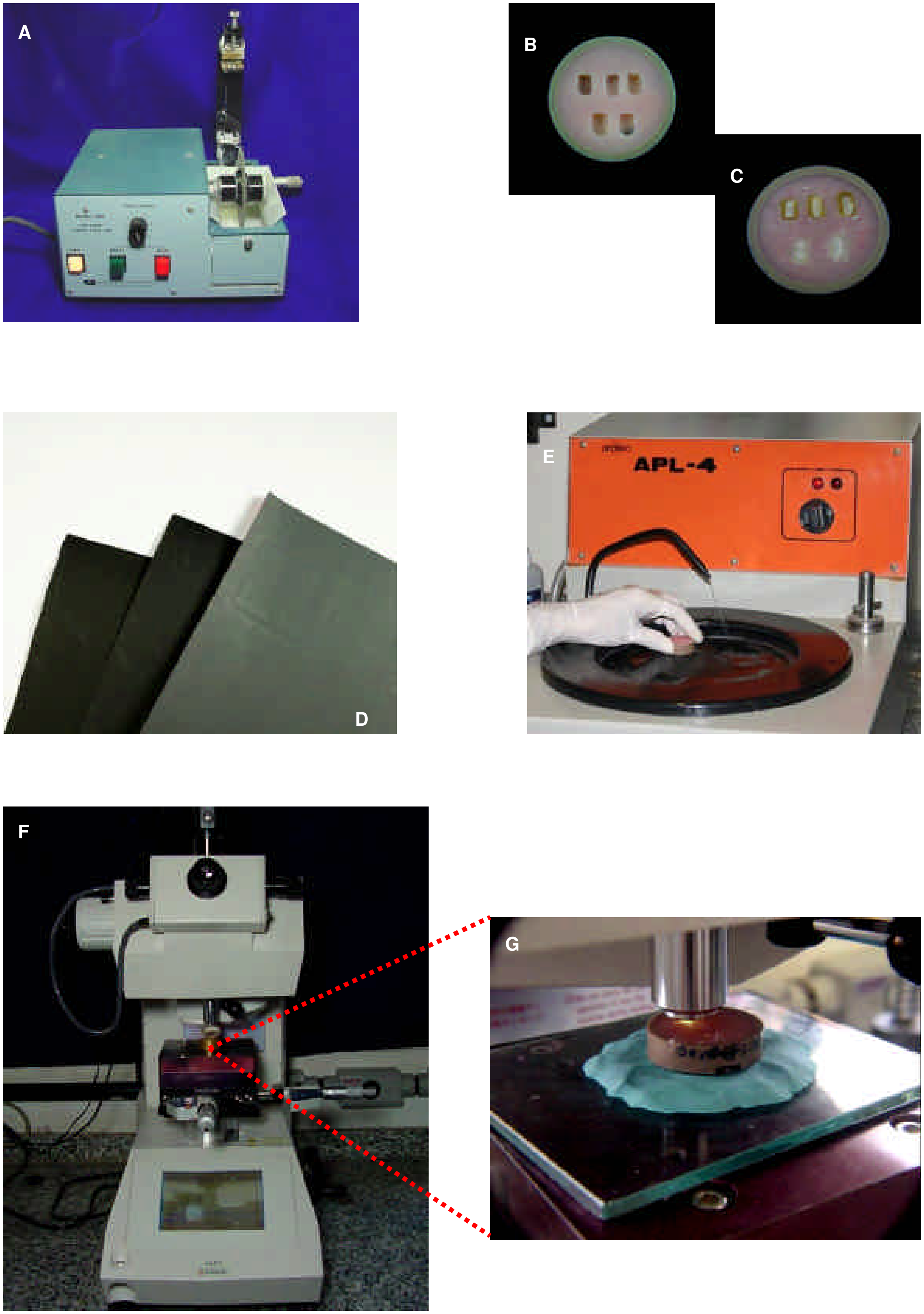
C. Amostras incluídas, após secção;

D. Lixas d'água de Carbeto de Silício (Saint-Gobain, Recife, Pernambuco, Brasil), com granulação 400, 600 e 1200, utilizadas durante 15s, 30s e 60s respectivamente, para posterior mensuração de dureza;

