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Fracture Resistance and Gap Formation of MOD Restorations: Influence of Restorative Technique, Bevel Preparation and Water Storage

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Clinical Relevance

Beveling of the cavosurface margin can improve resistance to fracture and the marginal adaptation of posterior composite restorations, reducing the deleterious effect of storage with thermal cycling on restoration quality. Generally, indirect restorations showed similar performance compared to direct restorations.

SUMMARY

This *in vitro* study evaluated the effect of technique, use of a bevel and thermal cycling on the fracture resistance and gap formation of resin composite MOD restorations. Fracture resistance was measured on standard MOD cavities prepared in 100 upper premolars that were stored for 24 hours and 6 months with 1000 thermal cycles. Subgroups (n=10) were: beveled or non-beveled preparations and direct restorations (Adper Single Bond/Filtek Z250) and indirect restorations (prepolymerized Filtek Z250 cemented with Rely X ARC). Ten sound teeth and 10 specimens with MOD preparations without restorations served as the positive and negative controls, respectively. The specimens were subjected to axial compression in a universal testing machine at a crosshead speed of 0.5 mm/minute. Failure patterns were analyzed by stereomicroscopy (40x). To evaluate gap presence or absence, proximal box cavities were prepared in 24 human third molars that were restored as described above. The specimens were evaluated under SEM examination after 24 hours and six months. Data were statistically analyzed by ANOVA and multiple comparison tests at the 0.05 level of significance. After 24 hours, the beveled restorations exhibited higher fracture strength values than the non-beveled restorations, and all groups

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showed resistance similar or superior to sound teeth. After six months, the highest fracture resistance was obtained for beveled inlays and the lowest values were observed for direct restorations with butt joints. Thermal cycling decreased fracture resistance in the majority of the groups. The main fracture pattern observed was cohesive failure in the material, but adhesive failures increased over time, especially in the non-beveled restorations. Under SEM examination, no difference was observed among the groups after 24 hours. However, after six months, the beveled restorations exhibited no gap formation. It was concluded that storage with thermal cycling decreased fracture resistance, bevels improved fracture resistance and, in general, indirect restorations were not superior to direct restorations.

INTRODUCTION

Despite significant improvements in adhesive systems and resin composites, the fracture of restored teeth, gap formation and, as a consequence, microleakage around composite restorations[1-2] remains a problem for clinicians. Polymerization shrinkage and questionable longevity of the adhesive interface are critical factors related to the performance of composite restorations, especially in posterior teeth.[3-4]

Reinforcement of the remaining dental structure, obtained with adhesive restorations, deteriorates with clinical aging.[4-5] Nanoleakage, microleakage, mechanical fatigue and hydrolysis are factors that could decrease bonding resistance.[6-7]

To prevent such deleterious effects, several restorative techniques have been developed. Indirect composite restorations have been reported to produce better anatomic contour and proximal contact, improved polishing and better esthetics.[4] Moreover, due to the higher degree of conversion obtained, improved mechanical properties could be expected.[5] Finally, polymerization shrinkage of indirect resin restorations occurs before the restoration is bonded.[6] Also, the use of a bevel could help to improve the fracture resistance and marginal adaptation of composite restorations.[8-9]

The removal of dental structure has a direct correlation with the decrease in fracture resistance;[10-11] however, when prepared teeth are restored with adhesive materials, there could be a partial or total recovery of fracture resistance.[9,12-13]

Nevertheless, if adhesive restorations provide an initial improvement in fracture resistance, clinical aging could reduce long-term performance. In fact, restorations maintained in aqueous solution showed reduced bond strength due to the hydrolytic degradation of the adhesive interface.[6-7,14]

With respect to marginal adaptation, failures at the adhesive interface can cause postoperative sensitivity by favoring degradation of the hybrid layer, marginal staining and penetration of bacteria and its byproducts.[2,15] However, beveling of the cavosurface could improve marginal behavior, especially in the first stages of the clinical life of the restoration.[8,16-17]

This study evaluated fracture resistance and gap formation in direct and indirect composite MOD restorations by evaluating the influence of bevel and storage with thermal cycling.

METHODS AND MATERIALS

This study had the approval of the Ethics Committee of the Federal University of Pelotas (number 21/05).

Both direct and indirect restorations were prepared using Filtek Z250 (shade A3, 3M ESPE, St Paul, MN, USA) and all cavities were treated with Adper Single Bond (3M ESPE). A dual-activated resin cement (RelyX ARC, 3M ESPE) was used to cement the indirect restorations.

