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Effect of Base and Inlay Restorative Material on the Stress Distribution and Fracture Resistance of Weakened Premolars

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Clinical Relevance

Considering the increase in esthetic restorative treatments and the increased emphasis on more conservative cavity preparations, it is timely to assess the influence of the type of direct base and indirect inlay material on the stress distribution in endodontically treated premolars with weakened cusps.

SUMMARY

The purpose of this study was to evaluate the influence of direct base and indirect inlay materials on stress distribution and fracture resistance of endodontically treated premolars with weakened cusps. Forty healthy human premolars were selected; five were left intact as controls (group C+), and the others were subjected to endodontic treatment and removal of buccal and lingual cusp dentin. Five teeth were left as negative controls (group C–). The remaining 30 teeth were divided into two groups according to the direct base material (glass ionomer [GIC] or composite resin [CR]). After base placement, each group was subjected to extensive inlay preparation, and then three subgroups were created (n=5): no inlay restoration (GIC and CR), restored with an indirect composite resin inlay (GIC+IR and CR+IR), and restored with a ceramic inlay (GIC+C and CR+C). Each specimen was loaded until fracture in a universal testing machine. For finite element analysis, the results showed that the removal of tooth structure significantly affected fracture resistance. The lowest values were presented by the negative control

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group, followed by the restored and based groups (not statistically different from each other) and all lower than the positive control group. In finite element analysis, the stress concentration was lower in the restored tooth compared to the tooth without restoration, whereas in the restored teeth, the stress concentration was similar, regardless of the material used for the base or restoration. It can be concluded that the inlay materials combined with a base showed similar behavior and were not able to regain the strength of intact tooth structure.

INTRODUCTION

Because structural strength depends on the quality and integrity of a tooth's anatomic form, the quantity of a sound tooth available to retain and support the restoration is a fundamental clinical concern.[1] Moisture content and stiffness of teeth with an endodontic access were not found to be different from those of untreated vital teeth[2,3]; however, the loss of strategic tooth structure as a result of caries and subsequent restorative procedures severely compromise the strength of these teeth. An extensive mesio-occluso-distal (MOD) cavity plus endodontic access, which is a common clinical finding, results in a reduction of tooth stiffness and fracture strength of approximately 60%.[4,5] This loss of strength constitutes a restorative challenge in terms of restoring fracture resistance.

Some studies claim that inlay restorations can provide the required protection and ensure clinical success of the restoration while providing the maximum preservation of tooth structure.[6] Adhesive restorations are advantageous since macroretentive design is no longer a prerequisite when an adequate amount of tooth surface is available for bonding.[7] Clinicians are particularly interested in using preparations with minimal or no macroretentive properties.[8]

Glass ionomer cement (GIC) has a long history of use in dentistry due to its ability to bond chemically to tooth structure and its cariostatic effect from fluoride release[9-11] in addition to antibacterial activity.[12] Moreover, GIC has little contraction during the setting reaction, and its coefficient of thermal expansion is close to that of tooth structure.[13] These factors have been considered important to the success of effective bonding to tooth structure and provide justification for the cement's use as a support material under weakened enamel.

Many studies have shown the benefit of using composite resin to support weakened tooth structure because it provides reinforcement to the cusps, increasing the strength of the remaining tooth structure.[5,14,15] Generally, the physical and mechanical properties of the material used influence the behavior of the restored tooth under testing conditions.[16] Thus, the purpose of this study was to evaluate, *in vitro*, the influence of the type of base and inlay restorative material on fracture resistance and stress distribution in weakened teeth.

METHODS AND MATERIALS

Fracture Resistance Test

The brand name, manufacturer, and basic description of the materials used in this study are listed in Table 1. Forty fresh and caries-free maxillary premolars, extracted for orthodontic reasons, were selected. The teeth had the occlusal surface area and the angle formed by the two cusps measured in a digital X-ray image by the software UTHSCSA ImageTool for Windows, version 3.0 (University of Texas Health Science Center at San Antonio, San Antonio, TX, USA), and those having values above or below 10% of the average were excluded.

