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Effect of Restorative Technique and Thermal/Mechanical Treatment on Marginal Adaptation and Compressive Strength of Esthetic Restorations

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Clinical Relevance

This study demonstrated that esthetic restorations prepared with indirect or direct techniques had similar compressive strengths and marginal adaptation. Marginal deterioration over time was observed for both types of restorations; however, there was an increase in the prevalence of catastrophic fractures among direct restorations.

SUMMARY

This study evaluated the compressive strength and marginal adaptation of composite onlays using indirect and direct techniques after thermal and mechanical cycling. Onlay standardized cavities were prepared in 50 permanent molars and restored with Z-250 resin composite using indirect (IRT) or direct (DRT) restorative techniques. The restorations were either submitted or not submitted to thermal (500 cycles, 5° to 55°C) and mechanical cycling (50,000 cycles, 50N). The teeth were distributed to 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 37°C for 24 hours, followed by finishing with Sof-Lex discs. A caries detector solution was applied on the tooth-restoration interface of all teeth for five seconds, followed by washing and drying. Four digital photographs were taken of each tooth surface. The extent of gaps was measured using standard software (Image Tool 3.0). All groups were submitted to compression testing in a universal testing machine (INSTRON) at a crosshead speed of 1 mm/minute until failure. The compressive strength (CS) and marginal adaptation data were submitted to ANOVA and Tukey test (*p*<0.05). For both evaluation criteria (compressive strength

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and marginal adaptation), there were no statistically significant differences among the restorative techniques. Deterioration over time was observed for both types of restorations. However, the prevalence of catastrophic fractures increased among direct restorations. The application of thermal/mechanical cycling only influenced marginal adaptation.

INTRODUCTION

In posterior teeth with resin composites, esthetic restorations are often performed in dental offices, since resin composites are considered less expensive than other esthetic materials.[1] Although composite materials have gone through significant development since their introduction, with modern formulations promoting improvements in biomechanical and esthetic properties,[2] composite shrinkage during polymerization is the main cause of failure of resin composite restorations.[3] Marginal shrinkage affects the integrity of the tooth/restoration bonding interface, creating a point of origin for marginal defects, gaps, secondary caries, cusp deflection and postoperative sensitivity.[4-5] Other factors may contribute to composite restoration failures, such as fracture toughness, coefficient of thermal expansion, water sorption, and perhaps most importantly, operator error in the clinical placement technique.[6-7]

The direct technique is commonly applied in esthetic restorations, because of its low cost and decreased number of clinical appointments.[8] However, resin shrinkage during polymerization is considered a significant clinical problem of this technique,[5] in addition to difficulty in achieving contact points, developing correct anatomical contour and accessibility to the proximal surface during light-curing.[9] For these reasons, restorative techniques that promote polymerization of resin composite outside the mouth have been investigated.[7]

The indirect technique used for resin restorations has some advantages over the direct technique, including restriction of polymerization shrinkage to a thin layer of luting cement used for cementation; maintenance of the adhesive interface; improved bond strength[10] and better finishing and polishing[11] and exerting a positive influence on the marginal adaptation of these restorations.[12] Although polymerization shrinkage can be reduced, rupture between the luting agent and tooth structure may still occur;[13] thus, complete elimination of marginal gaps using the indirect technique is still not possible.[14]

The number of long-term studies on the clinical performance of resin composite inlays is very limited. Wassel and others[15] evaluated a five-year follow-up of failure, wear rates and other aspects of the clinical performance of resin composite inlays compared to conventional composite restorations and observed no clinical advantage using the inlay technique. Van Dijken and Horsted[16] observed that more than 84% of enamel/luting agent/composite inlay interfaces had gap-free margins. In a study by Spreafico and others,[17] with respect to clinical performance and marginal adaptation over 3.5 years, no significant differences were observed between direct composite restorations and semi-direct restorations using silicone casts.

Methodologies simulating thermal and mechanical stresses that normally occur in the oral cavity have been applied to *in vitro* studies, measuring the longevity of restored teeth.[18] Studies evaluating the effects of thermal and mechanical stress on the microleakage of dental materials have shown contradictory results.[19-20] The cycling methods were verified for bond strength between tooth structure and restoration, although few studies on bond strength have applied these types of stresses simultaneously.[21-22] The null hypothesis in this study was that the restorative technique and thermal/mechanical cycling do not influence the compressive strength and marginal adaptation of onlay preparations in permanent teeth.