Fracture Resistance Test

Specimen Preparation

One hundred sound human premolars, extracted for orthodontic reasons, were selected. After removal of the soft tissue, the teeth were stored in 1% chloramine solution for 72 hours.[18] In order to be included in the study, the premolars were required to have the following crown dimensions:[19] 9.0- to 9.6-mm bucco-lingual distance; 7.0- to 7.4-mm mesio-distal distance and 7.7- to 8.8-mm cervico-occlusal distance. Also, the teeth needed to be free of cracks as determined under magnification (30x). The teeth were stored in distilled water at 37°C, which was changed periodically throughout the study. Then, the teeth were randomly divided into six groups (Table 1) according to restorative procedures and storage times.

The teeth had their roots embedded in a PVC matrix using acrylic resin (Artigos Odontológicos Clássico Ltda, São Paulo, Brazil) up to 1 mm below the cement-enamel junction. Twenty premolars were not prepared or were prepared with unrestored MOD cavities as the positive and negative controls, respectively (Table 1).

A guide was used to standardize the correct position of the specimen inside the PVC matrix. Standard Class II MOD inlay cavities were prepared. Number 4138 diamond burs (KG Sorensen, Alphaville, Brazil) were mounted in a Galloni Machine (S Colombano, Milano, Italy) to obtain a standardized cavity preparation. The burs were replaced after every four cavity preparations to ensure high cutting ability. The occlusal box was 4-mm deep (without axial wall) and 2 mm in the buccal-lingual dimension. The cervical walls were located in enamel (1 mm above the cemento-enamel junction).

Table 1: *Factors for Groups Evaluated with the Different Restorative Protocols and Times*

Groups	24 Hours	180 Days
MOD cavity and direct composite without bevel	10	10
MOD cavity and direct composite with bevel	10	10
MOD cavity and indirect composite without bevel	10	10
MOD cavity and indirect composite with bevel	10	10
Sound teeth (positive control)	10	--
MOD prepared teeth (negative control)	10	--

The buccal and lingual walls were tapered (6°) and the internal angles rounded.

For those specimens with beveled margins, a 2135 diamond bur (KG Sorensen) was used at high-speed under air-water cooling to prepare a 1-mm bevel (45°) in all extensions of the cavosuperficial margin.

Direct Restoration Procedures

The entire cavity was conditioned with 35% phosphoric acid for 30 seconds (enamel) and 15 seconds (dentin). Following washing and gentle drying to leave a moist dentin surface, the adhesive system Adper Single Bond (3M ESPE) was applied in two coats and light cured for 20 seconds. The cavity was filled with increments of a direct resin composite (Filtek Z250, 3M ESPE). Tofflemayer metal matrices were used to reestablish the proximal surface of the restorations.[17,20] The polymerization of each increment was performed from the occlusal aspect for 40 seconds. An XL3000 light-curing unit (3M ESPE) with energy higher than 470 mW/cm^2 was used for the polymerization procedures. Before beginning each new restoration, the intensity of the light source was measured with a radiometer (Curing Radiometer Model 100, Kerr/Demetron, Danbury, CT, USA). After removal of the matrix, excess material was removed using scalpel blades.

Indirect Restorative Procedures

For those specimens restored using the indirect technique, each cavity preparation was isolated using KY gel (Johnson & Johnson, New Brunswick, NJ, USA). The resin composite was applied and polymerized in increments, filling the entire preparation. After removal of the restoration, the cavity was washed with air/water spray and dried. Thereafter, etching with 35% phosphoric acid was performed in enamel (30 seconds), dentin (15 seconds) and the internal restoration surface (15 seconds). Following washing and drying, the adhesive system was applied, the resin cement (RelyX ARC, 3M ESPE) was mixed, a thin coat was applied in the cavity preparations and the restoration was cemented and maintained in place with digital pressure. The resin cement was photo-activated at all margins for 40 seconds. Excess resin cement was removed using scalpel blades. The specimens remained untouched for an additional 10 minutes to allow for chemical cure of the resin cement.

Polishing procedures were performed immediately using Sof-lex disks (3M ESPE).[21] All the materials were used in accordance with the manufacturer's instructions and only one operator performed all the operative and restorative procedures.

Fracture Resistance

The specimens were tested after storage for 24 hours in distilled water or after 180 days in distilled water with two thermal cycling treatments (60 and 120 days) that comprised 500 cycles between 5°C and 55°C, with a dwell time of 30 seconds.