For the simulation of 0.3-mm-thick periodontal ligament, each root was immersed in melted wax up to the demarcation line 2 mm apical to the cemento-enamel junction (checked by a digital caliper). Roots were placed in a self-cured polyurethane resin up to the demarcation line in a polyvinyl chloride cylinder (20-mm height × 18-mm diameter). After curing, the wax was carefully removed from the root using hot water so that the wax could be replaced by polyether impression material[17] (Impregum F, 3M ESPE, St Paul, MN, USA). The root was then stored in distilled water in a refrigerator at 5°C.

The teeth were randomly separated in eight groups, according to direct base and inlay materials, as illustrated in Figure 1. First, an MOD opening was made with refrigerated #3131 diamond burs (KG Sorensen, Cotia, SP, Brazil) at high speed, positioned perpendicular to the long axis of the tooth, 1 mm below the cemento-enamel junction, through the aid of an adapted optical microscope. The marks left by the contact between a 10-mm-diameter steel ball and the occlusal face of the teeth guided the buccal-lingual width of the cavities (0.5 mm inner to the marks). For the removal of the cusp dentin, a 2.5-mm-diameter spherical diamond bur (#3017, KG Sorensen) was introduced until its rod limit into the buccal and lingual walls of the cavity (Figure 2).

Table 1: *Brand Name, Manufacturer, and Basic Description of the Materials Used*			
Material	**Manufacturer**	**Characteristic**	**Lots**
IPS e.max Press	Ivoclar Vivadent	Ceramic lithium disilicate	N30995
Variolink II	Ivoclar Vivadent	Resin cement	M44477 L46354
Monobond Plus	Ivoclar Vivadent	Silanizing agent	M15219
SignumCeramis	Heraeus	Composite resin indirect	010131
Vidrion F	SS White	Glass ionomer cement	0080911 0080811
Impregum-F	3M ESPE	Impression material polyether based	421709 420540
Resina F16	Axon	Polyurethane resin	SKRP-4560
Express	3M ESPE	Silicon	1127000396
GuttaPercha	Dentsply	Gutta-percha	578692D
AH Plus	Dentsply	Endodontic sealer	1106001642
Condac 37	FGM	Phosphoric acid 37%	150911
CondacPorcelana	FGM	Hydrofluoric acid 10%	110311

To perform the endodontic treatment, spherical diamond burs (#1014, KG Sorensen) and cone-drill Endo Z (Maillefer Instruments SA, Ballaigues, Switzerland) were used for the access opening. The canals were prepared with rotary instruments (Bio Race, FKG Dentaire, La Chaux-de-Fonds, Switzerland) according to the manufacturer's recommendations. Subsequently, the canals were dried with paper points and filled by insertion of gutta-percha with AH Plus sealer (Dentsply, Petrópolis, Brazil).

After endodontic treatment, with the exception of group C–, direct bases were placed using composite resin (CR, Z350, shade A2, 3M ESPE) or GIC (Vidrion F, SS White, Rio de Janeiro, Brazil). For the composite resin, the teeth were etched with 37% phosphoric acid (Condac 37, FGM, Joinville, Brazil) for 15 seconds, followed by the application of the adhesive Single Bond (3M ESPE), and photoactivated for 20 seconds (Poly Wireless, 1100 mW/cm^2, KAVO, Ind. Com Ltda, Joinville, Brazil). The light curing unit irradiance was verified using a radiometer (Kondortech, São Carlos, Brazil). The composite was placed in 2-mm-thick increments, each photoactivated for 40 seconds. For the GIC, mixing occurred according to the manufacturer's recommendations, and the cement was injected into the cavity with a syringe in an attempt to minimize the number of gaps and voids. To avoid dehydration, a surface layer of Single Bond adhesive was placed and light cured for 20 seconds. The specimens were stored in distilled water at 37°C for 24 hours. Then the specimens were again brought to the adapted optical microscope for MOD cavity preparation.