METHODS AND MATERIALS

The utilization of extracted teeth for this laboratory study was approved by the Institutional Review Board of the Dental School, State University of Campinas (protocol n 099/2005). Fifty freshly extracted, sound, caries-free human mandibular molars of similar dimensions were selected for this study. The dimensions of the teeth were determined by measuring the bucco-lingual/mesiodistal widths in millimeters. Teeth with similar dimensions (a maximum deviation of 10% from a mean determined from data obtained in a pilot study) were chosen for both the treatment and control groups in such a way that mean dimensions were not statistically different for all groups (ANOVA, $p>0.05$). The teeth were cleaned, disinfected and stored frozen until used in the study. The teeth were distributed into five groups, according to the restoration treatment—resin composite using indirect (IRT) or direct (DRT) placement and thermal/mechanical cycling. The groups were: G1-IRT/cycling; G2-IRT/no cycling; G3–DRT/cycling; G4–DRT/no cycling and G5 (control group)—sound teeth. Each group contained 10 teeth (n=10): five third molars anatomically similar to the mandibular first molars and five third molars similar to maxillary second molars.

Each tooth was embedded in a PVC cylinder (18-mm diameter and 25-mm height) using polystyrene resin (Piraglass Ltda, Piracicaba, SP, Brazil). The crowns were placed in the resin up to 1 mm below the cementoenamel junction, with the crown 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 #4137 burs with a 6°

inclination to the wall cavities (KG Sorensen, São Paulo, SP, Brazil) positioned parallel to the long axis of the tooth at high-speed under water cooling. Forty teeth were prepared, with 10 sound teeth making up the control group. The diamond burs were replaced after five cavity preparations. The teeth were prepared with the following characteristics:

Occlusal box: the isthmus width was approximately one-third of the buccolingual 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 the cementoenamel junction due to variations in cervical-occlusal height. The diameter of the active tip of the bur was used as a parameter for the mesial-distal width of the gingival wall. The inner angles of the 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: the palatal cusp of teeth anatomically similar to maxillary second molars and the mesiobuccal cusp of teeth similar to mandibular first molars.

Indirect Technique

Impressions of the preparations were taken using putty and light polysiloxane (Flexitime Trial Kit, Heraeus Kulzer, Hanau, Germany); a PVC cylinder (12.5 mm) fixed to a metallic handle was used as an impression tray. After one hour, the casts were poured in stone (Durone IV, Dentsply, Petropolis, RJ, Brazil) and removed after 60 minutes. Indirect restorations (groups G1 and G2), which were previously isolated with Isolacril (Asfer, São Paulo, SP, Brazil), were made on the stone with a hybrid composite (Filtek Z-250, C4 shade, 3M ESPE, St Paul, MN, USA) using the incremental technique, starting with the proximal box followed by the occlusal box. Each increment was light-cured for 40 seconds using the Elipar Trilight curing unit (ESPE, Germany; Norristow, PA, USA). Bonding of the restorations to tooth surfaces was performed according to the manufacturer's instructions using the adhesive system Single Bond 2 (3M ESPE) and the dual-cured resin luting agent Rely-X ARC (3M ESPE), which was applied to the inner surface of the onlays after phosphoric acid etching (Scotchbond, 3M ESPE). The onlay was placed under 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 for 40 seconds. The restoration/tooth set was stored in 100% relative humidity at 37°C for 24 hours, followed by finishing with a diamond bur 3139F (KG Sorensen Ind Com Ltda, Barueri, SP, Brazil) and Sof-Lex discs (3M ESPE).

Direct Technique

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

Marginal Adaptation Test

After storage, an acid red solution in propylene glycol (Caries Detector, Kuraray Co, Japan) was applied for five seconds onto the restoration margins of groups G2 and G4 and rinsed in tap water; the specimens were then dried with absorbent paper. Two points were drawn on each tooth surface (buccal, palatal/lingual, mesial and distal) with a pen using a digital caliper at a distance of 2-mm from each other. These points were used to calibrate the spatial measurement. In addition, a line was drawn on all tooth/restoration margins, and the tooth/restoration total length was determined by adding the four tooth surface lengths. Color photographs were taken of each tooth surface at the same distance, magnification and lighting with a digital camera and tripod (Mavica FD 97, Tokyo, Japan). All digital photographs were evaluated in the Image Tool 3.0 software (Periodontology Department, University of Texas and Health Science Center, San Antonio, TX, USA). All measurements were performed by the same investigator (ABP); the intra-examiner correlation was investigated with the Pearson Correlation Test to 25% of the total sample. The correlation results showed 97% confidence (R^2=0.9538); p=0.00. The total gap length was obtained by the sum of the dyed lengths of each surface. Data from each specimen were transformed to gap percentage in relation to the total margin using the following formula:

$$\%\, GAP \frac{l}{l_T} \text{ x } 100$$

where l is the dyed length; l_T is the total margin length (Borges & others[11]).

Data were submitted to two-way ANOVA at a significance level of 95%; the means were compared by the Tukey test (p<0.05).

