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Fracture Resistance of Premolars Restored with Partial Ceramic Restorations and Submitted to Two Different Loading Stresses

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Clinical Relevance

The fracture resistance of ceramic restorations is associated with the quantity of the dental structure removed. In relation to the fracture resistance, preference should be given to inlay restorations rather than to onlays; however, no restorative technique was able to attain the fracture resistance of intact teeth.

SUMMARY

This *in vitro* study evaluated the fracture resistance of teeth restored with different designs of partial ceramic restorations using two diameters of steel ball to apply fracture stresses. One hundred and twenty sound maxillary premolars were randomly divided into three groups of 40 elements; each group was submitted to one of three indirect restoration designs: inlay, onlay with only lingual cuspal coverage and onlay with buccal and palatal cuspal coverage. Another 20 intact teeth were randomly assigned as control groups. The restorations were produced with Super Porcelain EX-3 and Vitadur Alpha ceramics and luted according to manufacturers' instructions. The specimens were subjected to compressive axial loading in a universal testing machine at 0.5 mm/minute using two steel balls (3 and 10 mm in diameter), evaluating a total of 14 groups with 10 specimens each. Peak load to fracture was measured for each specimen. The results were submitted to analysis of variance and Tukey's test. Statistical analysis revealed that the inlays showed a significantly higher fracture resistance than both onlay designs, but with fracture resistance lower than that of intact teeth. Onlay fracture strength was equivalent for both designs. The force required to cause fracture with the 10-mm diameter ball was greater than with the 3-mm diameter ball. There were no differences between the tested ceramics.

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INTRODUCTION

Dental structure removed during cavity preparation has been associated with a progressive decrease in fracture resistance in teeth (Vale, 1959; Mondelli & others, 1980). The removal of marginal ridges, cuspid enlongment and occlusal enamel reduction have been highlighted as the main reasons for this decrease (Mondelli & others, 1980; Larson, Douglas & Geistfeld, 1981; Edelhoff & Sorensen, 2002).

To minimize this shortcoming, indirect metallic restorations or amalgam restorations with occlusal recovering (Vale, 1959; Salis & others, 1987; Mondelli & others, 1998) were first indicated. However, advances in new materials and the increasing demand for esthetic restorations have influenced the search for alternative materials to replace metallic restorations (Ritter & Baratieri, 1999).

Among restorative materials, ceramic restorations exhibit superior esthetic appearance, biocompatibility, wear resistance, stability in the oral cavity, high compression resistance and the coefficient of thermal expansion similar to dental structure (Burke & others, 1991; Anusavice, 1996). Based on these favorable characteristics, and with improved bonding to dental structure obtained with adhesive cements, the application of posterior ceramic restorations has recently experienced a significant increase (Banks, 1990). Nevertheless, studies evaluating the resistance to fracture of teeth with partial ceramic restorations have presented controversial results, sometimes exhibiting resistance values higher than sound teeth (Bremer & Geurtsen, 2001; Dalpino & others, 2002), while in other studies, fracture resistance values were significantly lower (Dietschi & others, 1990; St-Georges & others, 2003).

In a comprehensive study of literature evaluating the long-term clinical longevity of different restorative materials, Hickel and Manhart (2001) found an annual failure rate of 0% to 7.5% for ceramic onlays and inlays. The main reason for the failure of ceramic restorations has been fracture of the restoration (Milleding, Ortengren & Karlsson, 1995; Thordrup, Isidor & Horsted-Bindslev, 2001). A series of different factors could influence fracture strength results, such as composition and mechanical characteristics of the material (Van Dijken, Hoglund-Aberg & Olofsson, 1998; Blatz, 2002) and load application over the restoration (Abu Hassan, Abu Hammad & Harrison, 2000).

The hypothesis investigated in this study was that cavity preparation design, ceramic composition and different load application methods could influence the fracture resistance of human teeth. Therefore, this study investigated the resistance to axial compression of human premolars with different designs of partial ceramic restorations made with two feldspathic ceramics under two load application methods.

