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ORIGINAL RESEARCH

The Effect of Mechanical Loading on the Cusp Deflection of Premolars Restored with Direct and Indirect Techniques

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ABSTRACT

Aim: This study assessed the effect of fatigue load cycling on human premolars restored with MOD restorations (direct and indirect approaches) on cuspal deflection, compared to intact teeth (unprepared) and unrestored teeth with an inlay preparation.

Materials and methods: MOD inlay preparations were performed on sixty premolars with their roots embedded in acrylic resin. These teeth were divided into six groups (n = 10): (1) intact teeth; (2) unrestored and prepared teeth; (3) teeth restored with direct composite resin; (4) teeth restored with an indirect composite resin; (5) teeth restored with injected ceramic inlays (IPS Empress 2 (Ivoclar); (6) teeth restored with CAD/CAM inlays made of feldspathic ceramic (Vita Mark II). All of the indirect restorations were adhesively cemented. Strain-gauges were bonded to the buccal and lingual surfaces of the specimens. Compressive axial loading of 100N was applied on the occlusal face of the specimens to measure the cuspal deflection (microstrain) under compressive loading. These measurements were obtained before and after mechanical cycling (1 Hz, 37°C, 100,000x).

Results: Comparing the results obtained before and after fatiguing, the cuspal deflection increased only in the CAD/CAM approach. The prepared tooth group had the highest cuspal deflection, before and after mechanical cycling.

Conclusion: The evaluated restoring approaches decrease the cuspal deflection, consequently appear to improve the cuspal reinforcement.

Keywords: Inlay restorations, Porcelain, CAD/CAM, Composite resin, Cusp deflection, Mechanical loading.

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INTRODUCTION

Recently, the concepts for restoring posterior teeth that have intracoronal cavities changed for two main reasons: adhesive technology and better materials in the production of metal-free fixed partial dentures made with feldspathic ceramics or direct composites. These conditions led to minimal intervention approaches, which also contribute to a reduction in the risk of cuspal fracture of posterior teeth restored with inlay restorations.[1-5]

Denehy and Torney[6] first proposed the use of adhesive materials to reinforce weakened teeth and support undermined enamel. Other studies have shown that the weakening effect of cavity preparation can be alleviated with adhesive materials.[7-9] Intact teeth rarely break under masticatory stresses; however, teeth with extensive restorations can frequently suffer cuspal fracture.[10,11] Cavity preparations have been routinely associated with the decreased fracture strength of restored teeth.[12] Tooth deformation is indicative of a combination of stresses in the tooth, in the restoration or across the tooth-restoration interface.[13] Bell et al[10] defined the mechanism of breaking teeth: 'Fragile cusps, caused by cavity preparation, injury or caries, break due to fatigue and propagation of cracks during cuspal deflection from masticatory load'. Cusp deflection is the result of interactions between the polymerization shrinkage stress of the composite and the compliance of the cavity wall, a common biomechanical phenomenon observed in teeth restored with composites.[14] The cusps suffer deflection when submitted to a masticatory load, as the isthmus of the preparation weakens the tooth.[15]

Composite resins are widely used for direct restorations in posterior teeth, even though they still show functional limitations due to polymerization contraction.[16-18] During the early 1980s, the technique of indirect composite resin restorations was introduced to improve the physical properties of this material and reduce the effect of polymerization shrinkage. Lopes et al[19] demonstrated that indirect restorations restored 97% of the initial tooth rigidity, establishing durability, esthetics and the ability of the restorative material to keep the cusps joined.[20]

Indirect restorations have better physical properties than direct composite restorations because they are fabricated under relatively ideal laboratory conditions.[21] Teeth restored with bonded ceramic inlays show biological compatibility, adequate compressive strength, similar thermal conductivity to dental tissues, marginal integrity and color stability.[22] However, all-ceramic restorations can fail due to the propagation of cracks through the matrix, aiding in the failure of the restoration.[23] Previous studies have shown that adhesive cementation increases the fracture resistance of these materials.[24]

Therefore, the purpose of this current study was to evaluate the effect of fatigue load cycling on human premolars restored with MOD restorations (direct and indirect approaches) on cuspal deflection, compared to intact teeth (unprepared) and unrestored teeth with an inlay preparation. The hypotheses were that the restoring approaches would promote similar cuspal deflection to sound teeth (cuspal reinforcement outcome) and that the prepared teeth would depict the highest values of cuspal deflection.