E. Polimento das amostras em uma Lixadeira e Polidora Universal modelo APL-4 (Arotec, Cotia, Brasil);

F. Microdurômetro modelo HMV2 Shimadzu Microhardness Tester (Shimadzu, Tóquio, Japão);

G. Amostras posicionadas no microdurômetro. Foi utilizada carga de 50gf durante 15s para a realização das endentações.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FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa "**Efeito do estresse mecânico na adaptação marginal e resistência à compressão de restaurações estéticas. efeito do tipo de substrato e restauração**", protocolo nº **099/2005**, dos pesquisadores **ANDRÉIA BOLZAN DE PAULA e REGINA MARIA PUPPIN RONTANI**, satisfaz as exigências do Conselho Nacional de Saúde – Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 23/09/2005.

The Research Ethics Committee of the School of Dentistry of Piracicaba - State University of Campinas, certify that project "**Effect of load cycling on marginal adaptation and compressive strength of esthetic restorations. Effect of substrate and restoration**", register number **099/2005**, of **ANDRÉIA BOLZAN DE PAULA and REGINA MARIA PUPPIN RONTANI**, comply with the recommendations of the National Health Council – Ministry of Health of Brazil for researching in human subjects and was approved by this committee at 23/09/2005.

Cinthia Pereira Machado Tabchoury
Secretária
CEP/FOP/UNICAMP

Jacks Jorge Júnior
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
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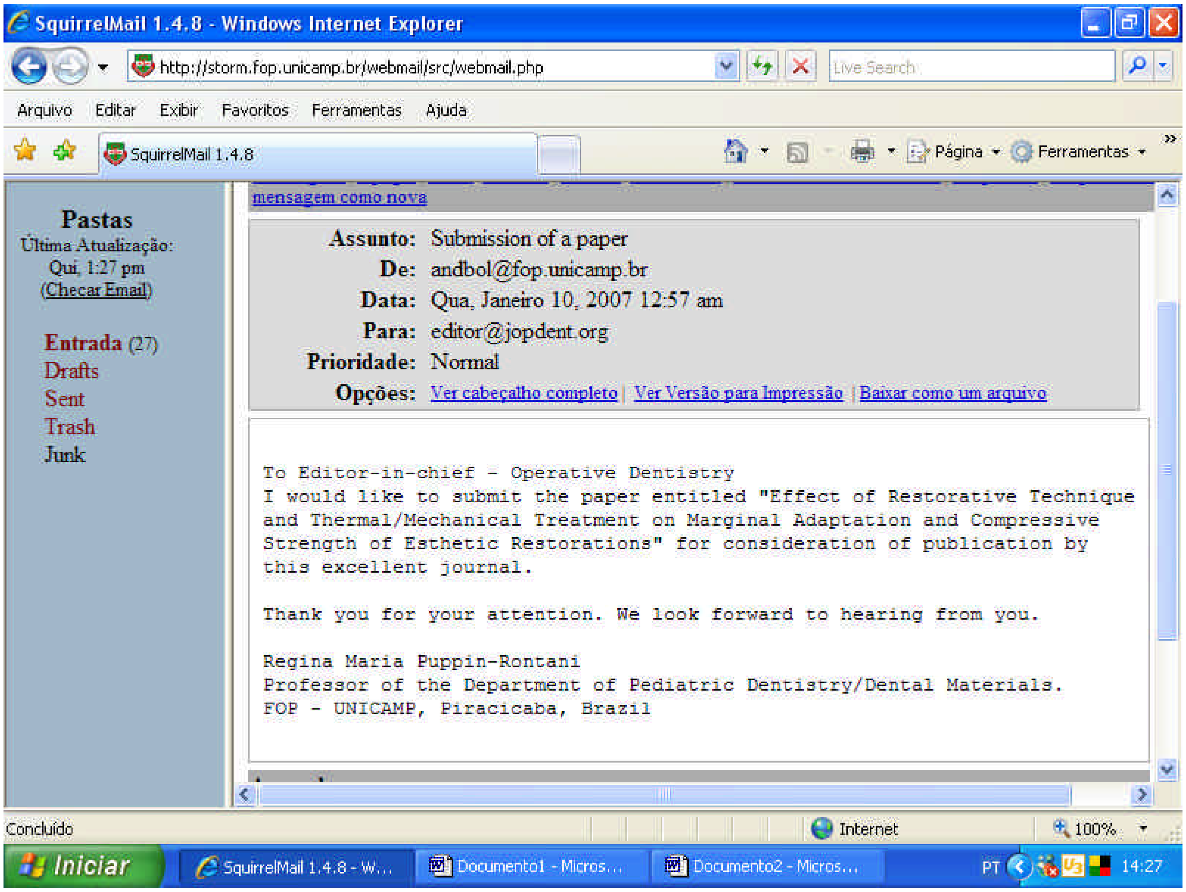

