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The Influence of Elastic Modulus of Inlay Materials on Stress Distribution and Fracture of Premolars

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Clinical Relevance

To produce inlays, it is important to know the type and behavior of material used because the elastic modulus and rigidity of the adhesive restorative material can promote different stress distributions and cusp deflection.

SUMMARY

The purpose of this study was to evaluate the influence the width of the occlusal isthmus and inlay material had on the stress distribution, displacement, and fracture resistance of upper human premolars. For this *in vitro* test, 35 intact upper premolars (UPM) were selected and five were kept intact for the control group (group I). The remaining 30 were divided into two experimental groups (n=15) according to the width of isthmus: conservative (CP) and extensive preparation (EP), one third and more than two thirds of cuspal distance, respectively. Five teeth from each experimental group were left without restoration for negative controls (CPnc and EPnc), and the remaining 10 in each group were subdivided according to the inlay material (resin or ceramic): group CPr, CP + indirect resin; group CPc, CP + ceramic; group EPr, EP + indirect resin; and group EPc, EP + ceramic. The cemented inlays were loaded in a universal testing machine at a crosshead speed of 0.5 mm/min until fracture. The fractured specimens were analyzed with stereomicroscopy, and the values of the fracture resistance evaluated by analysis of variance and Tukey test. For the finite element analyses, an average

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UPM for each group was modeled in Rhinoceros CAD software and imported to Ansys 13.0. An average of 320,000 tetrahedral elements and 540,000 nodes for the seven models were performed using the same experimental simulation setup for each. The models were constrained on the base, and a displacement of 0.02 mm was applied to keep a linear behavior for the analysis. A von Mises stress and total displacement fields were used for the coherence test and the maximum principal stress fields were used for mechanical behavior comparisons. Group I (161.73 ± 22.94) showed a significantly higher mean value than the other experimental groups (EPc: 103.55 ± 15.84; CPc: 94.38 ± 12.35; CPr: 90.31 ± 6.10; EPr: 65.42 ± 10.15; CPnc: 65.46 ± 5.37; EPnc: 58.08 ± 9.62). The stress distribution was different in all of the groups. EPnc showed a higher concentration of tensile stress on the cervical region of the proximal box. CPc and EPc provided a lower tensile stress and a smaller cuspal displacement. Within the limits of this study, the configuration of the inlay preparation is a significant factor in the fracture resistance of premolars: the smaller the amount of remaining tooth, the lower the fracture resistance. In addition, the teeth restored with ceramic materials showed a higher fracture resistance than those restored with composite resin.

INTRODUCTION

With the advent of adhesive dentistry and new and better materials, it is important that professionals be made fully aware of the importance of preserving the natural structures such as enamel, dentin, and pulp vitality. But, it is also important that the preparation be adequate to fulfill the esthetic and functional requirements of the restoration.

The preparation design for an indirect restoration must strike a balance between preserving the tooth structure and obtaining sufficient retention and resistance. Thus, some fundamental aspects are needed to determine the design of a preparation, such as the tooth's structural condition, its functional aspect, esthetic aspect, tooth inclination, retention, occlusion, reconstruction, and the patient's satisfaction.

The resistance to fracture is directly related to the amount of remaining tooth structure. The removal of marginal ridges, the increase in the width of the isthmus, and the increase in the depth gingival of the preparation are the main reasons for the decrease in resistance.[1]

The masticatory loads in the posterior region are much higher than in the anterior region. Among the posterior teeth, the maxillary premolars suffer the most from vertical fractures, leading to the loss of the dental element.[2] This is due to its complex anatomy, location in an area of high masticatory load, and the presence of a very pronounced groove in the buccal root of the first bifurcated premolars that lead to stress concentration, all three of which may cause vertical fractures.

In addition to concerns with maintaining vitality, esthetics is a very important element in meeting the patient's expectations. Indirect restorations have been made in both composite resins and ceramics and show different optical and mechanical properties.

The analysis of the compatibility between the mechanical properties of restorative materials and the tooth structure may assist in the selection of the material that is best for a specific clinical situation. It also has the preparation characteristics that pose the lowest risk of fractures of the restorations.

The restorative material is considered to be a factor that affects the biomechanics (the stress distribution and deflection of the cusp) during occlusal loading. Ceramic materials are fragile and stiff and tend to increase the rigidity of the tooth's structure, thus decreasing the cusp deflection, as was said previously. On the other hand, composite resins show mechanical properties nearer to those of enamel and dentin, but tend to distribute stresses by deformation.[3]

The aim of the current study was to evaluate how the size of the occlusal isthmus and the restorative material can influence stress and displacement distribution and their impact on the fracture resistance of human maxillary premolars. This was done through laboratory testing of fracture resistance and by analyzing the stress distribution and cusp deflection by a method of mathematical three-dimensional finite element analysis.

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.

In accordance with approval from the research protocol by the local ethics committee (052/2010-PH/CEP), 35 fresh and caries-free maxillary premolars

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Table 1: *Brand Name, Manufacturer, and Basic Description of the Materials Used*

Material	Manufacturer	Characteristic	Lot
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
Signum Ceramis	Heraeus	Composite resin indirect	010131
Adper Single Bond 2	3M ESPE	Adhesive system	N190472ER
Impregum-F	3M ESPE	Impression material polyether-based	421709
			4205\40

were selected, having been extracted for orthodontic treatment. The dimensions were checked by a digital x-ray image by the software Image Tool (UTHSCSA for Windows version 3.0, San Antonio, TX, USA). The exclusion criterion was the crown's occlusal surface area and the angle formed by the two cusps having a value above or below 10% of the average.