METHODS AND MATERIALS

Tooth Selection and Preparation

This research protocol had the approval of the Ethic Committee (Federal University of Pelotas). One hundred and forty sound human premolars were selected and extracted for orthodontic reasons. After soft tissue removal, the teeth were stored in 1% chloramine solution for 72 hours (Haller & others, 1993). To be included in the study, the premolars were required to have the following crown dimensions proposed by Galan (1970): 9.0–9.6 mm bucco-lingual distance; 7.0–7.4 mm mesio-distal distance and 7.7–8.8 mm cervico-occlusal distance. The teeth, which were also free of cracks while viewed under magnification observation (10x) and fiber optic transillumination, were washed in tap water for 24 hours and stored in distilled water at 37°C, which was changed periodically (every five days) throughout the study.

The premolars had their roots embedded in a PVC matrix, using acrylic resin (Artigos Odontológicos Clássico Ltda, São Paulo, Brazil), up to 1 mm below the cementoenamel junction. An impression of each tooth was taken with a polyvinylsiloxane material (Express, 3M ESPE, St Paul, MN, USA) that was used as an anatomic guide during tooth reduction. The teeth were randomly divided into three groups (n=40) in accordance with the different cavity designs: inlay, partial onlay and total onlay. Twenty of the premolars remained without preparation and were randomly assigned as a control group.

Diamond bur #4137 (KG Sorensen, Barueri, Brazil) was used for cavity preparation at high speed under copious air-water cooling. The burs were replaced after every four tooth preparation to ensure high cutting efficiency. To finish the preparations and standardize the convergence angle of the cavity walls, the same bur was used at low speed adapted in a Galloni machine. The dimension of the cavity was measured with the polyvinylsiloxane model and a digital caliper.

The standard sizes for each cavity preparation included:

a) Inlay MOD (Dalpino & others, 2002)

- occlusal box with 1/2 of the buccal-lingual distance and a depth of 2 mm;
- cervical wall located 1 mm above the cementoenamel junction, 1/2 of the buccal-lingual distance and 1.5 mm at the cervical wall in a proximal-proximal direction (Figure 1).

b) Partial Onlay

- occlusal box with 1/2 of the buccal-lingual distance and a depth of 2 mm;
- 2 mm occlusal reduction of the functional cuspid (Ritter & Baratieri, 1999), with the preparation

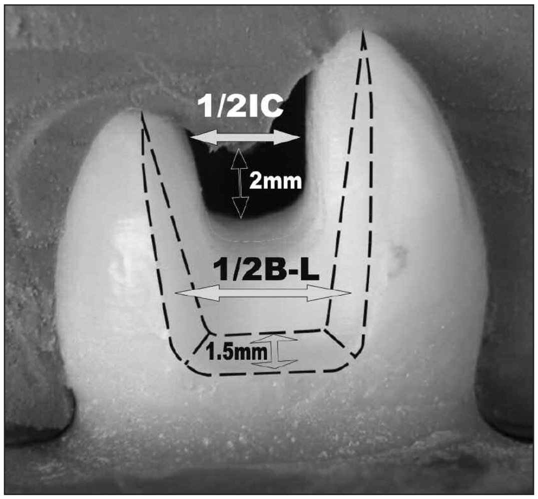

Figure 1. *MOD ceramic inlay preparation sizes. (IC—intercuspid distance; B-L—bucco-lingual distance).*