MATERIALS AND METHODS

Sixty intact human maxillary premolars of similar size and shape were selected, according to the inclusion criteria of a lack of cracks in the tooth. The teeth were extracted for orthodontic reasons and with the informed consent of the patients (protocol n° 088/2005-PH/CEP). The teeth were homogeneously divided into 6 groups (Table 1), according to their vestibular-lingual dimensions.

The roots of each specimen were embedded in a metallic cylinder filled with chemically cured acrylic resin (Dencrilay®, Dencril, Caieiras, Brazil) up to 3 mm from the cervical line, in an apical direction and with the assistance of a surveyor (Figs 1A and B).

MOD Cavity Preparation

Standardized MOD cavity preparations (Fig. 2) were performed in groups 2, 3, 4, 5 and 6, using fresh conical trunk diamond burs with rounded angles (KG Sorensen 3131, Barueri Brazil) at high speed under air/water spray cooling in a handpiece that was fixed to an adapted optic microscope. Thus, the MOD preparations were as parallel as possible to the long axis of the tooth. Cavity depth was standardized at 2 mm for the occlusal box and 4 mm for the proximal box. The cavosurface angle was straightened and all the specimens had rounded internal angles. The pulpal and gingival walls were perpendicular to the long axis of the tooth and the buccal, axial, lingual and proximal boxes walls had an angulation of 12°.[25,26]

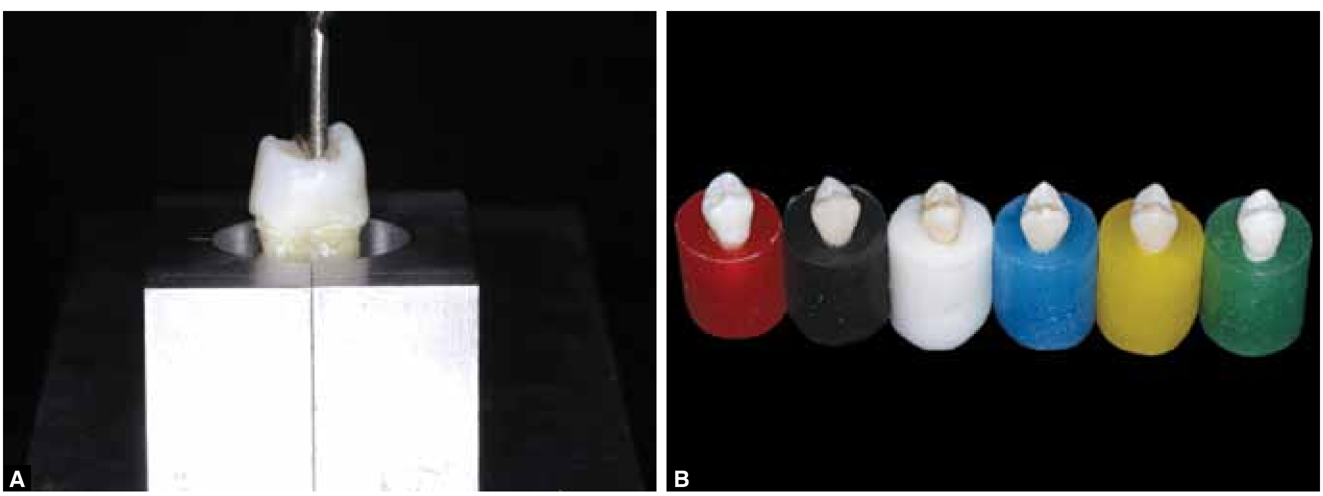
Inlay Restorations

The specimens from groups 3, 4, 5 and 6 were restored as follows:

Table 1: Testing groups according to the restoring technique and control groups

Groups (n = 10)	*Material*	*Restoring approach*
1*	Sound teeth	-----
2**	Cavity preparation only (no restoration)	None
3	Composite resin	Direct
4	Composite resin	Indirect
5	Pressable glass-ceramic (lithium disilicate)	
6	CAD/CAM porcelain (feldspathic)	

*gold-standard group; ** Negative control group



Figs 1A and B: (A) Teeth being mounted in a cylindrical base; (B) Teeth embedded in acrylic resin (each color indicates an experimental group)

Group 3

MOD cavities were restored with a direct approach using a 3-step etch and rinse adhesive system (Scotchbond Multi-Purpose System, 3M ESPE) and composite resin (Z350, 3M ESPE), according to the manufacturer's instructions. The entire cavity was etched with 35% phosphoric acid and dried, avoiding dehydration. The primer and adhesive agent were applied and light cured for 10 seconds. The composite resin was placed using the incremental insertion technique. Each increment was light-cured for 40 seconds using a visible-light curing unit (XL 3000-3M ESPE, with an intensity of 620 mW/cm^2).

The crowns with MOD cavities from groups 4, 5 and 6 (indirect approach) were impressed. A one-stage impression was taken of each prepared tooth using a double-viscosity polyvinylsiloxane impression material (Aquasil Ultra LV, Dentsply), and an individual impression tray. Master dies were then produced (Stone type IV, Durone, Dentsply). One technician produced the indirect restorations.

Group 4

MOD inlay preparations were made and restored with the Sinfony System. This indirect composite material was subjected to a first and second polymerization cycle as determined by the manufacturer. For inlay cementation, a 3-step etch and rinse adhesive system (Scotchbond Multi-Purpose Plus system, 3M ESPE) was used and combined with a dual-cure resin cement (Relyx ARC, 3M ESPE). The entire cavity was etched with 35% phosphoric acid and dried, avoiding dehydration. Then, the Activator®, Primer® and Catalyst® products were applied on enamel/dentin, as recommended by manufacturer. A resin luting agent (RelyX ARC, 3M ESPE) was manipulated and applied to the internal surface of the inlay, the cement excess was carefully removed from the margins and the resin cement was cured with a visible-light curing unit (XL3000-3M ESPE, with a light intensity of 620 mW/cm^2) for 20 seconds on each face.

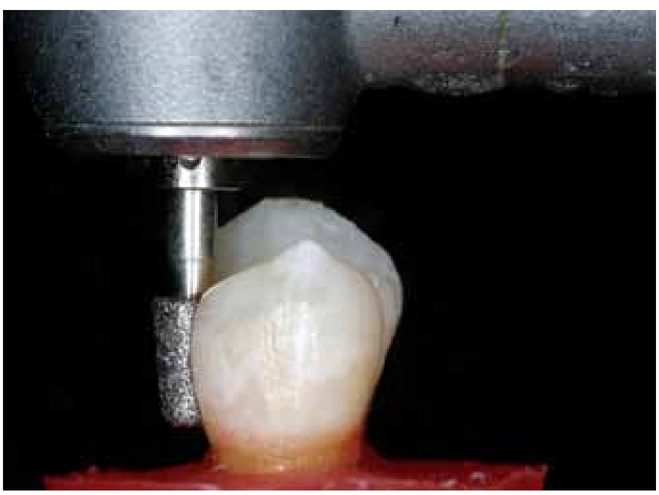


Fig. 2: Preparation of a specimen

Group 5

Hot-pressed, all-ceramic restorations were made with a lithium disilicate material (IPS Empress, Ivoclar-Vivadent, Schaan, Liechtenstein), using the injection molding technique. All of the instructions recommended by the manufacturer were followed. Before inlay cementation, the inner surfaces of the restorations were etched with 5% hydrofluoric acid (IPS Ceramic Etching, Ivoclar Vivadent) for 20 seconds, rinsed with water, dried, and Salinized (RelyX Ceramic Primer-3M ESPE). The cementation procedures (dentin treatment) were the same as for those described in Group 4.