Each root was immersed in melted wax up to the 2-mm demarcation line apical to the cementoenamel junction, analyzed by a caliper accurate for simulation of 0.3 mm of periodontal ligament, and then placed in a self-cured polyurethane resin up to the demarcation line in a polyvinyl chloride cylinder 20 mm in height and 18 mm in diameter. After curing, the wax was carefully removed from the root using hot water so that the wax could be replaced with polyether (Impregum F, 3M ESPE, St Paul, MN, USA) to simulate the elastic modulus of the periodontal ligament. The root was then stored in distilled water in a refrigerator at 5°C.

The teeth were then randomly separated into three groups: group I, intact teeth (n=5); group CP, conservative preparation (n=15); and Group EP, extensive preparation (n=15). Groups CP and EP were subdivided into three subgroups; group CPnc – conservative preparation without restoration (negative control); group CPr, conservative inlay + indirect **r**esin; group CPc, conservative preparation + **c**eramic; group EPnc, extensive preparation without restoration (negative control); group EPr, extensive preparation + indirect **r**esin; and group EPc, extensive preparation + **c**eramic.

All preparations were made with a diamond bur No. 3131 (KG Sorensen, Cotia, SP, Brazil) and placed perpendicularly to the long axis of the tooth, with a taper of 6° in the surrounding walls of the cavities. The internal angles were rounded, as is characteristic of the tips used.

The occlusal and proximal boxes of groups CPnc, CPr, and CPc were standardized to a width of 2 mm and a depth of 2 mm using a diamond bur (2 mm) as illustrated in Figure 1.

For the extensive preparations (groups EPnc, EPr, and EPc), two lines mesiodistally generated the occlusal contact point between a steel ball 10 mm in diameter. The intact premolar was first marked at 0.5 mm, the distance considered to be the limit of the width of the isthmus. The occlusal and proximal depths were made the same way as the CP groups (Figure 1).

All teeth were impressed with silicone (Express, 3M ESPE) and sent to the laboratory to manufacture two types of indirect restorations: composite resin (Signum Ceramis, Heraeus, Frankfurt, Germany) and lithium disilicate ceramic (IPS e.max press, Ivoclar Vivadent, Schaan, Liechtenstein). All teeth were etched with 37% phosphoric acid for 15 seconds, washed with a water jet for 15 seconds, and the excess water was removed with absorbent paper. Then, the two layers of adhesive (Single Bond 2, 3M ESPE) were applied and cured following the manufacturer's instructions (Figure 2).

The inlays were ultrasonically cleaned (Ultrasound E15H Elma, South Orange, NJ, USA) with distilled water for 15 seconds then air-dried for 30

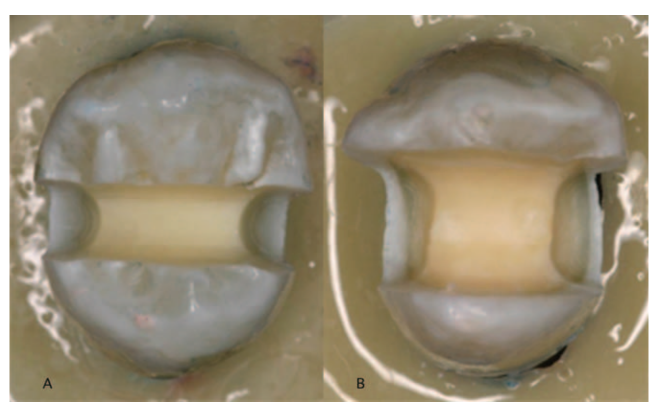

Figure 1. *(A): Conservative Preparation. (B): Extensive preparation.*

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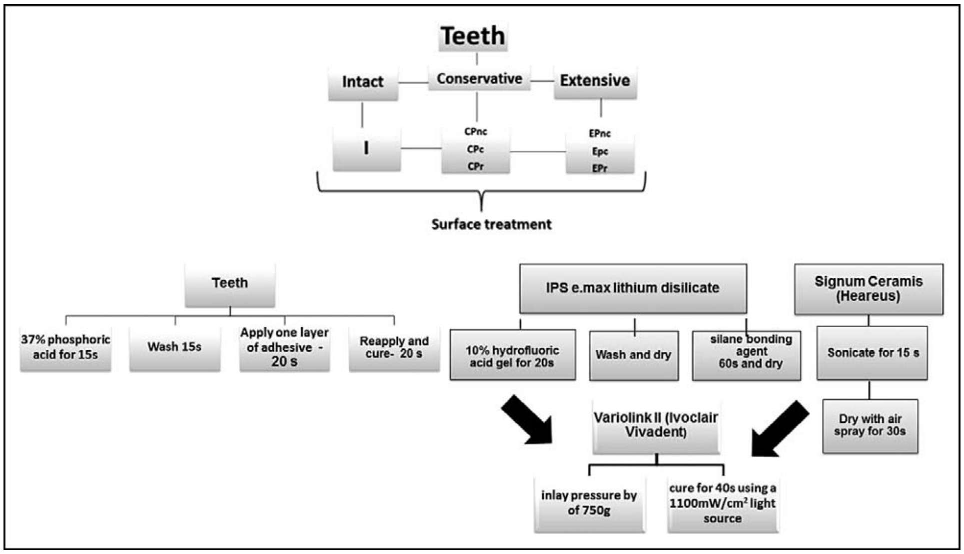

Figure 2. *Scheme of methodology.*

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 (Figure 2).