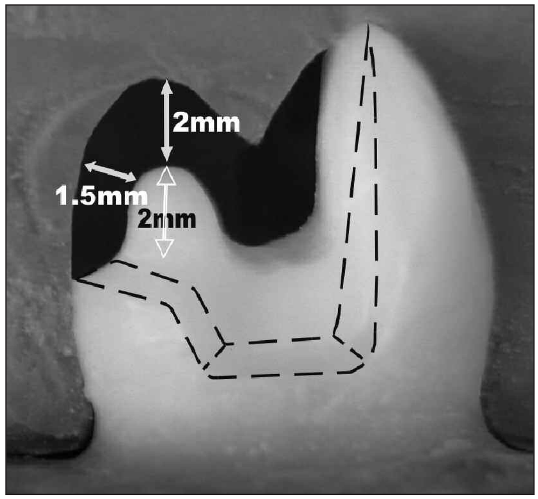

Figure 2. *MOD partial onlay preparation.*

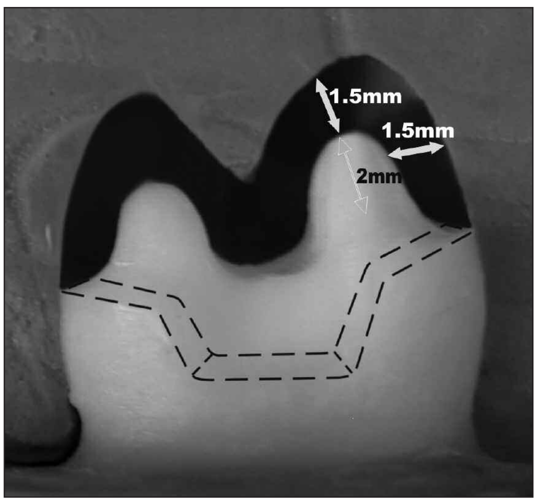

Figure 3. *MOD total onlay preparation.*

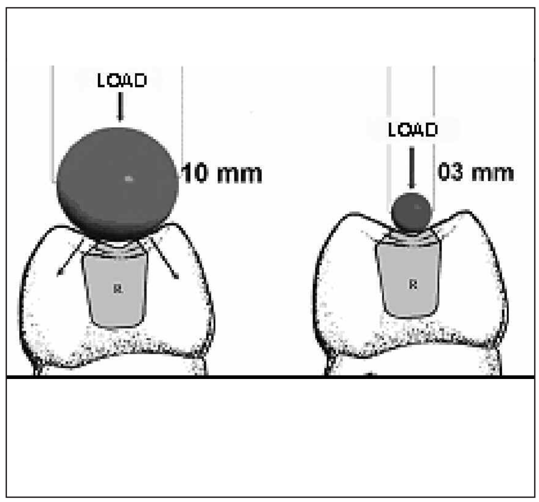

Figure 4. *The representation of the load application of the two spheres used for the axial compression test.*

Table 1: *Characterization of the Ceramics Used in This Study*

Ceramic	Manufacturer	Color	Batch #	Flexural Strength (MPa)*
Super Porcelain EX-3	Noritake Co Nagoya, Japan	A_2B E1	OD313 OO903	110.32
Vitadur Alpha	Vita Zahnfabrik D-79704, Bad Säckingen, Germany	A_3 EN_2	4411 4801	84

**Information provided by the manufacturers*

extended 2 mm in the cervical direction at the lingual surface (Figure 2).

c) Total Onlay

- this preparation was similar to that of the partial onlay; the only difference was the 1.5 mm occlusal reduction in the buccal cuspid (Figure 3).

Fabrication of the Restorations

Half of the specimens in each group received restorations made with feldspathic ceramic Super Porcelain EX-3. The remaining 20 premolars received restorations made with feldspathic ceramic reinforced with 10% aluminum oxide, Vitadur Alpha (Table 1).

The Super Porcelain EX-3 restorations were submitted to four firings (600–930°C) and finished with silicone points and glaze application (930° without vacuum) according to the manufacturer's instructions. The Vitadur Alpha restorations were fabricated similar to Super Porcelain EX-3; the difference was burning temperature (600–960°C) and auto glaze (940°C without vacuum). The internal surfaces were cleaned with glass particle blasting.

The restorations were cemented using the adhesive resinous cement Enforce (Caulk/Dentsply, Petrópolis, Brazil) according to the manufacturer's instructions. Before cementation, the ceramic restorations were conditioned with 10% hydrofluoric acid for four minutes, then silane coated to improve adhesion.

Tooth surfaces received 37% phosphoric acid etching for 15 seconds, and dentin was kept moist after washing and lightly drying. The dentin-bonding agent (Prime & Bond 2.1, Caulk/Dentsply) was applied in two coats to etched surfaces and photocured for 20 seconds. Equal amounts of base and catalyst (Enforce) were dispensed and mixed. The ceramic restoration with resin cement was placed into the cavity, remaining in place under pressure (1 kgf of loading, using one adapted Vicat needle) for two minutes. The excess cement was removed with scalers, and the mesial and distal interfaces were photocured for 40 seconds using a light curing unit XL 3000 (3M ESPE, St Paul, MN) with energy higher than 450mW/cm^2.

