Fracture strength of endodontically treated premolars restored with different post systems and metal-ceramic or monolithic zirconia crowns

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The purpose of this study was to investigate the fracture strength of endodontically treated human maxillary premolars (ETP) restored with posts and metal ceramic (MC) or monolithic zirconia (MZ) crowns. Sixty ETP were randomly divided into 3 groups. Teeth in control group (C) received a resin filling. ETP in the MC group were restored with prefabricated metal posts, composite cores and MC crowns while in the MZ group with glass-fiber posts, composite cores and MZ crowns. Half of the specimens were loaded at a 135° angle and half under axial loading until fracture. The fracture modes were divided in repairable and irreparable using optical microscopy. Mean fracture strength was significantly higher for MC than for MZ crowns and control group only under axial loading. The distribution of repairable and irreparable failures presented no significant differences. Crown placement significantly improved the fracture strength of ETP irrespectively of post and crown type.

Keywords: Dental restoration failure, Post and core technique, Metal ceramic crown, Monolithic zirconia crown, Premolars

INTRODUCTION

Fracture strength of endodontically treated teeth (ETT) is affected by various factors including the amount of remaining coronal tooth structure13), presence of ferrule and its height12), tooth position14), type of crown15), post and core design and material used16). Different types of posts, including metal or fiber posts, have been recommended for the restoration of endodontically treated teeth with a moderate or excessive loss of coronal structure to improve the retention of a core build up and to provide retention to the definitive prosthesis16-14). For many years, cast post and cores have been considered the gold standard, although their rigidity has been associated to high loads transmitted to the weakened root, increasing the probability of root fracture7). Prefabricated titanium posts have been alternatively applied, due to the significantly reduced treatment time, as they can be inserted in a single appointment and can be combined with composite resin core build up. They have an elastic modulus three times higher than that of dentin and similar or higher to cast metal posts15), and have similar survival rates and risk of root fracture16). Several studies have advocated that posts should attain specific biomechanical characteristics, as close to those of dentin as possible, as this ensures even stress distribution along the root, minimizing the risk of catastrophic failures15,17-19) although contradictory results have also been reported20-22). Based on this, glass-fiber posts (GFP) with elastic modulus similar to that of dentin23), were introduced as a viable alternative, although their survival rates are lower compared to cast post and cores24-26). Their increased use is justified by the less clinical time needed, the enhanced esthetic result and reduced financial cost, as well as the low incidence of irreparable root fractures compared to cast or metal posts6,19,22,27-36). Glass-fiber posts in combination with composite resin and ceramic crowns, constitute a common clinical practice due to favorable biomechanics6,7,37) and the increasing demand of esthetic restorations29,32).

Metal posts, both prefabricated and cast, have been widely used in combination with metal ceramic crowns to restore endodontically treated teeth (especially posterior) because of their good physical properties and long-term survival rates38,39). Several in vitro studies comparing the fracture strength of different post systems, revealed conflicting results favoring cast39), titanium40), or fiber reinforced posts7,29). Furthermore, studies that compare the survival rates of endodontically treated teeth restorations with various post type have, also, yielded controversial findings favoring metal24) or fiber reinforced posts43), or reporting similar findings for both types of posts42).

Posterior teeth present different dental restorative needs due to their structure and the axial or lateral occlusal loading exerted during function and/or parafunction6). Furthermore, endodontically treated premolars, particularly when their marginal ridge is thin or removed, are prone to fractures due to functional compressive or parafunctional oblique occlusal forces43). The use of posts has been associated with greater fracture strength and fewer root fractures in crowned endodontically treated premolars44). Crown placement significantly improves fracture strength and survival of endodontically treated posterior teeth, whereas it does not improve the clinical success of anterior teeth4,5,45).

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Metal ceramic crowns with cast occlusal surfaces are considered a safe and predictable prosthetic option in heavy loading situations such as in posterior areas\textsuperscript{46-49} or unfavorable lateral occlusal forces during parafunctional habits (bruxism)\textsuperscript{50-52} where the risk of technical complication is increased\textsuperscript{53}.