Axial compression was performed in a universal testing machine (Pantec Versat 500, São Paulo, Brazil) using an 8-mm metal sphere with a crosshead speed of 0.5 mm/minute. Care was taken to maintain the sphere in contact with dental structure without touching the restorative material. Fracture resistance was reported in Newtons.

The fractured specimens were examined under magnification (40x) using a stereomicroscope to evaluate the failure patterns as follows: cohesive fracture of the tooth—CS, adhesive fracture at the interface—AD, cohesive failure of the restorative material—CM and complete fracture of the specimens involving the two cusps and the restorative material—CO.

Marginal Gap Formation

Twenty-four recently extracted human third molars were selected. After removal of the soft tissue, the teeth were stored in 1% chloramine solution for 72 hours. The molars were randomly assigned to four groups.

Each tooth received two proximal box cavities that were prepared using a 4137 diamond bur (KG Sorensen). After every two cavity preparations, a new diamond bur was used. The cervical wall was located in enamel 1 mm above the CEJ. Half of the cavity preparations had their cavosuperficial margins beveled and the balance of the cavities remained without bevel (butt-joint).

Beveled or butt-joint cavities were restored with direct or indirect restorations, similar to the procedures used for the fracture resistance test. Three specimens for each group were observed under a scanning electron microscope (SEM) after one day, while the remaining specimens were examined in distilled water aging (with 2 thermal cycling treatments) after 180 days.

For SEM examination, the specimens were sectioned in a mesio-distal direction through the center of the restoration using a diamond saw under water-cooling.

Both the mesial and distal restorations for each tooth were analyzed. The specimens were cleaned in an ultrasonic bath and prepared for SEM examination, receiving gold sputtering (30-nm layer).

A SEM (JEOL JSM—6060, Japan) was used to observe the presence or absence of marginal gaps, using a standard magnification (1000x) along the entire cervical wall.

Table 2: *Means and Standard Deviations of Fracture Resistance (N) for Different Groups at Both Evaluation Times*

Groups	Means (SD) After 24 Hours	Means (SD) After 180 Days
Direct without bevel	1020 (170) Ba	570 (180) Cb
Direct with bevel	1750 (180) Aa	970 (260) Bb
Indirect without bevel	910 (150) Ba	1030 (310) ABa
Indirect with bevel	1840 (360) Aa	1300 (220) Ab
Sound teeth	1030 (250) B	
Prepared teeth	320 (50) C	

**Different capital letters indicate statistically significant differences among means of treatment groups (columns)*
***Different small letters indicate statistically significant differences between means of times (rows)*

Table 3: *Failure Patterns Observed for Different Groups at Both Time Intervals**

Groups	Fracture Pattern—24 Hours				Fracture Pattern—180 Days			
	CS	***AD***	***CM***	***CO***	***CS***	***AD***	***CM***	***CO***
Direct without bevel	4	1	4	1	1	7	2	-
Direct with bevel	-	3	9	1	2	1	6	1
Indirect without bevel	2	-	5	-	-	4	6	-
Indirect with bevel	-	-	7	3	-	-	10	-
Total	6	4	25	5	3	12	24	1

**Cohesive fracture of the tooth—CS, adhesive fracture at the interface—AD, cohesive failure of the restorative material—CM, and complete fracture of the specimens involving the two cusps and the restorative material—CO*

Statistical Analysis

Fracture resistance data were submitted to parametric tests (ANOVA and Tukey tests). The student *t*-test was used to compare the two evaluation times. The evaluation of fracture patterns was performed using the non-parametric Fisher's Exact Test. Also, marginal gap formation was evaluated using the Fisher's Exact Test. For all tests, the confidence level was set at a 0.05 level of significance.

RESULTS

Fracture Resistance

For both storage periods, ANOVA disclosed a significant difference between the groups ($p<0.01$). In Table 2, the means and standard deviations of fracture resistance are listed for both groups at both storage times.

After 24 hours, specimens with beveled margins demonstrated similar fracture resistance and performed statistically better than all the other experimental groups, including sound teeth. Both non-beveled direct and indirect restorations showed fracture resistance similar to sound teeth. The lowest fracture resistance was observed in the non-restored prepared teeth.

After 180 days, higher values of fracture resistance were observed in indirect restorations (with or without bevel). Direct restorations with bevel had a fracture resistance similar to indirect restorations without bevel and a higher fracture resistance than direct restorations without bevel ($p<0.01$).