The inlays were coated with resin cement (Variolink II, Ivoclar Vivadent), settled in the cavity under 750 g pressure, and the excess removed. The inlays were cured for 40 seconds using a 1100 mW/cm^2 light source (Poly Wireless KAVO, Brazil Ind Com Ltda, Joinville, SC, Brazil), allowed to set for 10 minutes, and then stored in distilled water at 37°C for 24 hours (Figure 2).

The specimens were loaded on the enamel surface until fracture using a sphere 10 mm in diameter in a universal testing machine (EMIC, DL200MF-EMIC Test Equipment and Systems Ltd, Pinhais, PR, Brazil) at a crosshead speed of 0.5 mm/min. The data were analyzed by Levene, two-way analysis of variance (ANOVA), and Tukey test with a significance level of 5%. The fragments were analyzed under a stereomicroscope at 20× magnification. The types of fractures are listed in Figure 3.

Finite Element Analysis

The complete tooth structure and polyurethane resin were modeled in the Rhinoceros 4.0 (McNeel North America, Seattle, WA, USA) software, within the BioCad (CTI Campinas, SP, Brazil) protocol,[4] and the *.stp* file was imported into Ansys 13.0 (ANSYS Inc, Houston, TX, USA) for the finite element analysis (FEA). All materials were considered isotropic, linear, homogeneous and their moduli included in Table 2. The contact regions between the structures were considered perfectly bonded, and the mesh, with a quadratic tetrahedral element, was controlled by a sizing method with 0.4 mm resulting in a total of 348,296 nodes and 231,444 elements. The base of the polyurethane was considered fixed in the three axes, and the sphere was displaced by 0.02 mm parallel to the principal axis to keep the analysis in the elastic field.

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

Material	Longitudinal Elastic Modulus, MPa	Poisson's ratio	Reference
Stainless steel	200,000	0.3	Ansys Library 13.0
Dentin	17,600	0.31	Reinhardt and others[27]
Enamel	48,000	0.3	Holmes and others[28]
Polyurethane Axson F16	3,600	0.3	Owner characterization
Ligament	68.9	0.45	Holmes and others[28]
IPS E.max Press	91,000	0.24	Albakry and others[29]
Signum Ceramis	4,854	0.3	Manufacturer data

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		Type of failure					
		I	II	III	IV	V	VI
Caracteristics Buccal or lingual		enamel	enamel+dentin at middle third	enamel+dentin at cervical line	Restoration+tooth at occlusal third	Restoration+tooth up to cervical line	At adhesive interface
Percentage of total fracture [%]		5.12	35.89	28.20	7.79	15.38	7.69
Experimental groups	**I**	2857	42.85	28.57	0	0	0
	CPnc	0	33.30	66.60	0	0	0
	EPnc	0	42.86	57.1	0	0	0
	CPr	0	80.00	0	20.00	0	0
	CPc	0	25.00	25.00	0	50.00	0
	EPr	0	0	0	60.00	20.00	20.00
	EPc	0	20.00	0	0	40.00	40.00

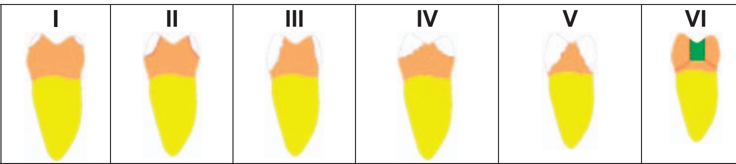

Figure 3. *Mapping of Fractures and Values of Total Percentage of Fracture in Each Group*

RESULTS

The descriptive statistics (mean, in kgf and standard deviation) for each of the seven groups, the statistical analysis that evaluated the effects of the variables studied on the fracture resistance, and the results are presented in Tables 3, 4, and 5, respectively. Group I (161.73 ± 22.94) had the highest average, followed by groups EPc (103.55 ± 15.84), CPc (94.38 ± 12:35), CPr (90.31 ± 6.10), EPr (65.42 ± 10.15), CPnc (65.46 ± 5.37), and EPnc (58.08 ± 9.62). Groups CPr and CPc and CPnc and EPnc showed no statistical difference between them.

The types of failure are given in percentages and are presented in Figure 3. In groups I and CPr, the most prevalent type of fracture was type II. For Groups CP and EP, the most prevalent type of fracture was type III. The fracture types IV, V, and VI were present in groups EPr, CPc, and EPc, respectively.

Under analysis by FEA, group I had a greater concentration of tensile stress in the central sulcus and also a larger difference in the concentration gradients in the lingual cusp, especially in the middle and occlusal third.

Groups CPnc and EPnc show that as the remaining tooth structure decreases, there is a greater concentration of tensile stress in the wall of the pulp preparation and a greater difference of the concentration gradient as compared with the intact tooth, especially in the lingual cusp (Figure 4).