Thermal Cycling and Mechanical Load Cycling Procedure

After 24 hours of storage followed by finishing and polishing, specimens from the G1 and G3 groups were submitted to mechanical load cycling. The apparatus used for the cycling load belonged to the Restorative Dentistry Department of Piracicaba Dental School (UNICAMP, Brazil) and consisted of five stainless steel pistons with cylindrical tips and spherical ends with a

Table 1: *Means (M) and Standard Deviations (SD) of Compressive Strength (Kgf) and Marginal Gaps (%)*

	Indirect Restoration		Direct Restoration		
	Cycling (G1)	No Cycling (G2)	Cycling (G3)	No Cycling (G4)	Control Group (G5)
Compressive Strength (M/SD)	203.435 ± 77.94[a*]	222.66 ± 51.63[a]	181.131 ± 61.62[a]	206.08 ± 66.77[a]	298.51 ± 79.93[b]
Marginal Gaps (M/SD)	17.42 ± 3.79[a]	8.69 ± 6.73[b]	15.48 ± 5.72[a]	8.19 ± 6.22[b]	-

**Means followed by different lower case letters (lines) are statistically different (p>0.05).*

2-mm diameter. These tips were placed in contact with the center of the occlusal surface of the restorations. The loading device delivered an intermittent axial force of 50N at a frequency of 2.5Hz, adding up to 50,000 cycles (corresponding to 5.5 hours in the machine). The specimens were kept moist during this time. The specimens were then subjected to 500 cycles in a thermal cycling apparatus of the same department, with two baths at 5° ± 2°C and 55° ± 2°C, each submersion with a dwell time of 30 seconds and a transfer time of seven seconds between each bath. After cycling, the marginal adaptation was measured as indicated for the no-cycling groups.

Compression Test

All groups were submitted to compression testing in a universal testing machine (model 4411, Instron Corp, Canton, MA, USA). The specimens were inserted into a metallic matrix that served as a supporting base and reinforced the PVC cylinder. A 5 mm stainless steel sphere was placed on the occlusal surface of the molars and loaded at a crosshead speed of 1 mm/minute until fracture. Data were obtained in Kgf, and the specimens were stored in distilled water for subsequent analysis of the fracture pattern. Data were analyzed by two-way ANOVA (p<0.05) and the Dunnet test for comparison, with the control group (p<0.05) using Biostat software (Professional 2006 2007.2.0.0). After the compression test, the set (tooth/fractured restoration) was observed by visual inspection with the naked eye and classified according to failure: catastrophic type (when the fracture occurred below the cementoenamel junction [CEJ] and non-catastrophic type (when the fracture was limited to the coronal portion of the tooth, up to the CEJ).

RESULTS

The means and standard deviations of the compressive strength (Kgf) and marginal gap (mm) values are displayed in Table 1. The ANOVA test showed no significant differences in compressive strength (CS) between the restorative techniques evaluated. 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 presented in Figure 1. The results indicated no statistically significant difference in the percentage of gaps obtained in direct restorations compared with the indirect technique. However, after thermal/mechanical cycling, both types of restorations had a significant increase in marginal gap values. The analysis of the fracture pattern showed a higher percentage of catastrophic fractures in G3 (70%), followed by G1 (30%), G2 (30%) and G4 (20%).

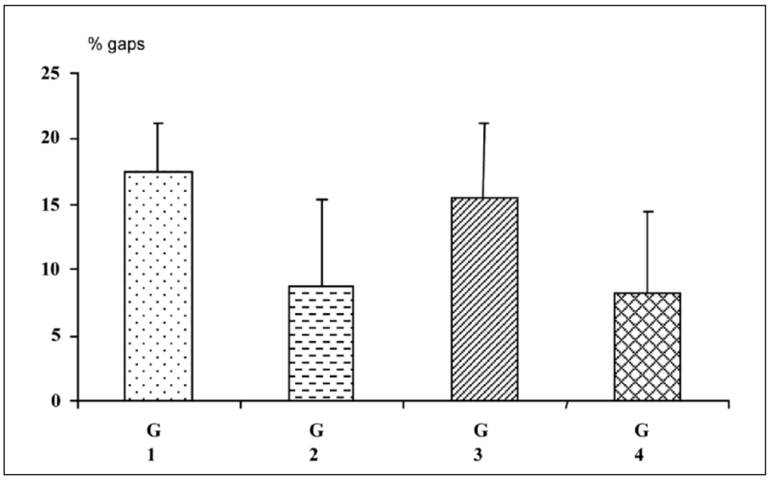

Figure 1: *Percentage means (columns) and standard deviations (bars) of gaps obtained for experimental groups.*

DISCUSSION

For many years, acid etching has been used in bonding procedures, and several studies demonstrated that etching strengthens the remaining tooth structure.[23] However, many studies have demonstrated that teeth with occluso-proximal cavities did not recover the same fracture strength of sound teeth after restoration with resin composite.[24] In the current study, the recovery of compressive strength of restored and prepared teeth reached values between 61% and 76% in relation to the control group, without statistically significant differences among groups. These findings are similar to those obtained by Geurtsen and García-Godoy,[24] who observed partial reinforcement of teeth restored with resin composite compared to sound teeth. Blaser and others[25] and Bakke and others[26] have determined compressive test values between 51% and 64% for large MOD preparations with occlusal boxes, presenting the isthmus width with one-third of inter-cusp distance and an approximate depth of 3 mm (without restoration), when compared to sound teeth.