When comparing 24 hours and 180 days, a significant decrease in fracture resistance for three groups ($p<0.01$) was detected. The only specimens that maintained similar fracture resistance after storage were those specimens restored with non-beveled indirect composite restorations.

Table 3 lists the classification of different failure patterns for the different groups and storage times. The most frequent failure pattern observed for all groups at the 24-hour evaluation was cohesive failure in the material (CM), which occurred in more than 60% of the cases ($p<0.05$). After six months, cohesive failure of the material remained the most frequently observed (60%), but there was an increase in adhesive failures (AD), especially for those non-beveled direct restorations ($p<0.05$).

Marginal Gap Formation

At the first storage time (24 hours), only one restoration exhibited a marginal gap in the cervical wall. Long-term storage significantly increased the presence of marginal gaps, which appeared in non-beveled restorations only ($p<0.05$).

Figure 1 shows a non-beveled direct restoration exhibiting a marginal gap after six months. In Figure 2, a beveled direct restoration free of marginal gap at the cervical wall is shown after storage (180 days).

DISCUSSION

The overall results of this study showed that a bevel placed around the cavosuperficial margin of direct or indirect restorations had higher fracture resistance and less gap formation when compared with the same restorations without bevel placement.

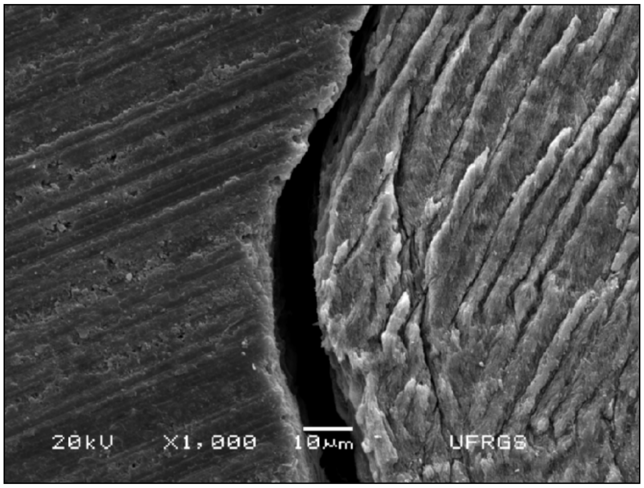

Figure 1: *Non-beveled direct composite restoration after 180 days exhibiting a marginal gap in the cervical wall.*

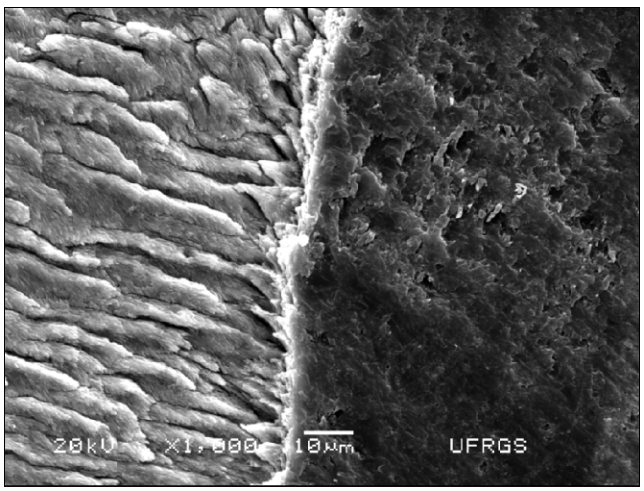

Figure 2: *Beveled direct composite restoration exhibiting gap-free cervical margin after 180 days.*

As demonstrated in the literature, decreased fracture resistance occurs when cavity preparations are prepared,[10,22] and this result was also confirmed in the current study, with a significant decrease in the fracture resistance of those specimens with non-restored MOD cavities. Adhesive restorations could partially or completely restore reduced fracture resistance.[13,23] Based on the findings of this study, improved fracture resistance with similar values to the positive control group was observed with beveled direct or indirect restorations; these groups had statistically higher values than sound teeth.

Since polymerization shrinkage has been associated with deleterious effects at the adhesive interface,[24-25] different restorative techniques have been advocated to minimize the harmful effects on restoration longevity. The indirect technique proposed in this study was employed to restrict polymerization shrinkage to resin cement and, as a consequence, reduce the adverse effects generally observed with long-term storage. When comparing the results of fracture resistance, beveled indirect composite restorations provided better resistance than beveled or non-beveled direct composite restorations after six months. However, these indirect restorations were not able to ensure better adaptation in the cervical wall when compared to direct restorations. In a recent study, better marginal sealing was observed for indirect composite restorations in enamel when compared to direct composite restorations.[25]

The bevel was also applied in order to produce a long lasting adhesive interface and, based on observations from this study, beveled restorations generally exhibited better fracture resistance and less gap formation initially and after six months.