The distribution of stress showed that the conservative teeth that were restored with ceramics (CPc) had a higher concentration of tensile stress in the sulcus occlusal of the restoration and a higher concentration of compressive stress on the walls of the gingival preparation (Figure 5). For the teeth with conservative preparation and restored with composite resin (CPr), there was a higher distribution of tensile stress in the cusps and a reduced difference in the concentration gradient (Figure 6).

Table 3: *Means and standard deviations of fracture resistance for groups without restoration*[a]

Group	Mean ± SD, kgf	Homogeneous Groups	ANOVA
I	161.73±22.94	A	SS: 46091.7
CPnc	65.46±5.37	B	MS: 23045.9
EPnc	58.08±9.62	B	$p<0.0000$

[a] *Different letters indicate statistically different values (ANOVA/Tukey tests). Abbreviations: SS, Sum of squares; MS, Mean square.*

Table 4: *Means and standard deviations of fracture resistance for groups with conservative preparation*[a]

Group	Mean ± SD, kgf	Homogeneous Groups	ANOVA
I	161.73±22.94	A	SS: 34591.2
CPnc	65.46±5.37	C	MS: 11530.4
CPr	90.31±6.10	B	$p<0.0000$
CPc	94.38±12.35	B	

[a] *Different letters indicate statistically different values (ANOVA/Tukey tests). Abbreviations: SS, Sum of squares; MS, Mean square.*

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Table 5: *Means and standard deviations of fracture resistance for groups with extensive preparation*[a]

Group	Mean ± SD, kgf	Homogeneous Groups	ANOVA
I	161.73±22.94	A	SS: 44998.4
EPnc	58.08±9.62	C	MS: 14999.5
EPc	103.55±15.84	B	$p<0.0000$
EPr	65.42±10.15	C	

[a] *Different letters indicate statistically different values (ANOVA/Tukey tests). Abbreviations: SS, Sum of squares; MS, Mean square.*

By restoring the contour of the marginal ridges with restorations, a reduction of the stress concentration can be observed on their dental structures when compared with the prepared teeth without the restoration. The teeth that were restored with ceramics showed a higher concentration of tensile stress in the restoration, unlike what happens with the teeth restored with resin, where stress restoration was transmitted to the dental structure (Figures 5 and 6).

Upon restoring the tooth, there was a decrease in the deflection of the cusps. The groups restored with indirect composite resin (groups CPr and EPr) showed a greater deflection than those restored with ceramics (groups CPc and EPc).

DISCUSSION

The purpose of this study was to investigate the possibility of performing an inlay at the maximum width allowed of the occlusal isthmus, before changing the preparation to an onlay due to the need to protect the cusp. The average occlusal force in the literature is 21.7 kgf (about 212 N).[5] In the region comprising the premolar and molar occlusal areas, these forces vary between 161 N and 351 N, respectively.

In this study, intact teeth showed a mean fracture resistance of 161.73 kgf (1584 N). This is superior to that found by Takahashi and others[6] in 2001, which was 736 N, but lower than that found by Soares and others[7] in 2006, which was 320.5 kgf (3140 N). In all three of these results, the tooth structure is strong enough to weather natural chewing forces since the results exceed the average forces of occlusion. However, this is not what happens in a real situation.

The cusp deflection is a good parameter for analysis when studying fracture resistance. The type of cement used and its interface quality can impact the values of displacement; the higher the adhesive strength, the lower the cusp deflection. Thus, the restorations cemented with conventional resin cement using the total etching technique have