Finishing and polishing procedures were completed using the Sof-Lex system (3M ESPE). The specimens were stored in distilled water at 37°C for seven days.

Test of Axial Compression

The specimens were subjected to testing in a universal testing machine MEM 2000 (EMIC, São José dos Pinhais, Brazil) using two different diameter spheres: 3 mm and 10 mm (Figure 4). The spheres were applied in the center of the occlusal surfaces with a 500kgf loading at a crosshead speed of 0.5 mm/minute until specimen fracture. The two diameter spheres were loaded over the three different cavity designs using both ceramics and the control groups for a total of 14 groups (n=10) as noted in Table 2.

The fracture pattern was evaluated based on a standard ranking developed for this study:

a) Pattern I—Fracture restricted to the restoration;

b) Pattern II—Fracture of the dental structure, but not through the long axis of the tooth;

c) Pattern III—Fracture of the tooth and the restoration but not through the long axis of the tooth;

d) Pattern IV—Fracture through the long axis of the tooth, being in the tooth/restoration or only at the tooth.

During this study, one experienced operator performed all procedural steps.

Statistical Analysis

Resistance to fracture data was submitted to parametric tests (ANOVA and Tukey tests). Evaluation of the fracture patterns was performed using the non-parametric Kruskal-Wallis test.

RESULTS

Analysis of the Resistance to Fracture

The means and standard deviations for each group are reported in Table 3. For the three variables that were evaluated, two demonstrated being statistically significant (multivariate ANOVA test). The specimens loaded with 10-mm diameter sphere disclosed higher fracture resistance values than those loaded with the 3-mm sphere ($p<0.001$). Also, differences were verified among the different cavity preparation designs ($p<0.01$). In Table 4, Tukey interval disclosed significant differences ($p<0.01$) between inlay preparations, with the best performance and partial and total onlay preparations exhibiting similar behaviors. Generally, no significant difference between the resistance to fracture of both ceramics ($p>0.05$) was detected. Ceramic was a significant factor only when evaluated in the interaction with cavity preparation (10-mm sphere diameter), where inlay preparation with Vitadur restorations exhibited more resistance to fracture than those made with EX-3 ceramic ($p<0.001$). No other interaction was statistically significant.

Despite the condition, no experimental group exhibited similar resistance to fracture as sound teeth. No experimental group exhibited a resistance to fracture higher than approximately 60% of the control group (Figure 5).

Table 2: *Experimental Groups*

Group	Preparation	Ceramic	Sphere
G1	Inlay	EX-3	3 mm
G2	Inlay	Vitadur Alpha	3 mm
G3	Inlay	EX-3	10 mm
G4	Inlay	Vitadur Alpha	10 mm
G5	Partial Onlay	EX-3	3 mm
G6	Partial Onlay	Vitadur Alpha	3 mm
G7	Partial Onlay	EX-3	10 mm
G8	Partial Onlay	Vitadur Alpha	10 mm
G9	Total Onlay	EX-3	3 mm
G10	Total Onlay	Vitadur Alpha	3 mm
G11	Total Onlay	EX-3	10 mm
G12	Total Onlay	Vitadur Alpha	10 mm
G13	Sound (control)	------------	3 mm
G14	Sound (control)	-------	10 mm

Table 3: *Fracture Resistance Means and Standard Deviations (kgf) for the Different Experimental Groups*

Groups		**Size of Sphere**	
		3 mm	**10 mm**
EX-3	Inlay	75.23 (± 10.33) D b	81.85 (± 8.79) D c
	Partial Onlay	72.30 (± 10.29) D b	77.74 (± 17.12) D c
	Total Onlay	68.50 (± 9.99) E bc	77.62 (± 15.93) D c
Vitadur Alpha	Inlay	79.52 (± 13.02) D b	109.77 (± 13.18) C b
	Partial Onlay	60.49 (± 11.60) E c	76.44 (± 14.27) D c
	Total Onlay	69.58 (± 14.63) E b	78.91 (± 13.06) D c
Control	Sound teeth	133.33 (± 30.34) B a	197.37(± 48.87) A a

Different upper case letters indicate significant differences in the rows (size of spheres). Different lower case letters indicate significant differences in the columns (cavity preparation factor).