Considering the restorative technique, G1 and G2 (teeth restored with the indirect technique) had similar compressive strengths and marginal adaptation compared to G3 and G4 (teeth restored using the direct technique), suggesting that both techniques had the same clinical performance. These results are similar to those found by other investigators who observed similar clinical effectiveness of both restorative techniques when the marginal integrity was evaluated.[4,17,27-28] Other studies have shown better performance of the indirect technique compared to the direct technique with regard to marginal adaptation[29] due to the decrease in polymerization stress. However, the current study found no statistical differences in relation to the presence of marginal gaps for both restorative techniques. This finding may have occurred, because the incremental technique was used in the direct restorations. This technique has been used to limit stress development and maintain satisfactory marginal adaptation.[30] The reduced thickness of cured resin decreases stress that may be caused by polymerization by the flow of material through free surfaces during the early stage of setting, in addition to greater uniformity and distribution of curing energy inside each increment.[31] For the indirect restorative technique, polymerization stress is controlled by a thin layer of resin cement[32-33] interposed between the restoration and tooth. However, inappropriate execution of any step of this technique could compromise the marginal integrity of the restoration and, consequently, originate interface gaps.[14,27]

In the current study, when the specimens were submitted to stress from different cycling, the extent of marginal gap formation increased, as observed in other studies,[21-22] but it remained clinically acceptable. Thermal and mechanical cycling methods have been used to simulate the oral conditions and stress caused by oral function.[34] *In vitro* studies using these types of stresses to evaluate the longevity of restored teeth have been performed,[18-22] but few of them have applied these types of stress simultaneously.[21-22] These studies have demonstrated contradictory results, making it difficult to compare those results with the results of the current study. In addition, the frequency and number of cycles, restorative material and C factor are important variables among studies.[19] In the current study, the intermittent axial force of 50N and a total of 50,000 mechanical cycles were chosen to simulate a constant occlusal load distributed during chewing.[34-35] 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.[18,34] In the current study, the thermal cycling test comprised 500 cycles in water between 5°C and 55°C, with a dwell time of 30 seconds in each temperature bath and a transfer time of seven seconds.[22,36-37]

Thermal/mechanical cycling may have more influence on the bond strength of material to tooth substrate[21-22,34] than the compressive recovery of restored teeth. In bond strength tests, such as microtensile and shear tests, the force is concentrated in small areas.[38] In compressive strength tests, the applied force is absorbed and dissipated in a greater area. In the current study, thermal/mechanical cycling negatively influenced marginal adaptation only, regardless of the restorative technique, with a significant increase in the percentage of marginal gaps, especially at the cervical areas. This finding may be due to occlusal stresses generated at the tooth/restoration interface.[39] Additionally, temperature cycling induces repetitive shrinkage and expansion stress on the tooth/restorative material interface.[40] These stresses can cause fissures that propagate through the entire bonding interface and enable a continuous flow of oral fluids in a process called percolation.[41] It could be suggested that the thermal/mechanical cycling of restored teeth results in significant stress between tooth and dental material. The frequency/number of cycles used in the current 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.

Catastrophic failure was observed for the direct technique, especially when associated with thermal/mechanical cycling (G3). Polymerization shrinkage is the most significant clinical problem of the direct restorative technique,[5] since it may lead to the rupture of bonding between the resin composite and cavity wall. The resin cement used in the current study contains bifunctional monomers, such as Bis-GMA, which assign high viscosity to the material and is reduced by the inclusion of monomer diluents (TEGDMA) to yield a polymeric network. However, significant polymerization shrinkage occurs in this reaction; a thin layer of resin cement could cause sufficient stress to generate bond failures, as observed in the current study.

CONCLUSIONS

Considering the compressive strength and marginal adaptation, no influence of the restorative technique was observed on the restoration's performance. However, neither restorative technique recovered the compressive strength of sound teeth. Thermal/mechanical cycling only influenced marginal adaptation, increasing the percentage of gaps. Despite acceptance of the tested hypothesis that the restorative technique and thermal/mechanical cycling did not recover compressive strength, the hypothesis that thermal/mechanical cycling does not influence the marginal adaptation of onlay restorations was rejected.

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