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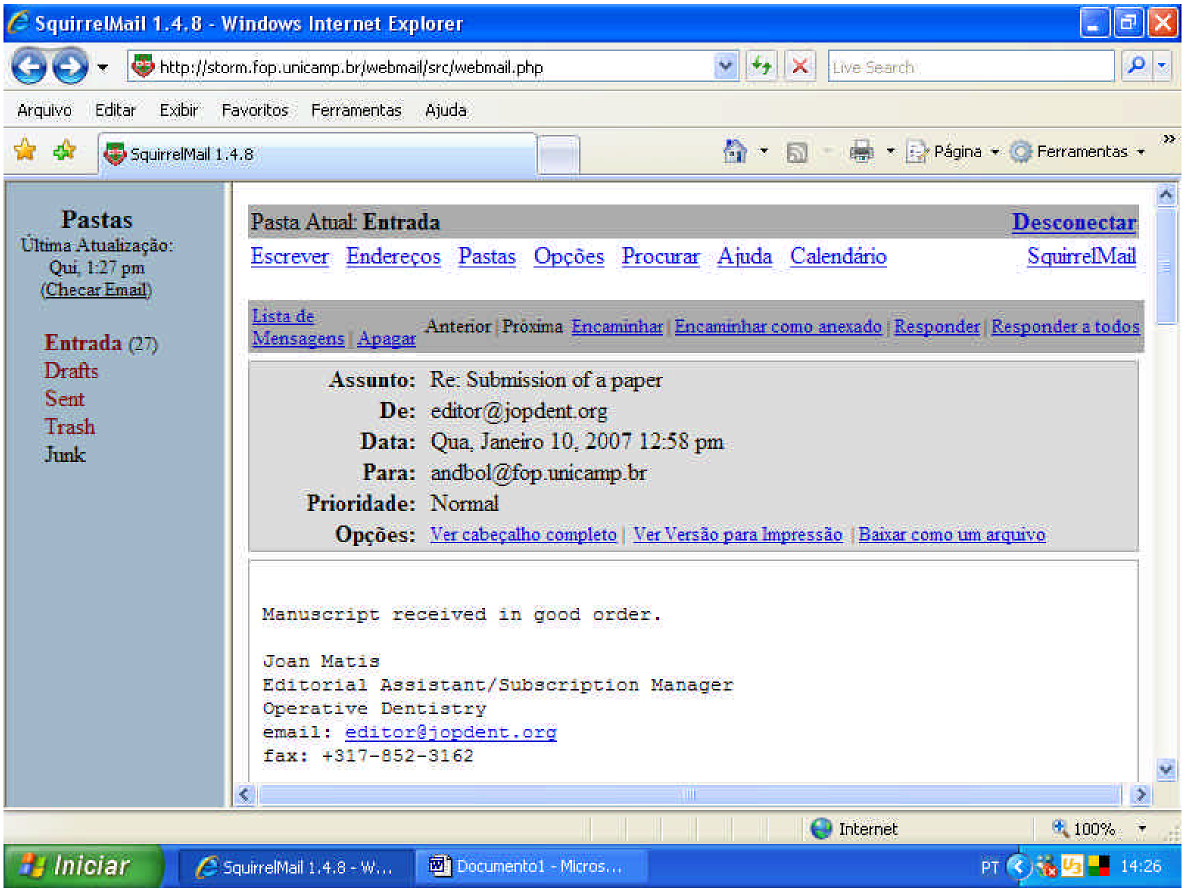
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