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Influence of restorative techniques on fracture load of endodontically treated premolars

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SUMMARY

Objective. This study evaluated the influence of restorative techniques on the fracture load and fracture mode of endodontically treated premolars with MOD cavities. Materials and Methods: Sixty maxillary premolars were divided into groups: G1 – sound teeth; G2 – direct technique using Four Season; G3 – Adoro inlays; G4 – Adoro onlays; G5 – Empress inlays; G6 – Empress onlays. The specimens were submitted to compressive axial loading until failure. The fracture mode was analyzed.

Results. According to ANOVA and Tukey's test (α=0.05), the sound teeth (1370.61 N) showed the highest fracture load mean, which did not differ statistically from IPS Empress onlays (1304.21 N). Intermediate values were obtained for IPS Empress inlays (918.76 N), Adoro onlays (861.15 N), Adoro inlays (792.71 N) which did not differ statistically among them. The lowest fracture load was obtained for direct restorations with Four Seasons (696.08 N), which did not differ statistically from the Adoro inlays.

Conclusions. The ceramic restorations provided higher fracture load and more incidences of catastrophic fractures. Cuspal coverage increased teeth fracture load. The results were similar for direct and indirect inlays with composite resin.

Key words: ceramics, composite resins, restorations, resistance.

INTRODUCTION

The fracture strength of a tooth is directly related to the quantity of healthy remaining tooth structure. Removal of marginal ridges, increase in isthmus width and deep preparation are the main causes of decrease in tooth fracture strength (1-3). Therefore, endodontic treatment weakens tooth structure and makes it susceptible to fracture, since a large portion of tooth structure is lost during the procedure (4, 5).

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When endodontic treatment and MOD cavity preparations are performed, the tendency is to increase cuspal deflection under masticatory loads. With time, repeated stress can reduce resistance to fracture and tooth fracture may occur even under forces lower than those necessary to fracture the sound structure. Therefore, it is important for the restoration to be capable of recovering the original strength of the tooth to decrease the mechanical fatigue of the cusps (6).

Several materials can be used for restoring endodontically treated teeth. However, due to esthetical requirements, composite resins and ceramics are the most frequently used materials. Ceramics restorations, in comparison with those of composite resin, exhibit superior esthetic appearance, biocompatibility, wear resistance, stability in the oral cavity, high compression resistance and a coefficient of thermal expansion similar to that of dental structure (7, 8). However, both materials favor reinforcement of the weakened tooth when combined with adhesive technology (5, 9).

Furthermore, direct or indirect techniques can be applied. Direct composite resin restorations present advantages such as greater preservation of the dental structure and lower cost. However, the direct restorative technique with light-cured composites may promote high shrinkage stress, and could lead to hybrid layer rupture, setting off microleakage and dentinal sensitivity (10). As an alternative, the indirect technique can be used. By producing a composite resin inlay, only shrinkage of the relatively thin layer of resin cement used for bonding the inlay to the tooth may compromise the margins, since shrinkage of the inlay itself takes place outside the cavity. Moreover, the indirect technique often makes it easier to achieve proper contours and proximal contacts of the restorations (11).

Another possibility for reinforcing the tooth structure is cuspal coverage. This procedure contributes to less cuspal deflection and greater protection of remaining tooth structure (4, 12).

Several studies have been conducted to verify which restorative technique would be capable of reestablishing tooth resistance (5, 9, 13, 14). Nevertheless, there are no studies in which the same methodology is used to compare the strength of endodontically treated maxillary premolars directly and indirectly restored with composite resin and indirectly restored with ceramic, with or without cuspal coverage. The current study was designed to evaluate these restorative techniques.

The hypothesis investigated in this study was that there are differences in fracture load and failure patterns in endodontically treated maxillary premolars when restored with different restorative techniques.

MATERIALS AND METHODS

Sixty sound maxillary premolars, extracted by therapeutic indication, were cleaned and immersed in 10% thymol for 24 hours for disinfection. After this period, they were stored in distilled water at 4º C for a maximum period of 6 months. These teeth had the following coronal dimensions: buccal-lingual distance of 9.0-9.6 mm; mesio-distal distance of 7.0 -7.4 mm; and cervical-occlusal distance of 7.7-8.8 mm. A variation of 0.5 mm was attributed to each measurement.