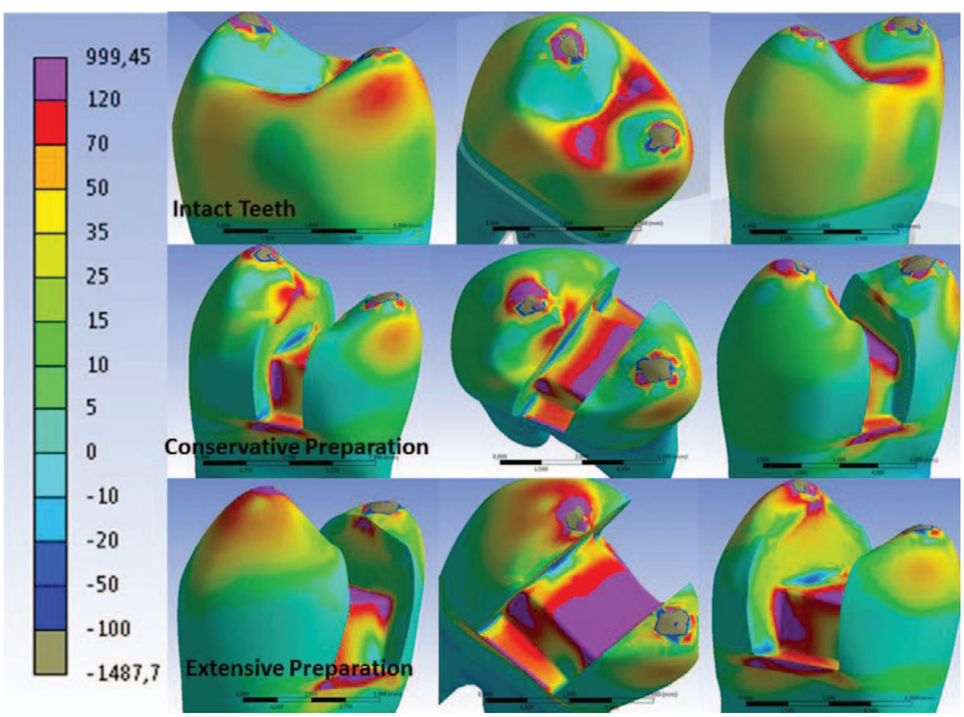

Figure 4. *Maximum principal stress distribution in groups I, CPnc, and EPnc.*

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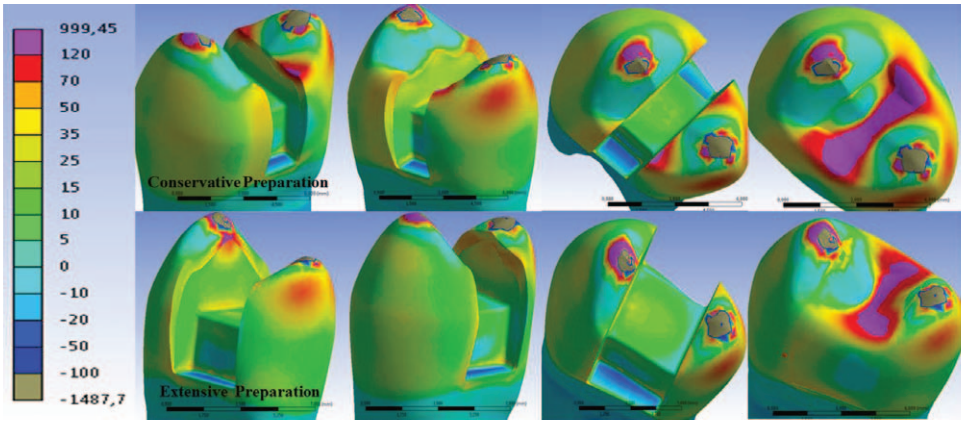

Figure 5. *Maximum principal stress distribution in groups CPc and EPc.*

a better union of the adhesive interface and show a greater resistance to cusp deflection.[8] However, restorations cemented with self-adhesive resin cement have a lower stability with a pronounced cusp deflection and, therefore, are less resistant to fracture.[8]

Analyzing the results, when compared with the intact control (group I), the conservative (CPnc), and extensive (EPnc) preparations showed a 50% reduction of tooth structure and, consequently, a reduction of structural strength and an increase in the risk of fracture.[9]

Though numerically, group CPnc had a greater fracture resistance than group EPnc, there was no statistical difference for a significance level of 5%, and the coefficients of variation were around 18%. We can therefore infer that by removing the marginal ridge, a marked decrease in fracture resistance occurs, regardless of the amount of tissue removed. Soares and others[7] found that inlays with a conservative preparation, even with a higher average of resistance to fracture, also did not differ from inlays with an extensive preparation. This is because the reduction of fracture resistance is due to the removal of marginal ridges rather than the uniting and supporting of the buccal and palatal cusp, as well as to the increase in the isthmus and the depth of preparation in the occlusogingival direction.

The absence of important structures, such as the marginal ridges, exerts an influence on the fracture resistance of teeth. The location of a lost tooth structure is often as relevant as the amount lost, and thus there should be maximum preservation of the prime areas of the teeth, such as the edges and marginal ridges.[10]

The findings that CPnc and EPnc did not show a statistical difference, though they were lower than group I (Table 3), are in agreement with those of Larson and others,[11] who showed that the extent of a cavity that involves the proximal boxes does not cause a significant reduction in the tooth's resistance, since only a small portion of dentin is removed. In the present study, Figure 5 shows that the stress distribution for both cavities studied was