Table 4: *Tukey Test for Preparation Factor*

Preparation	Means (kgf)	Tukey Interval (1%)
Control	165.349 A	8.566
Inlay	86.593 B	
Total onlay	73.652 C	
Partial onlay	71.742 C	

Different upper case letters following means indicate significant differences.

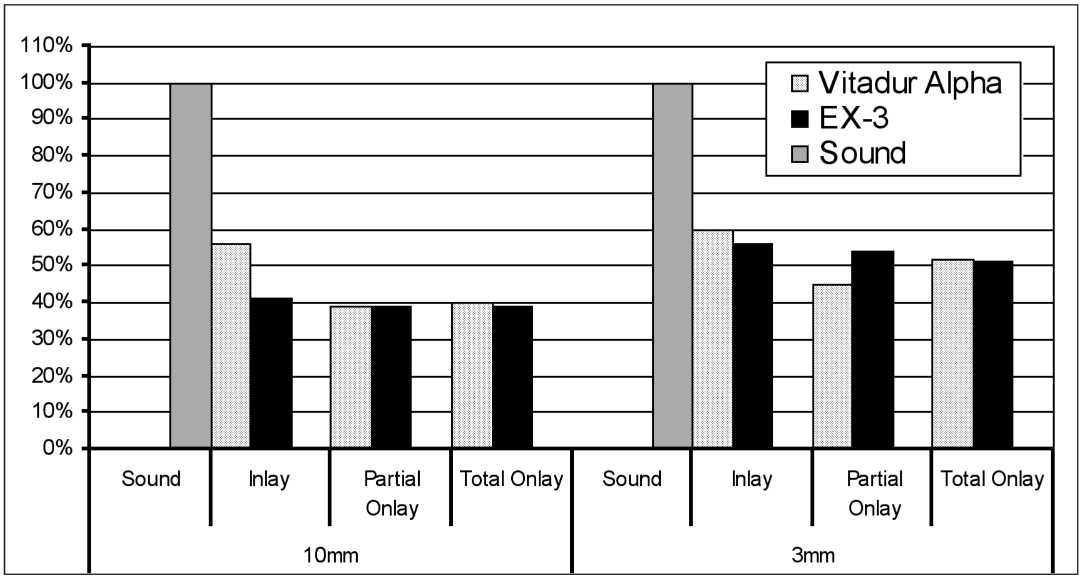

Figure 5. *Fracture resistance recovering (%) for the different groups compared with sound teeth.*