Monolithic zirconia crowns have been introduced as a promising alternative to metal ceramic crowns due to their good mechanical properties, biocompatibility, esthetic outcomes and satisfactory fracture strength without the risk of chip-off veneering materials fractures\textsuperscript{54-57}. Placing an esthetic fiber post in endodontically treated premolars followed by the insertion of a monolithic zirconia restoration, is a therapeutic strategy in esthetic areas. Although premolars are posterior teeth, they are partially visible in more than 80\% of the smiles, and display more than 65\% of their clinical crown length during smiling, especially in the upper jaw\textsuperscript{58}. For this reason, they are considered teeth with increased esthetic demands. However, current literature provides only limited information on the fracture strength of endodontically treated premolars restored with different types of post material and metal ceramic or monolithic zirconia crowns. Restoration fracture strength under both axial and oblique forces is required to provide data on the clinical performance of prosthodontic materials\textsuperscript{22,27,28,31,35,36,38} as different configuration puts the materials under different compressive or tensile stresses\textsuperscript{14,59-63}. Therefore, the aim of this study was to investigate the fracture strength and the fracture mode of endodontically treated premolars restored with either prefabricated metal posts and metal ceramic crowns or fiber posts and monolithic zirconia crowns. The null hypothesis was that there would be no difference in fracture strength between groups when subjected to different loading protocols. The null hypotheses were: a; fracture strength and fracture mode would not differ among the groups after axial loading, b; fracture strength and fracture mode would not differ among the groups after oblique loading.

**MATERIALS AND METHODS**

The sample included 60 single-rooted mandibular premolars extracted for orthodontic or periodontal reasons. The study protocol was approved by the department’s Ethical Committee. The included premolars attained comparable tooth dimensions measured by a digital caliper and tested with the LSD test according to which the mean width and length values did not differ at \( p<0.05 \). They were free of restorations, caries, internal absorptions, calcified root canals, micro-fractures, and calculus, as verified by either X-ray or examination under stereo microscope. Teeth preservation was performed in 0.9\% NaCl saline at \(-20^\circ\text{C}\) for no more than 2 months\textsuperscript{64,65}.

Root canals were prepared by the Protaper Ni-Ti system (Maillefer, Dentsply Sirona, Charlotte, NC, USA) with F2 and F3 instruments. They were obturated with the use of F3 gutta-percha cones, single cone technique, and AH-26 sealer. A temporary filling material (Cavit, 3M, Minneapolis, MN, USA) was used to seal the access cavities before the teeth were put into storage at 37\^\circ\text{C} and 100\% humidity.

The test specimens were made by embedding teeth in self-polymerizing acrylic resin (Triplex, Ivoclar Vivadent, Schaan, Liechtenstein) with the use of a surveyor (Surveyor Parallometer System, Dentsply Ceramco, Dentsply Sirona). Root surfaces were marked parallel to the cementoenamel junction and 2 mm below. Up to this line the root was covered with aluminum foil. After resin polymerization, the aluminum sheet was removed and teeth were repositioned and stabilized with polyvinyl siloxane (Virtual, Ivoclar Vivadent) in attempt to represent the periodontal membrane\textsuperscript{66,67}. The teeth were randomly assigned to three groups of 20 specimens each based on the restoration type (C: control, MZ: monolithic zirconia crown and glass-fiber posts, MC: metal ceramic crown and pre-fabricated metal post) and subdivided to two based on the type of loading (axial and oblique) of 10 specimens each (Figs. 1, 2). The number 10 specimens per group was considered adequate based on the majoritiy of related studies and the assignment of the

**Fig. 1** Groups of endodontically treated premolars.

**Fig. 2** A: Endodontically treated premolars, B: Endodontically treated premolars with resin filling in access hole, C: Endodontically treated premolars prepared for metal ceramic crown, D: Endodontically treated premolars prepared for monolithic zirconia crown, E: Metal ceramic crown, F: Monolithic zirconia crown, G: Axial loading, H: Oblique loading
specimens to each group was performed through random block allocation (www.randomizer.org).