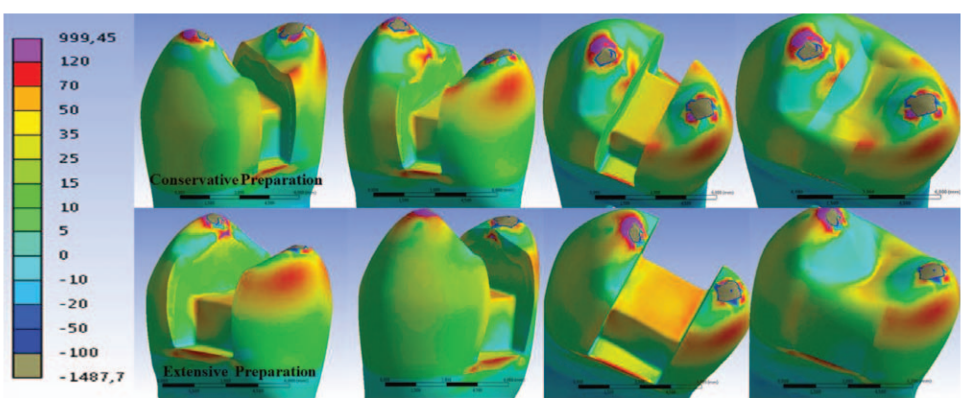

Figure 6. *Maximum principal stress distribution in groups CPr and EPr.*

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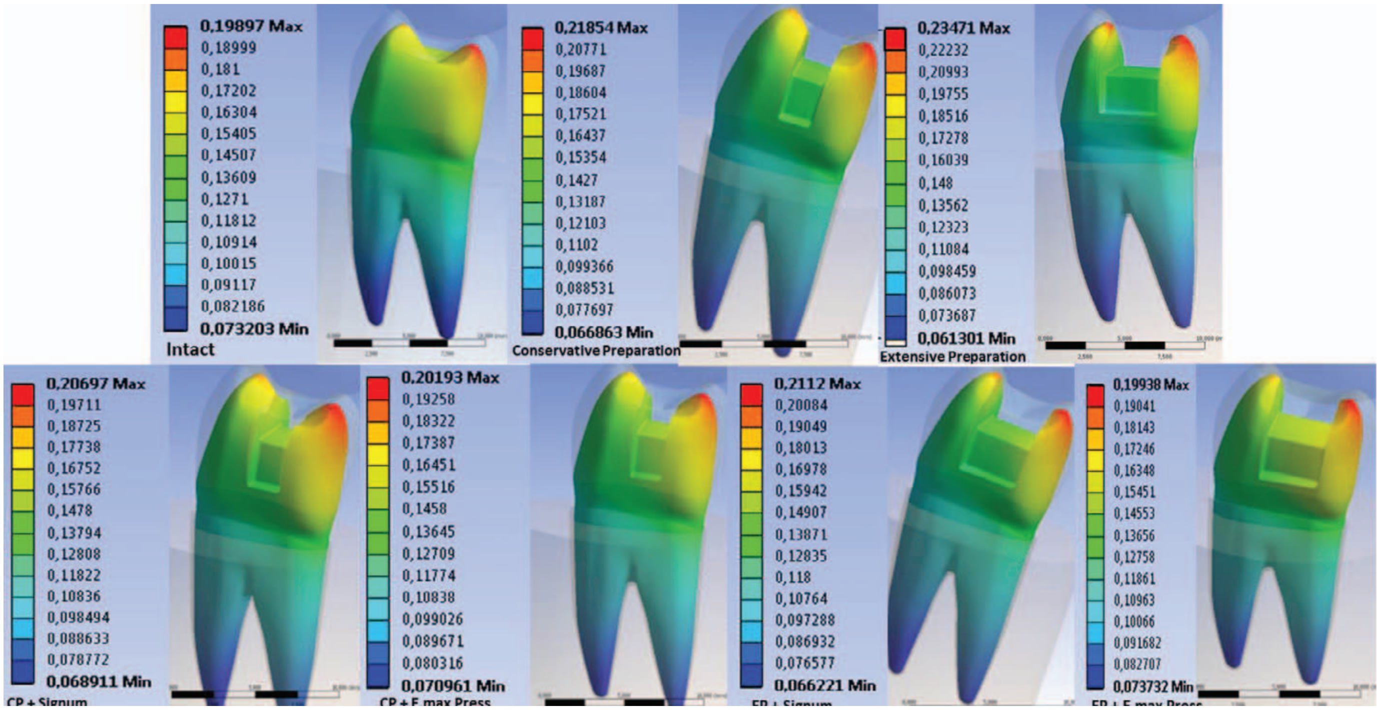

Figure 7. *Total displacement in all groups.*

similar. Figure 4 shows the teeth that are missing a portion of their structures, such as the marginal ridges. There was also a large increase in tensile stress concentration, crossing the occlusal isthmus in the intact portion of the tooth. In groups CP and EP, this stress increases in the region of the pulp wall.

However, the numerical value showed the larger the isthmus the lower the resistance to fracture, despite the nonstatistical difference. The progressive elimination of the dental tissue, such as severe loss of the marginal ridge and dentin remaining above the pulp chamber, is associated with an increased bending of the cusps.[12] According to studies by Mondelli and others,[1] Reeh and others,[13] and Hansen and others,[14] the cusps should be preserved whenever possible to maintain the resistance of the tooth, agreeing with the trend observed in FEA (Figure 7).

Through the analysis of the total displacement, consistency and connectivity of the meshes, von Mises stress fields of the models, and the compared results from the literature, it was shown that it is feasible to use these models in the analysis of stress distribution by means of the FEA. This analysis is a simulation, thus the results are approximate to what occurs *in vitro*. However, the use of FEA is necessary for understanding the failure types and the probable place of the fracture origin.

Group I presented a predominance of fractures in the lingual cusp and occlusal and middle thirds, with cohesive failures in the enamel (types I and II). This probably occurred because the applied load exceeded the proportional limit of the enamel (Figure 3).

As the remaining tooth structure decreases, there is a greater concentration of tensile stress in the pulpal wall of the preparation as compared with the intact tooth, especially in the lingual cusp. This corroborates the findings by Lin and others,[15] who found a higher stress concentration along the lingual-pulpal line angle and, when compared with the intact tooth, found that maximum principal stress was higher as the depth of the pulp wall increased. That is, the greater the depth of preparation, the greater the risk of fracture in restored teeth.

Blaser and others[16] observed that the reduction in tooth resistance is more significant when there is an increase in the depth of preparation, approaching the pulp, compared with the weakening of the occlusal isthmus, when there is an increase in the extent of preparation mesiodistally.

The greater predominance of fractures in groups CPnc and EPnc occurred in the middle third of the occlusal-lingual cusp and in the center of the pulp

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wall . This trend can be explained by the presentation of the stress gradient, as shown in Figures 1 and 2, where the path of the fracture is perpendicular to the contour of maximum principal stress.

The groups that have been restored (CPr, EPr, CPc, and EPc) showed fracture resistance values greater than the groups without restoration. According to St-Georges and others,[9] the restored teeth have a 4%-15% increase in fracture resistance compared to the unrestored teeth.