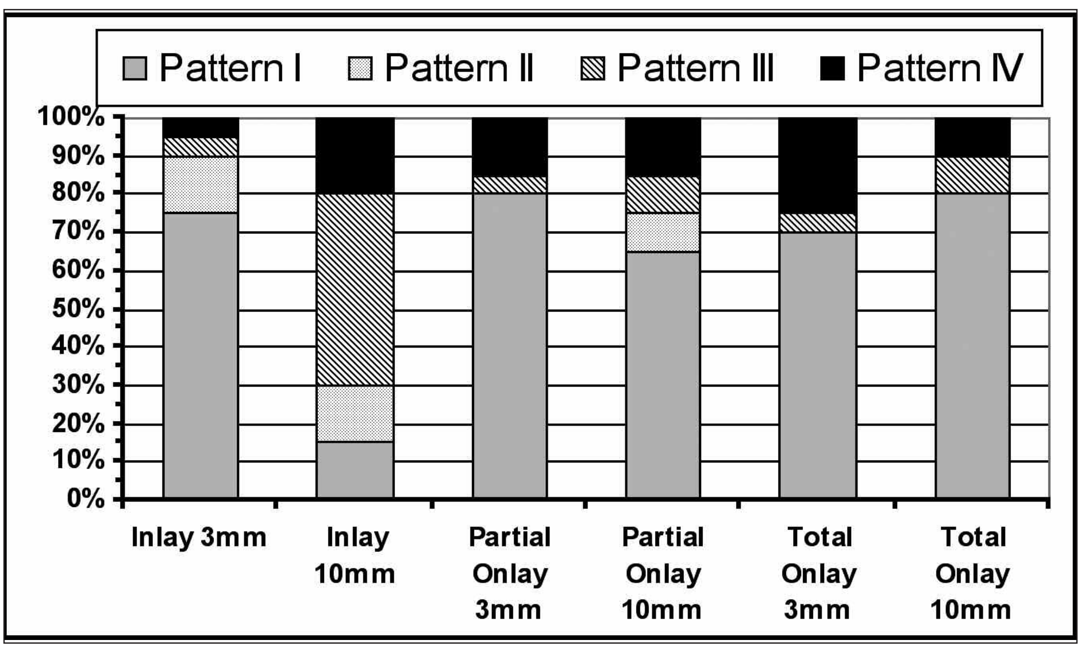

Figure 6. *Frequency rate of the failure pattern observed for each group (Pattern I = Fracture of the restoration; Pattern II = Fracture of the dental structure; Pattern III = Fracture of the restoration and the dental structure; Pattern IV = Fracture through the long axis of the tooth).*

Analysis of the Failure Patterns

After compression testing, the specimens were analyzed to determine failure pattern (Figure 6). The data were submitted to statistical analysis using non-parametric Kruskal-Wallis. There was a significant difference ($p<0.05$) between inlay restorations with 10 mm sphere, which presented a higher frequency of Pattern III failure in relation to all other groups, where Pattern I failure was most frequently observed.

DISCUSSION

Using various methodologies, investigators have demonstrated an inverse relationship between the removal of dental structure and fracture resistance (Vale, 1959; Mondelli & others, 1980; Larson & others, 1981; Cavel, Kelsey & Blankenau, 1985; Salis & others, 1987; Lopes, Leitao & Douglas, 1991; Dalpino & others, 2002; St-Georges & others, 2003). Therefore, the restorative material should not only replace the missing dental structure, but it should also increase fracture resistance and improve marginal seal (de Freitas & others, 2002).

In this study, human premolars were used for many reasons: they present similar fracture rates to molars of the same dental arch (Cavel & others, 1985); they need esthetic restorations (Watts, Wilson & Burke, 1995); under occlusal loading, the cuspids receive high tensions; their anatomy facilitates flexion and fracture (de Freitas & others, 2002) and these teeth are commonly employed, facilitating the comparison among studies.

A large standard deviation (mean = 17.65%) was observed in this study. Such a finding is typically found in mechanical tests on irregular anatomic surfaces (Larson & others, 1981). Moreover, individual variations in morphology and tooth sizes, and variations between loading contacts with dental structure can contribute to the behavior of fractures (de Freitas & others, 2002). However, the SD found in this study was similar to that observed in other studies that investigated the resistance to fracture of restored teeth (Larson & others, 1981; Dalpino & others, 2002; St-Georges & others, 2003).

Metallic restorations with occlusal coverage have been related to fracture resistances similar to those values observed in sound teeth (Vale, 1959; Salis & others, 1987). When comparing composite restorations with or without cuspid coverage, Burke, Wilson and Watts (1993) found that larger restorations significantly improved resistance to fracture. Cuspid coverage could avoid the wedge effect, increasing the absorber shock capacity and relieving the tensions (Salis & others, 1987; Burke & others, 1993).

However, in this study, both partial and total onlay ceramic restorations produced lower resistance to fracture compared to inlays in human premolars. The hypothesis for the difference among the results could be related to the lower resilience of ceramics in relation to the other materials, thus decreasing the capacity to absorb shocks and suffer deformations (Dalpino & others, 2002).

In addition, no experimental group has achieved resistance to fracture similar to the control teeth. These results are in agreement with those found by Dietschi and others (1990), where feldspathic ceramic inlays were not able to provide similar fracture resistance of intact teeth, with no difference between the different ceramics used. In contrast, studies using inlays made with machinable ceramics—CEREC, Sirona—(Bremer & Geurtsen, 2001) or leucitic hot-pressed ceramic—IPS Empress, Ivoclar/Vivadent—(Dalpino & others, 2002) disclosed a resistance recovering similar to that of non-prepared, non-restored teeth. The principle reason for this finding relies on the addition of aluminum oxides in the first system and increased lucite in the second system, both of which increase the elastic modulus and decrease the propagation of cracks through the restorations.