A silicone key was received from teeth included in the metal ceramic and monolithic zirconia group to guide their preparation for the crowns. Initially, teeth crowns were cut horizontally in order to leave 3 mm of remaining tooth crown in each tooth. The total length of both type posts was 20 mm. The diameter of the glass-fiber posts was 1.5 mm and 0.8 mm apically and of the prefabricated parallel posts, 1.5 mm. Post spaces were prepared according to manufacturers’ instructions, leaving in all roots 5 mm of apical gutta percha seal. Posts were cut at 6 mm above cemento-enamel junction and cemented with dual-polymerized resin cement (Panavix F 2.0, Kuraray, Tokyo, Japan). A thin layer of primer (mixed ED primers II A&B, Panavix F 2.0, Kuraray) was applied in the root canal and left for 30 s. After mild drying with air, its excess was removed with paper points. After thorough mixing the A and B pastes of the resin cement, the half amount of paste was applied in the canal with the aid of a lentulo while the rest was applied on the post. Post was inserted with constant finger pressure and gentle rotational movements to avoid air trapping. Then the cement excess was removed and photopolymerization followed for 40 s. In order to ensure homogeneity of the core restorations, a prefabricated cellulite matrix (Kemdent, Wiltshire, UK) was used to place the composite resin. The matrix was shaped to a total height of 10 mm (8 mm clinical tooth crown and 2 mm above resin). The remaining tooth crown was etched for 15 s with 35% orthophosphoric acid (Total Etch; Ivoclar Vivadent), then rinsed with water and dried with a mild stream of air. Adhesive agent (Dental adhesive; Excite, Ivoclar Vivadent) was then applied, mildly air flowed and photopolymerized for 20 s. The composite resin (Empress Direct, Ivoclar Vivadent) was placed in three layers, with the latter being placed in the cellulite matrix and photopolymerized for 40 s. After matrix removal, teeth were prepared with diamond burs (Brasseler, Lemgo, Germany) of two different grits (coarse and fine) to attain 7 mm of crown height measured from the buccal axial wall. Cutting of the axial walls was accomplished with tapered cylindrical diamond burs (depth of cut of 1.2 mm and sloping about 6 degrees) leaving margins with 1 mm circumferential deep chamfer margin (Fig. 1).

A silicone key from an intact premolar was used to fabricate wax models, in order to ensure equal thickness of the fabricated crowns. Metal ceramic crowns were fabricated using a nickel-chromium alloy (Verabond 2, Albadent, Fairfield, CA, USA) and veneered with appropriate ceramic (VK95, Vita Zahnfabrik, Bad Säckingen, Germany). For monolithic zirconia crowns, the prepared teeth were scanned (3Shape D700, 3Shape Dental system, CAD Design Software) along with the wax model and milling/sintering procedures were performed according to manufacturer’s instructions (Bruxzir, Glidwell Laboratories, Newport Beach, CA, USA). Crown cementation was performed with the same resin cement (Panavix F 2.0; Kuraray). The occlusal surface of all crowns was designed with a 1 mm-widening of the central groove, to increase the contact area between the crown and the indenter in order to evenly distribute the load and avoid localized contact damage. Specimens were mounted in a customized steel die and half specimens of each group were subjected to axial compression load, while the rest at a 135 degrees angle to the long axis of the root. The forces were transferred through a stainless steel rod (1 mm diameter×1 cm length) which was attached to a universal testing machine (M350-20, The Testometric Company, Rochdale, UK). The specimens were subjected to static loading, with a crosshead speed of 1 mm/min until fracture. The point of fracture was determined by the sudden drop in force in the strain–stress diagram. An optical microscope was used to determine the fracture origins and evaluate the fracture modes, which were divided to repairable and irreparable. Fracture of the crown, fracture of the core material and fracture of the root up to 2 mm below cemento-enamel junction were considered repairable, while fracture of the root more than 2 mm below cemento-enamel junction, and the combination of post, core, crown and vertical root fracture were considered irreparable. The type of fracture was further confirmed by an X-ray radiograph.