Intact teeth will rarely fracture under masticatory stresses. However, fractures can occur in teeth that have cavity preparations and restorations, either with composite resin or ceramic, because the cavities will weaken the remaining tooth structure. By restoring the tooth, directly or indirectly, the tooth's fracture resistance can be partially restored.[17-19]

In this study, the increase in fracture resistance in the preparation of conservative management was approximately 38% for both groups CPr and CPc; in the extensive preparation there was an increase of 12% for the EPr and 94% for the EPc compared with CPnc and EPnc, showing the influence of the rigidity of the material in this property. The capacity of the adhesive bond interface influences the displacement of the cusp since the rebuilding of the dental structure, the marginal ridge, and the enamel bridge restores the occlusal anatomy. This reduces the deflection of the remaining cusps, regardless of the material used, which reduces the chance of a fracture.

After restoration, the groups with conservative preparation showed similar fracture resistance values for both materials, but the mechanical behavior, which was analyzed by the finite element method, was different. This is because when the conservative preparations were restored with ceramic, there was a higher concentration of stress compared with those restored with composite resin, showing a dissipation of stress in the tooth's restoration. In the groups with extensive preparation, the values of fracture resistance, such as the mechanical behavior between the groups restored with composite resin (EPr) and ceramics (EPc), were different.

For groups CPc and CPr, the type of restorative material had no influence on the fracture resistance. The data showed no statistically significant difference for the two materials used. The elastic modulus of the restorative material also did not affect the results of the fracture resistance. The effect of the adhesion and the quantity of the material removed from the teeth during the preparation did not change the displacement of the cusp. The higher rigidity of ceramics compared to resin and the pertinent smaller deflection of the cusps, with which an adequate bonding to the interface is associated, causes the whole to become more resistant and reduces the probability of a fracture. This is because the stress values are related to the modulus of elasticity of the restorative material.[20,21] This finding corroborates the study by Scherrer and de Rijk[22] which showed that the higher the elastic modulus of the material, the higher the stiffness and then the greater the value of fracture resistance.

For many authors, while adhesively cemented ceramic inlays that extend 1/3 up to 1/2 of the intercuspal distance have similar resistance as sound tooth, this does not occur when the tooth is restored with composite resin.[19,23-26]

Since the elastic modulus of the composite resin is less than the elastic modulus of teeth (enamel and dentin), it will concentrate and transmit to the tooth a tensile stress. In 2011, Desai and Das[19] also showed that in materials exhibiting low elastic modulus, a higher concentration of stress is transferred to the tooth structure. Because of this, there will be a greater deflection of the cusps and, consequently, a higher probability of fracture in the tooth compared to the ceramic restoration, which explains the predominance of the type II fracture (tooth only). In the group restored with ceramics (CPc), where there was a larger tensile stress in the restoration, the material will probably fracture before the tooth structure, which explains the greater number of type V fractures (tooth-restoration) (Figure 3).

The groups with extensive preparation restored with ceramic (EPc) showed a higher value of fracture resistance than those restored with composite resin (EPr). This probably occurred due to the difference in structural rigidity of the system caused by the different modulus of the two restorative materials. The large quantity of ceramic seems to have replaced much of the dentin. As the ceramics have a higher elastic modulus, the flexibility of the structure decreases, causing the offset tooth to be smaller, and thus more resistant than the teeth with conservative preparation (CPc).

Despite the limitations of the FEA models (related to the cement layer, simplification of experimental setup and assumption of a linear behavior), valid results were achieved that could explain the experimental fracture behaviors.The combination of mechanical testing and fracture resistance analysis by finite element methods has shown promise in

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assessing the influence of the restorative material and the configuration of the preparation in the failure of indirect restorations.

Thus, this experiment raises the awareness for the need of further studies to formalize a method of occlusal loading that can take place in a more real and ideal simulation (contacts A, B, and C), as well as in endodontic treatment. These analyses take into account the thickness and mechanical properties of the cement, as well as the inclination of the walls of the preparation and the rounding of the line angle.

CONCLUSIONS

According to the methodology employed in this study and within its limitations, we concluded the following: 1) the volume of the cavity preparation is a significant factor influencing stress distribution and resistance to fracture, and 2) ceramic restorative material tends to concentrate more stress inside the inlay and results in lower cusp deflection than the resin; resin tends to transfer more stress to the tooth structure and promote lower fracture resistance than the ceramic.

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Conflict of Interest

The authors of this manuscript 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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REFERENCES