Group 6

Inlay restorations were fabricated from Vita Mark II ceramic blocks (Vita, Bad Sackingen, Germany) using the standard technique of the Cerec software. The inner surfaces of the restorations were then etched with 5% hydrofluoric acid (IPS Ceramic Etching, Ivoclar Vivadent), rinsed with water, dried and silanized (RelyX Ceramic Primer- 3M ESPE). The same cementation procedures described in group 4 was followed.

All of the specimens were stored in distilled water at 37° C for 24 hours.

Static Compressive Load and Deflection Measurements

Single precalibrated strain gauges (model 060 BG-Excel Sensory) were bonded with superglue (Super Bonder Gel, Loctite, Sao Paulo, Brazil) to the buccal and lingual cusps of each specimen, 0.5 mm above of the cementoenamel junction. Two gauges were bonded to each tooth, one on the buccal and one on the lingual surface of the crown, in order to independently measure the deflection of each cusp. The gauges were bonded at a level that corresponded with the intended pulpal floor of the MOD cavity. This was reported to be the location of the highest strains, leading to cuspal deflection. A metallic cylinder, with an 8 mm diameter, was applied to the internal surfaces of the crown, with a load of 100N in a universal testing machine (EMIC, model DL-1000, Sao Jose dos Pinhais, Brazil) at a speed of 1 mm/min. The cuspal deflection before mechanical cycling was registered in micron deformation (µst) (Fig. 3).

Mechanical Cycling Testing

After the initial measurements (before cycling), the specimens were submitted to 100,000 mechanical cycles with a load of 50 N and a frequency of 1 Hz. During

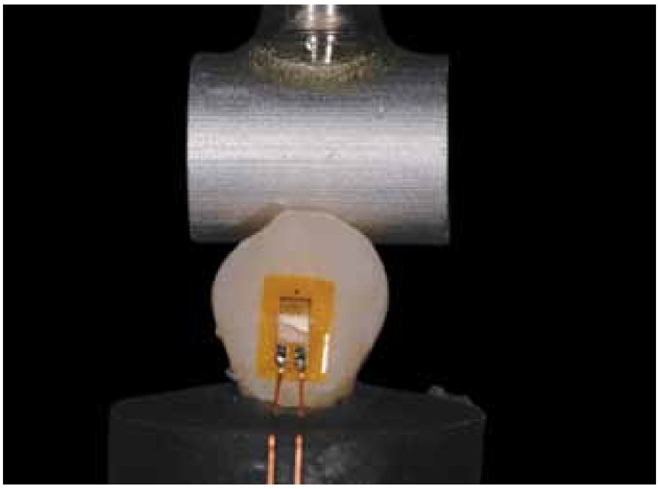


Fig. 3: Static compressive load applications on teeth

cycling, the specimens were kept immersed in water at 37 ± 1°C, regulated by a thermostat. After the fatigue testing, the magnitude of cuspal deflection was evaluated again, as described previously.

Experimental Design and Statistic Analysis

This study presented two factors (restorative approach in 6 levels, and mechanical cycling in 2 levels). Thus, the data in microstrain was submitted to 2-way ANOVA and Tukey's test (5%).

RESULTS

Two-way ANOVA (Table 2) shows that mechanical cycling (p = 0.0334) had statistically significance on cuspal deflection results. Also the tooth condition (p < 0.0001) significantly affected the deflection (the prepared and unrestored tooth group had the highest cuspal deflection).