The teeth were mounted individually in plastic cylinders, 20 mm in diameter and 30 mm high (Tigre, São Paulo, SP, Brazil), and the roots were embedded in acrylic resin (Jet Classico, São Paulo, SP, Brazil) up to 2 mm below the cement-enamel junction. The teeth were randomly divided into six groups (n=10): Group 1: sound teeth (control); Group 2: direct restorations with Four Seasons composite resin (Ivoclar/Vivadent, Schaan, Liechtenstein); Group 3: inlays with Adoro composite resin (Ivoclar/Vivadent, Schaan, Liechtenstein); Group 4: onlays with Adoro; Group 5: inlays with IPS Empress ceramic (Ivoclar/Vivadent, Schaan, Liechtenstein); Group 6: onlays with IPS Empress.

Tooth Preparation

Standard MOD cavity preparation, with a width of two thirds the intercuspal distance, 1 mm above the CEJ and rounded internal angles, was performed in 50 teeth with a 4159 diamond tip (4159, KG Sorensen, Barueri, SP, Brazil) using a high-speed handpiece (Kavo do Brasil Ltda, Joinville, SC, Brazil). The handpiece was coupled to a device adapted to the base of a microscope to standardize the preparations. The MOD preparation had only buccal and lingual walls, a common floor from the mesial to the distal area. The diamond tip was changed after every five preparations, which were performed by a single operator. In 20 teeth (Groups 4 and 6), 2 mm of both cuspids were prepared with a diamond bur. After the preparations were completed, an endodontic access opening was prepared with a spherical carbide bur (No. 8, SS White, Lakewood, NJ, USA). The preparation of the chambers was round and expulsive. The root canals were instrumented with Flexo-File files (Kerr, Orange, CA, USA), from number 15 to 40. A 2.5% sodium hypochlorite solution was used to irrigate and clean the root canal. After the root canal preparation, all teeth were filled with gutta-percha cones (Dentsply Maillefer, Ballaigues, Switzerland) and endodontic cement (N-Rickert; Inodon, Porto Alegre, RS, Brazil).

Direct Restorations

Group 2: enamel and dentin were etched with 35% phosphoric acid (FGM, Joinville, SC, Brazil) for 15 seconds, washed with air-water spray for 15 seconds, and dried with absorbent paper. The Excite adhesive (Ivoclar/Vivadent, Liechestein) was applied on the enamel and dentin. After gentle air drying for 5 seconds, the adhesive was light-cured for 20 seconds with a halogen light-curing unit (XL 3000; 3M/ESPE, Saint Louis, MN, USA). The Four Seasons composite resin was inserted incrementally in 2-mm thicknesses and then light-cured for 40 seconds. The first increment was to fill the pulp chamber, followed by the lingual wall, buccal wall and proximal boxes. The curing light intensity was monitored with a radiometer (Demetron/Kerr, Danbury, CT, USA), remaining in the range of 400-450 mW/cm^2.

Indirect Restorations

Impressions of the preparations of Groups 3, 4, 5 and 6 were made with a one-step technique, using addition silicone (Adsil; Vigodent, Santo André, SP, Brazil). The light-body material was injected around and over the prepared teeth. A plastic tray 20 mm in diameter and 30 mm high was filled with the heavy-body material, and then the tray was placed over the preparation. The impression material was allowed to set for 10 minutes before it was removed from the preparation. After one hour, each impression was boxed and taped with adhesive tape, then filled with type IV Durone stone (Dentsply, York, PA, USA). After one hour, the casts were removed from the impression, suitably numbered according to their group, and they were sent to a laboratory to process the indirect restorations.