Although the resistance values found for the ceramic restorations in this study were lower than those observed in the control groups, they were superior to those efforts developed during normal masticatory function, situated between 22.65 and 45.4Kgf (Anusavice, 1996). The results of *in vitro* studies and the overall success observed in long-term clinical evaluations (Fuzzi & Rappelli, 1998) have demonstrated the viability of partial ceramic restorations in posterior teeth. Nevertheless, the friability and low mechanical properties of feldspathic ceramics cause limitations in their usage. Most of these ceramics were developed to be combined with metallic structure in total crowns, causing limitations in their indication for situations such as those tested in this study (Milleding & others, 1995).

Until now, sound dental structure could not be effectively replaced with any kind of restorative material. The most important factor that influences the failure of restorations is the size of the cavity preparation, instead of the nature of the ceramic system (Hickel & Manhart, 2001). More conservative inlay preparations should be preferred in relation to other indirect preparations (Edelhoff & Sorensen, 2002) and should not be replaced by restorations that promote additional occlusal reduction (Eakle, Staninec & Lacy, 1992; Krejci & others, 2003).

In accordance with the findings of Burke and others (1993), similar performances were detected for partial and total onlays. With this in mind, the buccal surface could be maintained, optimizing the esthetic results with ceramic restorations in premolars.

The 10-mm loading sphere exhibited higher significant resistance values compared to those observed for the 3-mm sphere. The alteration of sphere size changes the position of load applications, modifying the concentration of tension patterns (Larson & others, 1981). Comparing this situation to the oral cavity, it could be suggested that mastication of small resistant foods would increase the risk of restoration fracture. Anusavice (1996) has suggested cuspid grounding of the antagonist teeth that come in contact with ceramics in order to produce larger occlusal contact areas, thus reducing the concentration of tensions.

Despite differences between ceramic compositions, the two ceramics tested have generally shown similar performance. This could be linked to the high concentration of compressive load promoted by spheres, which were loaded directly against the restoration body. This could promote a high propagation of cracks into the body of the two ceramics, thus eliminating the alleged reinforcement provided by the incorporation of aluminum oxide.

The test used in this study does not simulate the reality of the clinical situation. Probably, failure in the mouth would occur due to fatigue, with micro crack propagation until structural failure (Lopes & others, 1991; Eakle & others, 1992). However, as stated by Dietschi and others (1990), compression applied on the occlusal surface with a sphere is the most appropriate laboratory model to estimate fractures observed in the clinic. These tests are largely employed in the literature and are an important source of information, indicating which component is more fragile: the restoration, the dental structure or the adhesive interface (Burke & others, 1993; Watts & others, 1995; Dalpino & others, 2002).

The analysis of failure patterns demonstrated that failure occurred most frequently in the restorations, which is better in the clinical situation, because the restoration could be replaced, while tooth failure may impair the prognosis (Watts & others, 1995; Mondelli & others, 1998). When the inlay restorations were loaded with 10-mm sphere, there was a fracture of the dental structure together with a fracture of the restorations. In this case, this finding could probably be linked to alteration of the contact area of the sphere, the point of high concentration of stress (Abu Hassan & others, 2000) that occurred in enamel. The 3-mm loading sphere may have better simulated the clinical environment as compared to the 10-mm sphere, as demonstrated by the higher percentage of restorative materials fractures.

Other factors may influence the resistance to fracture of indirect restorations: internal angles of the preparation, the cement used, the quality of the adhesion obtained, the thickness of the restorative material, internal adaptation, finishing and polishing, and mainly, the correct indication of the technique. Despite the importance of laboratory studies to answer some questions in a short time, the real performance of restorations can only be determined by long-term clinical trials.

The hypotheses tested in this study were partially confirmed—the types of cavity preparation and load application influenced fracture resistance and were rejected, in part, since the ceramic composition did not influence the results observed.

CONCLUSIONS

Within the limitations of this study, it could be concluded that:

a) The feldspathic ceramics used did not provide resistance to fracture similar to that achieved for the control group;

b) The addition of aluminum oxide in Vitadur Alpha did not produce increased performance when compared to Super Porcelain Ex-3;

c) Inlay restorations exhibited superior resistance to fracture compared to the other cavity designs;

d) The sphere with higher diameter provided higher values of resistance to fracture.

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