1. Mondelli J, Steagall L, Ishikiriama A, Navarro MFL, & Soares FB (1980) Fracture strength of human teeth with cavity preparations *Journal of Prosthetic Dentistry* **43(4)** 419-422.
2. Cohen S BL, Blanco L, Bakland L, & Kim JS (2006) A demographic analysis of vertical root fractures *Journal Endodontics* **32(12)** 1160-1163.
3. Magne P, & Belser UC (2003) Porcelain versus composite inlays/onlays: Effects of mechanical loads on stress distribution, adhesion, and crown flexure *International Journal of Periodontics & Restorative Dentistry* **23(6)** 543-555.
4. Noritomi PY, Xavier TA, & Silva JVL (2012) A comparison between BioCAD and some know methods for finite element model generation In: Silva da Bártolo (ed) *Innovative Developments and Physical Prototyping* Taylor & Francis Group, London 685-690.
5. Burke FJT (1992) Tooth fracture *in vivo* and *in vitro* *Journal of Dentistry* **20** 131-139.
6. Takahashi CU, Cara DE, & Contin AA (2001) Resistance to fracture of direct restorations with cuspal coverage in endodontically treated upper bicuspids [in Portuguese] *Pesquisa Odontológica Brasileira* **15(3)** 247-251.
7. Soares CJ, Martins, LR, Fonseca RB, Correr-Sobrinho L, & Fernandes Neto AJ (2006) Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations *Journal of Prosthetic Dentistry* **95(6)** 421-429.
8. Mak YF, Lai SC, Cheung GS, Chan AW, Tay FR, & Pashley DH (2002) Micro-tensile bond testing of resin cements to dentin and an indirect resin composite *Dental Materials* **18(8)** 609-621.
9. St-Georges AJ, Sturdevant JR, Swift EJ Jr, & Thompson JY (2003) Fracture resistance of prepared teeth restored with bonded inlay restorations *Journal of Prosthetic Dentistry* **89(6)** 551-557.
10. Soares PV, Santos-Filho PC, Queiroz EC, Araujo TC, Campos RE, & Araujo CA (2008) Fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin *Journal of Prosthodontics* **17(2)** 114-119.
11. Larson TD, Douglas WH, & Geistfeld RE (1981) Effect of prepared cavities on the strength of teeth *Operative Dentistry* **6(1)** 2-5.
12. González-López S, De Haro-Gasquet F, Vílchez-Díaz MA, Ceballos L, & Bravo M (2006) Effect of restorative procedures and occlusal loading on cuspal deflection *Operative Dentistry* **31(1)** 33-38.
13. Reeh ES, Messer HH, & Douglas WH (1989) Reduction in tooth stiffness as a result of endodontic and restorative procedures *Journal of Endodontics* **15** 512-516.
14. Hansen EK, Asmussen E, & Chistiansen N (1990) *In vivo* fractures of endodontically treated posterior teeth restored with amalgam *Endodontics & Dental Traumatology* **6** 49-55.
15. Lin CL, Chang CH, & Ko CC (2001) Multifactorial analysis of an MOD restored human premolar using auto-mesh finite element approach *Journal Oral Rehabilitation* **28(6)** 576-585.
16. Blaser PK, Lund MR, Cochran MA, & Potter RH (1983) Effect of designs of Class 2 preparations on resistance of teeth to fracture *Operative Dentistry* **8(1)** 6-10.
17. Cobankara FK, Unlu N, Cetin AR, & Ozkan HB (2008) The effect of different restoration techniques on the fracture resistance of endodontically-treated molars *Operative Dentistry* **33(5)** 526-533.
18. Santos MJ, & Bezerra RB (2005) Fracture resistance of maxillary premolars restored with direct and indirect adhesive techniques *Journal of the Canadian Dental Association* **71(8)** 585.

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19. Desai PD, & Das UK (2011) Comparison of fracture resistance of teeth restored with ceramic inlay and resin composite: An *in vitro* study *Indian Journal of Dental Research* **22(6)** 877.

20. Cadenaro M, Codan B, Navarra CO, Marchesi G, Turco G, Di Lenarda R, & Breschi L (2011) Contraction stress, elastic modulus, and degree of conversion of three flowable composites *European Journal of Oral Sciences* **119(3)** 241-245.

21. Kikuti WY, Chaves FO, Di Hipólito V, Rodrigues FP & D'Alpino PH (2012) Fracture resistance of teeth restored with different resin-based restorative systems *Brazilian Oral Research* **26(3)** 275-281.

22. Scherrer SS, & de Rijk WG (1993) The fracture resistance of all-ceramic crowns on supporting structures with different elastic moduli *International Journal of Prosthodontics* **6(5)** 462-467.

23. Jensen ME, Redford Da, Williams BT, & Gardner F (1987) Posterior etched-porcelain restoration: An *in vitro* study *Compendium* **8(8)** 615-617, 620-622.

24. Ragauska A, Apse P, Kasjanovs V, & Berzina-cimdina L (2008) Influence of ceramic inlays and composite filling on fracture resistance of premolars *in vitro Stomatologija* **10(4)** 121-126.

25. Dalpino PH, Francischone CE, Ishikiriama A, & Franco EB (2002) Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly with ceramic materials *American Journal of Dentistry* **15(6)** 389-394.

26. Soares CJ, Martins LR, Pfeifer JM, & Giannini M (2004) Fracture resistance of teeth restored with indirect composite and ceramic inlay systems *Quintessence International* **35(4)** 281-286.

27. Reinhardt RA, Krejci RF, Pao YC, Stannard JG (1983) Dentin stresses in post-reconstructed teeth with diminishing bone support *Journal Dental Research* **62(9)** 1002-8.

28. Holmes DC, Diaz-Arnold AM, Leary JM (1996) Influence of post dimension on stress distribution in dentin. *Journal Prosthetic Dentistry* **75(1)** 140-147

29. Albakry M, Guazzato M, Swain MV Biaxial flexural strength, elastic moduli, and x-ray diffraction characterization of three pressable all-ceramic materials (2003) *Journal Prosthetic Dentistry* **89(4)** 374-80.

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