For the Adoro restorations, initially, a resin liner layer (SR Adoro liner 200; Ivoclar Vivadent, Schaan, Liechtenstein) was applied and light-cured in a special unit (Targis Quick; Ivoclar Vivadent, Schaan, Liechtenstein) for 15 seconds. Next, 1-mm increments of dentin shade resin (Shade A2, SR Adoro; Ivoclar Vivadent, Schaan, Liechtenstein) were placed in the die, and each increment was light-cured in the processing unit (Targis Quick; Ivoclar Vivadent, Schaan, Liechtenstein) for 15 seconds. This was followed by light-curing for 25 minutes at 95º C in another processing unit (Targis Power, Ivoclar Vivadent, Schaan, Liechtenstein). After 24 hours, the internal surface of the resin restoration was airborne-particle abraded with 50-µm aluminum oxide for 5 seconds, from a distance of 5 mm, washed with water-air spray for 60 seconds, air-dried, and then a silane bonding agent (Ceramic Primer; 3M/ESPE, St. Paul, MN, USA) was applied, followed by gentle air for 5 seconds.

The ceramic restorations were made with a leucite-reinforced ceramic (IPS Empress). A spacer (Die Spacer; Talladium Inc, Valencia, CA, USA) was applied over the high-density stone dies, and wax patterns (Classic; Renfert, Hilzingen, Germany) were made for the ceramic restorations. The wax coping was invested in IPS Empress investment and eliminated in a burnout furnace (700-5P; EDG Equipments Ltda., São Carlos, SP, Brazil) by heating the refractory die at the same time the IPS Empress ingots (Shade A2) and the alumina plunger were heated at 3º C per minute to 850º C and held for 90 minutes. After the procedure described, the investment plunger, and ingot were transferred to a furnace (EP 500; Ivoclar-Vivadent, Schaan, Liechtenstein) that increased the temperature to 1180º C and automatically pressed the melted ingot into the mold. After pressing and cooling to room temperature, the specimens were divested with 50-µm glass beads at 4-bar pressure, followed by airborne-particle abrasion with 50-µ m aluminum oxide at 2-bar pressure to remove the refractory material. The internal restoration surface was etched with 8% hydrofluoric acid (Bisco, Schaumburg, IL, USA) for 60 seconds, washed with air-water spray for 60 seconds and air-dried. Then a layer of silane bonding agent (Ceramic Primer) was applied, followed by a gentle air drying for 5 seconds.

Luting procedure

The enamel and dentin were etched with 35% phosphoric acid (FGM, Joinville, SC, Brazil) for 15 seconds, washed with air-water spray for 15 seconds, and dried with absorbent paper. The Excite adhesive (Ivoclar/Vivadent, Schaan, Liechtenstein) was applied on the enamel and dentin. After gentle air drying for 5 seconds, the adhesive was light-cured for 20 seconds with XL 3000 light-curing unit. A layer of Excite adhesive was applied in the internal part of the restorations, followed by a gentle air drying for 5 seconds. The indirect restorations were luted with dual-polymerized cement (Variolink; Ivoclar/Vivadent, Schaan, Liechestein). The base and catalyst pastes were mixed for 15 seconds and applied on the restoration and on the preparation. The restoration was placed on the respective preparation under a 1 Kg standard load for 3 minutes. The excess cement was removed and light-cured for 40 seconds on each surface (buccal, lingual, mesial, distal and occlusal surfaces) with XL 3000 light-curing unit. All restorations were finished and polished with multiblade burs (FG7901; KG Sorensen) and diamond paste at low speed (Diamond paste; FGM Dental Products, Joinville, SC, Brazil). The specimens were stored in distilled water at 37º C for 72 hours.

Testing

After the storage time, the specimens were submitted to compressive axial loading in a universal testing machine (EMIC DL 2000; São José dos Pinhais, PR, Brazil) with a steel bar 4.5 mm in diameter and 16 mm long at a cross-head speed of 0.5 mm/minute until failure. The results were obtained in N and submitted to one-way ANOVA and Tukey's test (α=0.05).

The fracture mode was evaluated visually, based on a standard ranking developed for this study: Type I – fracture restricted to the restoration; Type II – restoration and cusp fracture above the cement-enamel junction; Type III – restoration and cusp fracture below the cement-enamel junction; Type IV – restoration and cusp fracture below the cement-enamel junction with pulp chamber exposure; Type V – longitudinal fracture, whose fracture line divided the tooth along the root portion. Types I, II, III and

IV were considered fractures that could be restored, and Type V determined tooth loss.