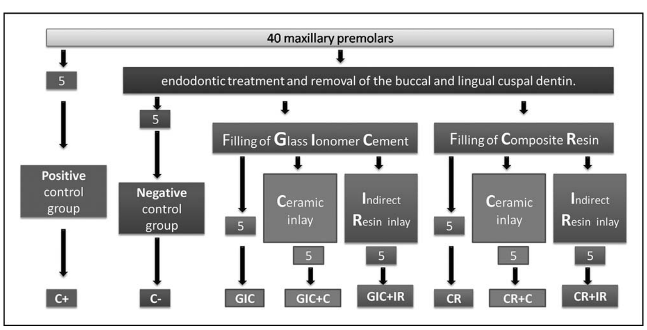


Figure 1. *Scheme of methodology.*

The incline of the pulpal and axial walls of the cavities was 6 degrees, and the inner corners were rounded, as characteristic of diamond bur #3131. Each diamond bur was used for five preparations under refrigeration. The occlusal and proximal boxes of groups were standardized to a width of 3 mm and a depth of 2 mm using a diamond bur (2 mm), as illustrated in Figure 2.

All teeth were impressed with addition silicone (Express, 3M ESPE) and sent to a laboratory to manufacture indirect restorations from two types of material: composite resin (Signum Ceramis, Heraeus, Frankfurt, Germany) and lithium disilicate

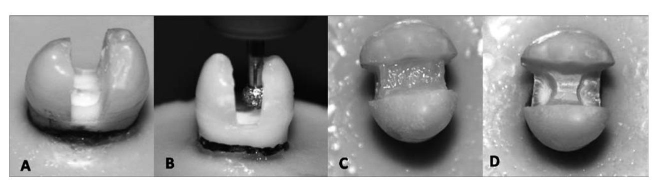


Figure 2. *Sequence of preparation. (A): Mesio-occluso-distal (MOD) preparation and root canal access. (B): Weakened cusps. (C): Fill. (D): Preparation finalized.*

Table 2: *Mechanical Properties of Materials Used in Finite Element Analysis*

Material	Longitudinal Elastic Modulus (MPa)	Poisson's Ratio	Reference
Stainless steel	200,000	0.30	Ansys Library 13.0
Dentin	17,600	0.31	Reinhardt and others[27]
Enamel	48,000	0.30	Holmes and others[28]
Axson F16 Polyurethane	3,600	0.30	Owner characterization
Ligament	68.9	0.45	Holmes and others[28]
IPS e.max Press	91,000	0.24	Albakry and others[29]
Z350Resin	10,000	0.24	Manufacturer data
Glass ionomer cement	7,300	0.30	Agnihotri and others[30]
Signum Ceramis	4,854	0.30	Manufacturer data

ceramic (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein).

All teeth were etched with 37% phosphoric acid for 15 seconds and washed with a water jet for 15 seconds, and the excess water was removed with absorbent paper. Then two layers of Single Bond adhesive were applied and cured following the manufacturer's instructions.

The inlays were ultrasonically cleaned (Ultrasound E15H, Elma, South Orange, NJ, USA) with distilled water for 15 seconds and air-dried for 30 seconds. The ceramic surface was etched with 10% hydrofluoric acid gel for 20 seconds, rinsed thoroughly, and dried with paper towels. A silane-bonding agent (Monobond Plus, Ivoclar Vivadent) was applied for 60 seconds.

The inlays were coated with resin cement (Variolink II, Ivoclar Vivadent) and seated in the preparation under 750 g of pressure, and the excess cement was removed. The inlays were cured, allowed to set for 10 minutes, and then stored in distilled water at 37°C for 24 hours.