Table 3 presents the means and standard deviations of the tested conditions and the Tukey posthoc test results (alpha = 0.05). All of the restored groups had significantly lower cuspal deflection when compared to the nonrestored prepared group, not only before, but also after mechanical cycling. When comparing the different restoring conditions and negative/positive control groups after mechanical cycling, the prepared and unrestored teeth had the highest cuspal deflection, while the sound teeth and the 'restored groups' were statistically similar. Only the restoration made of CAD/CAM porcelain (group 5) had a significantly increased cuspal deflection after fatiguing.

DISCUSSION

This current investigation observed that the cuspal deflection in restored premolars with inlay cavities is similar to sound teeth. The adhesive properties of the restorative approaches appear be the main reason for reinforcement of the prepared premolars.

Vital teeth with conservative restorations are less susceptible to fracture than prepared teeth, as confirmed in the literature.[7,19,27-29] When comparing the deflection values of sound teeth with those of restored teeth, the restored teeth exhibited a capacity of cuspal reinforcement with lowered resistance to breaking. The adhesive approaches of indirect and direct restorations promote the bond between hard dental tissues and restorative materials,[19,30] cuspal reinforcement and reducing deflection.

Choosing the best technique and material according to functional demands and determining the amount of remaining tooth structure for optimum strength against fracture are key factors for success.[11] The results from the current study support the hypotheses proposed, since the restored teeth had similar cuspal deflection to sound teeth, and lower cuspal deflection than those teeth that were only prepared and not restored.

The results of the current study indicated that a direct composite resin restoration was able to improve the resistance to fracture when compared with intact teeth. Dental composite materials are widely used with many techniques and compositions to increase the resistance of the composite resin. The resin system of 3M, Filtek Z350, shows good results, possibly due to the composition (manufacture's information), consisting of three major components: TEGDMA, UDMA and BIS-EMA, where the

Table 2: Two-way ANOVA of the data of microstrain

Source	*df*	*SS*	*MS*	*F*	*P*
Mechanical cycling	1	19.04	19.036	4.64	0.0334
Restoring condition	5	533.62	106.724	26.02	0.0000
Interaction	5	32.69	6.539	1.59	0.1679
Error	108	443.03	4.102		
Total	119	1028.38			

Table 3: Mean values and SD of cuspal deflection (µst) before and after mechanical loading for each restorative material and the control groups

Tooth condition	*Mechanical loading*	
	*Before***	*After***
Sound teeth*	577.0 ± 2.7 Ba	577.5 ± 2.6 Ba
Prepared teeth*	583.4 ± 2.8 Aa	584.4 ± 0.8 Aa
Direct composite resin*	579.2 ± 3.9 Ba	579.2 ± 0.9 Ba
Indirect composite resin*	578.1 ± 1.4 Ba	578.2 ± 1.1 Ba
Pressable glass-ceramic*	578.7 ± 1.6 Ba	578.7 ± 0.8 Ba
CAD/CAM porcelain*	577.5 ± 1.9 Ba	580.5 ± 1 Bb

*Means from the same row followed by the same lower-case letters are not significantly different at p < 0.05 according to Tukey HSD test; **Values from the same column followed by the same capital letter do not differ according to the Tukey HSD test (p < 0.05) majority of TEGDMA has been replaced with a blend of UDMA and BIS-EMA, contributing to the resistance of a tooth breaking that has been restored with this material and an associated adhesive.[7,28]

The filler contains a combination of a nonagglomerated/nonaggregated, 20 nm nanosilica filler and loosely bound agglomerated zirconium/silica nanoclusters, consisting of agglomerates of zirconium/silica particles. It is proposed by the current authors that this material increases the resistance of cusp deflection by joining the two cusps.[27,31] Similar results for composite resin in class II MOD preparations were found by many authors when they compared direct composite resins with other indirect restoring materials.[8,12,28,32]

Jensen et al[28] and Cötert et al[8] compared direct composite with indirect ceramic restorations and concluded that both restorations re-established resistance to breaking that was similar to intact teeth. When these authors compared the materials in compression, ceramics presented better results. Dalpino et al[12] concluded that composite resin restorations increased the resistance to breaking without significant differences between the groups of indirect materials (resin and ceramics). Similar results were achieved by Burman et al[32] Even though these studies assessed fracture resistance, their findings corroborate with the results displayed from this current study.