Statistic

The fracture load data was submitted to the Kolmogoriv-Smirnov normality test. To compare the fracture load of the studied groups, the ANOVA and Tukey ($P<0.05$) parametric statistical tests were applied. All statistical analyses were performed using SPSS version 10.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The one-way ANOVA showed that there were significant differences ($F=47.452$) among all groups with respect to fracture load. The highest fracture load mean was obtained for sound teeth (1370.61 N), which did not differ statistically from IPS Empress onlays (1304.21 N), and both the values were statistically higher than those in the other groups ($p<0.05$). Intermediate values were obtained for the IPS Empress inlays (918.76 N), Adoro onlays (861.15 N) and Adoro inlays (792.71 N), which did not differ statistically among them. The lowest fracture load mean was obtained for the direct restorations with Four Seasons (696.08 N), which did not differ statistically from the Adoro inlays (Table 1).

With regard to fracture mode, the IPS Empress inlays and onlays presented the highest incidence of catastrophic fracture Type V. The sound teeth and Adoro onlays presented the highest incidence of Type II and Type I fractures, respectively. Direct restorations with Four Seasons and Adoro inlays presented the highest incidence of Type IV fractures (Table 2).

Table 1. Fracture load (N) of the experimental groups

Group	n	Mean (N)	SD
G1: Sound teeth	10	1370.61[a]	173.42
G6: Empress onlays	10	1304.21[a]	202.84
G5: Empress inlays	10	918.76[b]	105.37
G4: Adoro onlays	10	861.15[b]	71.36
G3: Adoro inlays	10	792.71b[c]	101.37
G2: Direct restorations with Four Seasons	10	696.08[c]	75.79

[a, b, c]Means followed by the same letter did not differ statistically according to Tukey's test at significant level of 5%.

Table 2. Fracture mode distribution among groups

Fracture mode	Group					
	G1	G2	G3	G4	G5	G6
Type I: fracture restricted to the restoration				7		
Type II: restoration and cusp fracture above the CEJ	6					
Type III: restoration and cusp fracture below the CEJ	4					
Type IV: restoration and cusp fracture below the CEJ with pulp chamber exposure		7	8	3	5	5
Type V: longitudinal fracture which divides the tooth along the root portion (worst prognosis – tooth loss)		3	2		5	5

DISCUSSION

Mechanical fracture tests are performed to verify the influence of restorative materials (15, 16) and cavity preparations (3, 17) on the fracture strength of teeth which are submitted to a concentrated and increasing load in the occlusal region. These tests generally produce fracture loads that exceed the load limits that occur in the normal stomatognathic system during mastication. However, application of high loads on the occlusal surface of teeth and/or restorations may occur when the individual bites on a small sized solid body, and force becomes concentrated on a single tooth. If this tooth is structurally debilitated or prepared with an inadequate cavity design, it may cause tooth or restoration fractures.

In this study, maxillary premolars were selected. These teeth have an unfavorable anatomic shape, crown volume and crown/root proportion which make them more susceptible to cusp fractures than the other posterior teeth, when submitted to occlusal load (18). The dimensions of the cavity preparation were standardized in all groups, representing a clinical situation of advanced caries, in which preparation becomes extensive.

According to the results, the hypothesis was accepted, because there were differences in fracture load and fracture type among the experimental groups. The sound teeth showed fracture load mean of 1370.61 N, similar to values found in other studies, which ranged between 732 N and 1584 N (4, 5, 13, 19, 20). This variability in values can be due to methodological differences, such as specimen preparation, tooth storage method and the type and design of the load application contact device (17, 19, 21).

The sound teeth presented the highest fracture load values, being in agreement with other studies with similar methodology (20-22). However, the IPS Empress onlays almost reproduced the strength of sound teeth. Probably this finding is related to the covering of both cusps, which would increase the fracture strength of the dental structure (3), as well as the use of the IPS Empress leucite-reinforced glass ceramic with flexural strength of 160-180 MPa (23).