The specimens were loaded on the enamel surface until fracture using a 10-mm-diameter sphere in a universal testing machine (EMIC, DL200MF, Test Equipment and Systems Ltd, Pinhais, Brazil) at a crosshead speed of 1 mm/min. The data were analyzed by Levene's test, one-way analysis of variance, and Tukey's test with a significance level of 5% and also by checking the power of the test. The fragments were analyzed under a stereomicroscope at a magnification of 20× to examine the types of fracture.

FEA

The complete tooth structure and polyurethane resin were modeled with Rhinoceros 4.0 software (McNeel North America, Seattle, WA, USA) within the BioCad (CTI Campinas, Brazil) protocol, and the STP file was imported into Ansys 13.0 (ANSYS Inc, Houston, TX, USA) for the FEA. All materials were considered isotropic, homogeneous, and linear and were represented by the elastic modulus and Poisson's ratio (Table 2). The contact regions between the structures were considered perfectly bonded, and the mesh was built with about 260,000 nodes and 160,000 elements for all models. The polyurethane base was considered fixed in the three axes, and the sphere was displaced by 0.02 mm parallel to the tooth principal axis.

RESULTS

Five samples were enough to find a maximum difference in the mean of 25 N among the groups with an 80% power of the test using Minitab (version 16) software. The means and standard deviations (in kgf) of the fracture resistance for each group are presented in Table 3. The lowest values were presented by groups C– (347 N), GIC (292 N), and CR (390 N), followed by the inlay groups (GIC+C, GIC+IR, CR+C, and CR+IR), which showed no statistical difference between them. All groups showed lower values than the positive control group C+ (1932 N).

The types of failure are given in percentages and are presented in Figure 3. All groups had a higher prevalence of type V fracture in the lingual cusp, except for the C+ group, which showed a higher percentage of type II fracture.

In the FEA, group C+ had a greater concentration of tensile stress in the central sulcus and also a larger gradient difference in the lingual cusp, especially in the middle and occlusal third (Figure 4). In group C, a tensile stress developed in the cervical region. In the buccal wall, the gradient increased significantly compared with group C+, indicating the increase of tensile stress in this

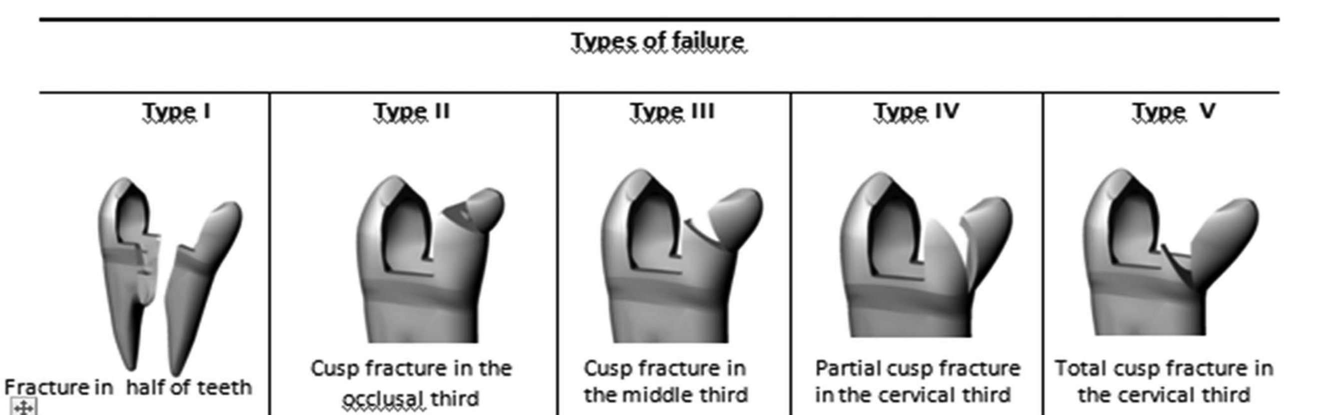
Table 3: *Means and Standard Deviations of Fracture Resistance (N).*