The principal limitation for the use of direct composite resin is the volume of the material that is used, with an effect on polymerization shrinkage and the resulting cracks in the remaining dental structure, causing postoperative pain and recurrent caries. Lee et al[14] indicated that the use of the incremental restoring technique[33] or an indirect inlay could reduce cuspal deformation.

Brunton et al[34] stated that indirect composite resin restorations presented greater flexibility and low rigidity, allowing the tooth to deflect when under occlusal forces, in relation to indirect ceramic restorations. Cötert et al[8] did not find significant differences in resistance to breaking between direct adhesive restoring materials, composite inlays, ceramic inlays and posterior composites. Additionally, the statistical data of resistance to fracture of the indirect composite resin was similar to intact teeth.[32] These findings agree with the findings from the current study, where the group that received indirect resin composite restorations presented deflection values that were similar with intact teeth.

In ceramic materials, the mechanism of crack propagation, leading to fatigue, is sufficiently distinct.[35] The resistance to crack propagation results from two mechanisms: intrinsic, which occurs in the crack and is related to the growth and propagation of a crack; and extrinsic, which is related to the retardation of the crack propagation.[36] The behavior under fatigue of these materials is a function of the competition between intrinsic parameters related to the mechanisms of structural degradation and extrinsic factors related to the discontinuation of the crack propagation. Thus, this would be one of the factors that could justify the success of teeth restored with IPS Empress 2, which presents a greater number of crystals of a homogeneous format that limits crack propagation through the process of energy absorption.[37] The resistance of the material is related the type of load, which would explain the biggest capacity of this material to resist tension. Most likely, the presence of crystals of lithium disilicate was responsible for the results found in the current study, presenting similar values to intact teeth before and after mechanical loading.

Several authors[8,12,32,34] concluded that ceramics have a resistance to fracture similar to other types of restorative materials when used in MOD inlay restorations by using comparative tests between direct composites, indirect composites and ceramics using diverse methodologies.

Some methods of restoration preparation have been developed to increase the main deficiencies of fragility, low tenacity and low tensile strength.[38] Machined ceramics have been indicated as excellent restorative materials. The results of the specimens restored with the CAD/CAM system in the current study exhibited no significant difference from the other restorative materials and the groups of sound teeth, before and after mechanical loading. However, only the Cerec group increased when comparing the values before and after mechanical cycling, different from the other groups, which had similar cuspal deflection before and after cycling. The feldspar restorations obtained by the CAD/CAM approach may be more susceptible to crack propagation under load stress.[39-41] It is proposed that these differences are due to machining (grinding using diamond bur) during the CAD/CAM process, which can provide machined grooves of different depths, leading to crack propagation.[39-41] Additionally, the restorative blank is formed from feldspathic porcelain, without the reinforcement of natural crystals, which would normally hinder the propagation of cracks, thus enabling greater cuspal deflection.[39-41]

Hannig et al[33] indicated that premolars restored with the CAD/CAM system presented a number of severe fractures, which was significantly greater then the results obtained with the control group of premolars.

Overall, this present investigation found that the studied restoring strategies to restore inlay cavities in premolars reestablished the cuspal deflection to values that were similar to sound teeth. Thus these strategies appear to be good strategies for these restorations, even though other factors may influence their performance. Further studies using long-term fatigue aging (fatigue life prediction) should be performed to better predict the clinical performance of these restoring approaches.

CONCLUSION

1. The restorative approaches (direct and indirect restorations) used to restore the MOD inlay promote cuspal reinforcement of premolars, since the cuspal deflections of the restored groups was similar to the sound teeth and lower than prepared teeth.
2. The adhesion between inlay restorations and dental hard tissues appears to be crucial for cuspal reinforcement.

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