For IPS Empress ceramic, the onlays promoted statistically higher fracture load in comparison with the inlays. It shows that the cuspal coverage was an important factor in increasing the tooth strength. The same was observed between the Adoro inlays and onlays, although there was no statistical difference between the two groups. This finding corroborates the study of Takahashi *et al*. (4), who also verified higher fracture loads in endodontically treated premolars with cuspal coverage. Similarly, Fennis *et al*. (12) found that the premolars restored with the onlay technique supported the cyclic load better (55% against 20% of teeth restored with the inlay technique).

In this study, the adhesive system Excite and the resin cement Variolink were used to lute the restorations, following the recommendations of the manufacturers. Restorations luted by the adhesive technique have shown to be efficient in reducing cuspal deflection and recovering part of the strength of endodontically treated teeth (6, 24). However, in the onlay preparation with cuspal coverage, the tendency is to lower cuspal deflection when they are submitted to occlusal load and, consequently, less fatigue stress over a long period of time. Furthermore, when there is replacement of 2 mm of the cuspal occlusal region by the restorative material, the material provides the initial strength. The same does not occur in the inlay preparation, in which the cusps are not covered and initial strength is provided by the sum of the dental structure, restorative material and bonding interface strengths. Although there was no statistical difference between the onlays and inlays with Adoro, it would be interesting for researches to verify the fracture strength of inlay restorations over time, since studies have shown that bond strength between the adhesive system and dental structure tends to decrease due to hydrolysis with the passage of time (25, 26).

Direct restorations with Four Seasons composite resin provided the lowest mean fracture load, which did not differ statistically from the Adoro inlays. Similar results were shown by Dalpino *et al*. (13) and Sun *et al*. (27). Within the limitation of this in vitro study, we would suggest that it is not clinically justifiable to use the indirect technique with the purpose of protecting a dental structure from possible fractures, since the direct technique presented similar values.

In the group of sound teeth, the majority of fractures occurred above the cement-enamel junction (Type II). Probably this type of fracture was predominant because sound teeth have maximum strength. Cavity preparation weakens the tooth (1) and the fractures have been described as more severe for the endodontically treated tooth, in which a large quantity of dental structure is removed, increasing incidence of periodontal involvement (22). When comparing composite direct restoration and composite inlays, there was a higher percentage of fractures type IV in both groups. This finding also shows that there was no advantage of using the indirect technique, as far as the restorative prognosis is concerned. When comparing inlays and onlays with Adoro and IPS Empress, there was a higher percentage of fracture type V for ceramic restorations, which are fractures that condemn the tooth to extraction. The possible explanation for this finding is that ceramic has a higher elastic modulus than composite resin; thus, fewer loads are absorbed within the ceramic than in composite resin (11). Therefore, as the ceramic transmits more of the applied load to the underlying tooth structure (28), it favored the occurrence of more severe fractures. For the Adoro onlays, 70% of the fractures were restricted to the restoration (Type I), presenting the best restorative prognosis. This probably occurred because the onlays received the load directly and the composite resin absorbed the compression load energy and fractured before this was transmitted to the dental structure.

In the current study, the fracture load of teeth in all groups was greater than the normal masticatory forces exerted on the maxillary premolars, which have been reported to range between 100 and 300 N (29). One limitation of this study was the lack of aging and fatiguing of the specimens. Although mechanical and destructive experimental tests are frequently used, these tests have a limitation in providing biomechanical and structural information about the behavior of specimens at the moment before fracture. In such experiments, a static compressive force is used; however, the forces in the oral cavity are dynamic, with constantly changing rate, magnitude and direction (30). Therefore, it is suggested that these findings be related to non-destructive laboratory analysis, such as finite element analysis and strain gauge tests to verify cusp deformation and the biomechanical aspects of stress distribution, as well as long-term clinical studies.

CONCLUSIONS

According to the results of the study, it was concluded that the cuspal coverage increases the fracture strength of the teeth, and that the ceramic restorations provide higher fracture strength but higher percentage of catastrophic fracture in comparison with composite resin restorations. Besides that, the indirect technique does not provide differences in fracture load and fracture mode in comparison with the direct technique for the composite resin restorations.

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