Experimental Groups	Mean	Standard Deviation	Homogeneous Groups				% Reduction of Fracture Resistance Compared to Healthy Group (C+)
C+	1,932	±95.6	A				0
GIC+C	618	±78.7		B			68.02
CR+C	582	±40.0		B			69.87
CR+IR	544	±119.4		B	C		71.82
GIC+IR	544	±83.6		B	C		71.85
CR	390	±85.8			C	D	79.81
C−	347	±75.8				D	82.02
GIC	292	±106.8				D	84.91

[a] *Different letters indicate statistically different values.*

region. The presence of direct base (GIC and CR) considerably reduced the stress concentration in relation to group C– (Figure 4), and these stresses were higher in the group based with glass ionomer.

The inlay groups showed a strengthening of tooth structure, where the values of tensile stress were smaller than in group C–. In the gingival wall, it is possible to see a concentration of compressive stress due to the stability provided by the restoration. It may be noted that with the resin inlay, there was a slight decrease in tension in all tooth structure when compared to ceramic inlay, and groups based with resin had lower tensile values compared to groups



	Type I	Type II B	Type II L	Type II B e L	Type III B	Type III L	Type IV B	Type IV L	Type V B	Type V L	Type V B e L
C+	-	-	60%	20%	-	20%	-	-	-		-
C-	-	-	-	-	-	-	-	-	-	60%	40%
RC	40%	-	-	-	-	-	-	-	-	60%	-
GIC	-	-	-	-	-	-	-	-	20%	80%	-
RC+IR	-	-	-	-	-	-	-	40%	-	60%	-
RC+C	-	-	-	-	-	-	-	20%	-	80%	-
GIC+IR	-	-	-	-	-	20%	-	-	-	80%	-
GIC+C	-	-	40%	-	-	-	-	-	40%	20%	-

Figure 3. *Mapping of fractures and values of total percentage of fracture in each group.*

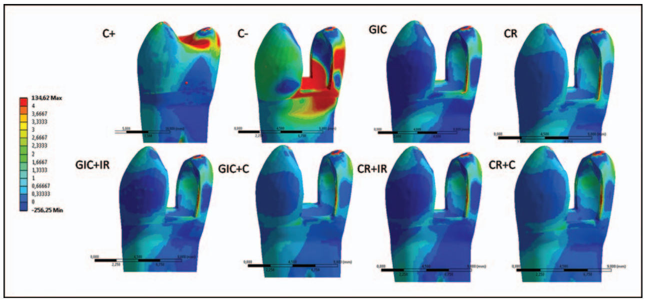


Figure 4. *Maximum principal stress distribution in experimental groups.*

based with glass ionomer, especially at the gingival wall.

The displacement fields can be seen in Figure 5, which shows that group C+ (9.1 μm) was more rigid than group C– (18.9 μm). For groups without inlays (GIC and CR), a smaller displacement was seen with resin basing (9.24 μm) than with glass ionomer basing (9.62 μm), but both types of materials presented values of maximum displacement near the cavity limits that were much smaller than those presented by group C–.

When glass ionomer basing was simulated, the displacement of the cusps was greater with indirect resin (GIC+IR; 9 μm) compared with the ceramic (GIC+C; 8.3 μm). The basing with resin led to slightly lower values of displacement for both inlays, and for CR+C, the values remained lower (8.1 μm) in relation to indirect resin inlays (CR+IR; 8.7 μm).

DISCUSSION

Premolar teeth were chosen for this study because of their greater tendency for cusp deflection when subjected to occlusal stress. In clinical investigations, the upper premolars have shown a higher fracture tendency than lower premolars[18] and are the posterior teeth with the highest incidence of fracture.[19,20] The reasons for such findings are probably their location in areas of intense chewing load in combination with lower amounts of structure when compared to molars. Thus, there is a greater disproportion between crown/root structure and its cervical constriction.