Data for “X1” were analyzed within the frame of General Linear Models according to two factors model: factor “Group” with 3 levels (control, monolithic zirconia and metal ceramic crowns) and factor “Type of loading” with two levels (axial and oblique loading). Two-way ANOVA was used to test the main effect of factor “Group”, and “Angle”, as well as their interaction “Group×Angle”. Comparisons of mean X1 values were performed with the Least Significant Difference (LSD) criterion. A series of X2 tests was used for comparing repairable and irreparable fractures among the groups. The observed significance level (p-value) for the X2 tests was computed with the Pearson Chi-square test. These approaches lead to valid conclusions even in cases where the methodological assumptions of the X2 test are not fulfilled. The significance level in all hypothesis testing procedures was preset at α=0.05 (p≤0.05). All statistical analyses were accomplished with the SPSS v.15.0 software (SPSS, Chicago, IL, USA) enhanced with the module exact tests.

**RESULTS**

Descriptive statistics of fracture strength values are presented in Table 1. Test of between-subjects effects for factors “Group”, “Type of loading”, and the interaction between the two factors “Group * Type of loading” are presented in Table 2 and pairwise comparisons based on estimated marginal means in Tables 3, 4. In all groups higher values were recorded under axial compared with oblique loading (Table 1), however this difference was statistically significant only for MC and MZ crowns (Table 3). Endodontically treated premolars presented comparable values irrespective of the loading type. Statistically significant differences in fracture strength...
Table 1  Descriptive statistics of fracture strength values

| Group | Type of loading | Min  | Max   | Mean  | St. deviation |
|-------|----------------|------|-------|-------|---------------|
| ETP   | Axial (n=10)   | 47.96| 725.59| 224.36| 196.25        |
|       | Oblique (n=10) | 73.13| 210.16| 121.93| 42.04         |
| MZ    | Axial (n=10)   | 992.43| 2,118.24| 1,422.85| 344.11       |
|       | Oblique (n=10) | 307.02| 706.96| 441.04| 152.28        |
| MC    | Axial (n=10)   | 1,703.42| 3,112.91| 2,427.17| 497.96       |
|       | Oblique (n=10) | 370.08| 612.82| 474.20| 90.47         |

ETP: Endodontically treated premolars, MZ: Monolithic zirconia crown, MC: Metal ceramic crown

Table 2  Tests of between-subjects effects for factors “Group”, “Type of loading”, and the interaction between the two factors “Group * Type of loading”

| Source                  | Type III sum of squares | df | Mean square | F     | Sig. | Partial eta squared |
|-------------------------|-------------------------|----|-------------|-------|------|---------------------|
| Corrected model         | 40,456,054.9b           | 5  | 8,091,210.998 | 110.8 | 0.000 | 0.911               |
| Intercept               | 43,546,442.8            | 1  | 43,546,442.845 | 596.5 | 0.000 | 0.917               |
| Group                   | 16,513,379.4            | 2  | 8,256,689.700 | 113.1 | 0.000 | 0.807               |
| Type of loading         | 15,374,429.9            | 1  | 15,374,429.913 | 210.6 | 0.000 | 0.796               |
| Group*Type of loading   | 8,568,245.7             | 2  | 4,284,122.839 | 58.7  | 0.000 | 0.685               |
| Error                   | 3,942,315.8             | 54 | 73,005.847   |       |      |                     |
| Total                   | 87,944,813.6            | 60 |            |       |      |                     |
| Corrected total         | 44,398,370.7            | 59 |            |       |      |                     |

Table 3  Pairwise comparisons of fracture strength mean values (in N) between the groups of different type of loading

| Type of loading (Axial loading-oblique loading) | Mean difference | Sig*  | 95% confidence interval for differences |
|------------------------------------------------|-----------------|-------|----------------------------------------|
|                                                |                 |       | Lower bound | Upper bound |
| ETP                                            | 102.4           | <0.0001 | -1,440.8 | -956.2 |
| MZ                                             | 981.8*          | <0.0001 | -2,445.1 | -1,960.6 |
| MC                                             | 1,953*          | <0.0001 | 762.1     | 1,246.6 |