For restorations with cuspal coverage, beveled restorations produced improved fracture resistance that was superior to that for sound, non-prepared teeth.[26] Ausiello and others[27] observed similar findings for fracture resistance when comparing sound teeth and adhesive composite restorations after 24 hours. Aging of the restorations produced a significant drop in fracture resistance for most of the groups tested,[14] including those with beveled margins. However, beveled direct restorations had higher fracture resistance than non-beveled direct restorations following aging. Probably, the beneficial effect of beveling resulted from an increase in the surface area for adhesion.[8,28]

The failure patterns observed in the current study showed predominantly cohesive failures in the restorative material and dental structure (CM). However, with storage, there was an increased occurrence in adhesive failures, especially for non-beveled direct restorations with the lowest fracture resistance after six months. The increase in adhesive failures could be due to the hydrolytic degradation of the adhesive systems,[3] impairing bonding resistance and favoring breakdown of the adhesive interface.[5]

SEM examination of gap formation at the cervical wall showed good marginal adaptation for all groups tested after 24 hours. It has been reported that initial bonding resistance[29] and initial marginal adaptation[25] are adequate with new adhesive systems, especially when the margins are located in enamel.[30] In fact, the interlocking formed by penetration of the adhesive system inside the microgaps originated by acid etching in highly mineralized enamel has been reported to be a more secure, stable bonding than adhesion obtained with dentin.[31] However, even the quality of marginal adaptation was impaired with long-term storage, with an increase in the number of restorations that showed gap formation. Nevertheless, direct or indirect restorations with beveled margins maintained good adaptation, which was obtained at the initial evaluation, demonstrating that beveling had a protective effect on disruption of the adhesive interface, which could be caused by polymerization contraction and temperature alterations occurring in the oral cavity. The protective effect of a bevel on gap formation in enamel was previously demonstrated.[8,20] Beveled margins provide a series of advantages, such as removing the non-prismatic enamel surface, which is rich in fluoride; increasing surface energy and enhancing the surface area of enamel, thereby improving adhesion and marginal sealing and providing a better esthetic result for the restorations.[16,28] The only disadvantage of a bevel is the additional removal of sound enamel structure.

The *in vitro* aging of restorations can be induced by storage in water or artificial saliva, thermal or mechanical cycling with the hydrolytic degradation of collagen and the adhesive being the most important mechanism to decrease bonding quality.[2] In the current study, aging was produced by storage in distilled water using two thermal cycling treatments, following ISO 11405 guidelines,[32] and it was shown to be an effective method to challenge the restoration. Water has a deleterious effect over the hybrid layer and collagen, especially over collagen not encapsulated by the adhesive.[6-7,33] The association with thermal stress accelerates aging of the restoration.[3]

The indirect technique proposed in this study presents some advantages, such as polymerization shrinkage restricted to the cement layer and possibly better proximal and occlusal contacts. However, for this kind of restoration, a non-retentive preparation is mandatory, requiring the removal of more sound dental structure and is more time consuming, resulting in a more expensive treatment. In this study, indirect restorations provided similar results compared to direct restorations, except for fracture resistance after six months. According to a meta-analyses of posterior restoration longevity, indirect restorations had a survival rate of 75% after 10 years, while direct restorations had a survival rate of 50%.[1] Nevertheless, with the decrease in caries prevalence, cavities have smaller dimensions, and with constant improvements in composite technology, there is an upcoming trend for placement of more direct restorations.[1] In fact, direct posterior composites could have good performance, even in periods longer than 10 years, especially in small cavities having less surfaces.[34]

The findings of this study were developed from *in vitro* studies; therefore, the results of the current study need to be confirmed in clinical trials.

CONCLUSIONS

Within the limitations of this study, it was possible to conclude that:

a) Use of a bevel results in improved fracture resistance and marginal adaptation, reducing the impact of long-term storage on restoration quality;

b) Long-term storage had a significant effect on restoration quality in almost all of the conditions tested;

c) In most of the conditions tested, indirect restorations presented similar results when compared with direct restorations, except for fracture resistance after six months.

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