The load application can be at three different points: on the restorative material, the interface, or the enamel. The results depend on this point of load application.[21] In the present study, application on the tooth was made to investigate the worst flexural condition for the remaining cusps, subjecting the axial adhesive interface to the highest intensity of stress. In such conditions, the sphere-tooth contact worked as a wedge between the buccal and lingual cusps in the nonrestored teeth, reducing the mean values of load at fracture and promoting more catastrophic fracture types.

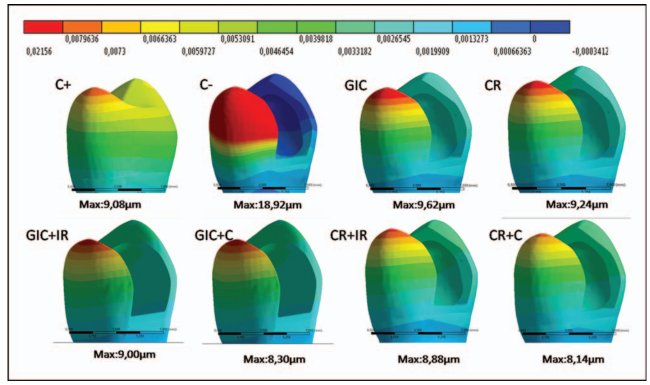


Figure 5. *Total displacement in all groups.*

A previous study[6] found that performing an extensive inlay preparation did not cause a statistically significant decrease in fracture load when compared to conservative preparations. The restorative material had an influence in the extensive inlays, where the higher elastic modulus ceramic material (103.55±15.84 kgf) resulted in a fracture load greater than inlays made of resin (65.42±10.15 kgf). Therefore, it was decided to test whether these materials would have an effect in the situation of greater tooth fragility, in which the extensive MOD preparation was also associated with weakened cusps and endodontic treatment.

The propagation of the fracture within dentin is dependent on the shape, composition, and properties of the restorative material adjacent to the fracture.[3] The higher the elastic modulus of the restorative material, the less the dental structures deform under the same stress.[21]

For direct bases, GIC and composite resin were selected. According to Yap and others,[22] the GIC has properties that make it very useful as a base material. Some of these features include the coefficient of linear thermal expansion being near to that of tooth structure, the promotion of chemical coupling to enamel and dentin, and the release of fluoride ions. However, the present study found that all the specimens filled with GIC showed fractures with larger tooth portions (type V fractures). A lower elastic modulus (7300 MPa) and lower bond strength to dentin and resin cement compared with composite resin may be factors that explain how this material resulted in fractures with poorer clinical prognosis.

Both types of direct base, in spite of not significantly changing the resistance values when compared with teeth without base or inlay (C–), could impact the crack that propagated, resulting in the more favorable type of fracture for these groups.

The FEA indicated a much greater concentration of stresses on the lingual cusp in both unprepared and prepared teeth. These results are in agreement with our experimental test, which found a higher frequency of fracture in the lingual cusps, probably due to their anatomy.

The presence of extensive MOD preparation, weakened cusps, and endodontic treatment (group C–) increased the stress concentration within the tooth structure (Figure 4). This stress developed markedly in the cervical region, near the gingival wall of the preparation, which explains the pattern of fracture that produced the largest loss of tooth (100% of the fractures were type V, involving cusps from the gingival wall to the cemento-enamel junction; Figure 3). But when direct bases and adhesive inlays were performed, there was strengthening of dental structures. Ceramic inlays with a direct resin base showed better stress distribution (Figure 4), which can also be related to the smallest displacement of this group (8.1 μm; Figure 5). As the adhesive interfaces were simulated with a perfect bonded contact, the material with higher stiffness resulted in a smaller displacement of the cusps, generating lower stress concentration, consistent with the increased fracture load seen in the laboratory tests.

The combination of experimental test and FEA supported that the approximations made in the modeling of the structures were effective for analyzing complex structures, such as the case of treated endodontic teeth. However, in spite of all the advantages of this method, it should be kept in mind that the accuracy of the results, among other factors, depends on the degree of simplification of the geometries involved, the quality of multibody interaction, and the accumulation of mathematical approaches. It is possible that the FEA has overestimated the difference between group C– and the other groups because in the experimental test there were nonlinear phenomena, such as crack propagation, failure in the interface, the presence of preexisting cracks, accommodation of a spherical tip within the teeth, and other behaviors of the structures that were not simulated in the analysis.

The defects created in the weakened cusps and endodontic treatment led to a decrease of 82.02% in the fracture load compared to the group of healthy teeth (Figure 3) and 38.8% when compared to the MOD without weakened cusps or endodontic treatment (569.18 N) obtained by Costa and others.[6] This research did not test covered cusp groups because the aim was to preserve as much tooth structure as possible applying adhesive material techniques. However, this extreme condition did not result in the reinforcement ability of ceramic restorations. It is likely that in smaller defects, the method for assessing the resistance would have greater sensitivity to detect significant differences between the performances of the materials.

Scotti and others[23] showed that cuspal coverage should provide improved fracture resistance in maxillary premolars, especially when the residual wall thickness is less than 2 mm. In our study, the remaining wall thickness was 2 mm, so the effect of weakening was highlighted. The restorations without cuspal coverage, when subjected to axial loads produced by dental contact, induce a wedge effect, leading to a deflection of the cusps. This becomes more critical in a posterior tooth where there is the loss of major dental structures, especially the marginal ridges, enamel ridges, and the roof of the pulp chamber.[24]

Nevertheless, we must emphasize that the applied loads used in this study were of a static nature in contrast to the repeated dynamic loads teeth are exposed to in the oral cavity. Typically, the dynamic simulation is used when one wants to analyze fatigue or crack propagation. In our study, we tried to relate the FEA with the experimental test, in which a static load was applied. In the case of static loading, we can verify stress concentrations and correlate them to the fracture pattern. Also, with the stress concentration in the static analysis performed by FEA, it is possible to correlate it with the maximum fracture load obtained in the experimental test: the group with the highest stress concentration in FEA should fail under lower forces in the *in vitro* test. In this study, thermocycling was not carried out before the failure tests because we tried to isolate the effect of mechanical properties of the materials on the resistance of the tooth/restoration complex, creating the fewest possible number of defects in the adhesive interface, which could interfere in the experimental results. With thermocycling, the materials are expected to present different coefficients of linear thermal expansion, producing defects at the interface. Also, the results obtained by the experimental tests could be better correlated with the FEA findings, in which a perfect bonded adhesive interface was simulated. In future work, we suggest performing thermocycling, more closely simulating the oral environment, to clarify the influence of temperature changes on the fracture load of these materials.

A critical factor in evaluating the results of tests with extracted teeth is to know how they may have been impacted by extraction.[25] This fact, together with the variability of dental anatomy itself, makes it difficult to standardize the study and may explain the high values of standard deviation. Studies should be conducted to improve understanding of the multiple variables existing when using natural objects with the aim of decreasing the variability of results and promoting an increase in the power of statistical tests to detect significant differences.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

- Sound teeth showed higher fracture load than groups having endodontic treatment and weakened cusps.
- Direct bases without inlays were not able to increase the values of fracture, independent of the type of material.
- Using direct bases and inlays increased the values of fracture load but resulted in lower values compared to healthy teeth, independent of the combination of materials.
- No difference was found in fracture load of teeth according to the types of direct base material (GIC or composite resin) or inlay (ceramic or indirect resin).

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Human Subjects Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies. The approval code for this study is 046/2011-PH/CEP.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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