Based on estimated marginal means
* The mean difference is significant at the 0.05 level.
* Adjustment for multiple comparisons: Least significant difference (equivalent to no adjustments).
ETP: Endodontically treated premolars, MZ: Monolithic zirconia crown, M: Metal ceramic crown

were found among the three groups (C, MZ, MC) in the case of axial loading (Table 4) and in the case of oblique loading between endodontically treated premolars and both monolithic zirconia and metal ceramic groups (Table 4). Regardless of loading type, metal ceramic crowns presented higher fracture strength compared with the monolithic zirconia crowns; however this difference was statistically significant (p<0.000) only under axial loading (Table 4).

Under axial loading, almost all endodontically treated premolars presented abutment or root fracture less than 2 mm below cementoenamel junction (90%) while only one had an irreparable root fracture. In the monolithic zirconia group, the main complication was root fracture (50%) with most being non-repairable fractures (30%). Other types of complications were veneer chipping (40%), concurrent abutment and crown fracture (10%) and post or crown decementation (20%). In the metal ceramic crowns group, the main complication was also root fracture (50%), only in this group irreparable
Table 4  Pairwise comparisons of fracture strength mean values (in N) among the groups

| Type of loading | (I) Group | (J) Group | Mean difference (I–J) | Sig* | 95% confidence interval for differences |
|-----------------|-----------|-----------|-----------------------|------|----------------------------------------|
|                 | ETP       | MZ        | −1,198.5*             | <0.0001 | −1,440.750 − 956.230                      |
|                 | ETP       | MC        | −2,202.8*             | <0.0001 | −2,445.077 − 1,960.557                   |
|                 | MC        | MZ        | 1,004.3*              | <0.0001 | 762.067 − 1,246.587                      |
| Axial           | ETP       | MC        | −319.1*               | 0.011 | −561.371 − 76.850                       |
|                 | ETP       | MZ        | −352.3*               | 0.005 | −594.539 − 110.019                      |
|                 | MC        | MZ        | 33.2                  | 0.785 | −209.091 − 275.429                      |

Based on estimated marginal means
*The mean difference is significant at the 0.05 level.
Adjustment for multiple comparisons: Least significant difference (equivalent to no adjustments).
ETP: Endodontically treated premolars, MZ: Monolithic zirconia crown, MC: Metal ceramic crown

DISCUSSION

This study investigated the fracture strength and fracture mode of endodontically treated premolars, restored with either prefabricated metal posts and metal ceramic crowns, or glass-fiber posts and monolithic zirconia crowns, under axial and oblique forces. Statistically significant differences were recorded among groups regarding only fracture strength when axial loading was applied, thus the first null hypothesis was partially rejected, while no statistically significant differences were recorded for both fracture strength and fracture mode under oblique loading, thus the second null hypothesis was accepted.

Axial and oblique loading conditions on endodontically treated premolars were used in the present study in order to simulate the forces generated during physiological and parafunctional activities and applied to posterior teeth. In this study, root fractures incidences were similar between the metal ceramic and monolithic zirconia groups and in most cases were located more than 2 mm below cementoenamel junction, thus constituting non-repairable complications, irrespectively of the loading conditions. However, the lower amount of root fractures, the high amount of repairable fractures, as well as the high load to fracture

one crown (10%) decementation were also recorded. In the third group irreparable root fracture was recorded in 4 teeth (40%), one of which involved a fracture of the apical third. Three (30%) specimens showed a reversible root fracture. Chipping of the esthetic ceramic material (10%), abutment fracture (10%) and a concurrent abutment fracture with post decementation were also recorded (10%). Representative images are presented in Fig. 3. There were no statistically significant difference in the mode of fracture either between the two types of loading (Pearson chi-square=0.580), or among the groups (Pearson chi-square=0.474) or with their combinations (Pearson chi-square: ETP=0.582, MC=1, MZ=1).

Fig. 3  Pictures from optical microscope.
A: Fracture of monolithic zirconia crown (veneer), B: Fracture of metal ceramic crown (veneer), C: Endodontically treated premolars abutment fracture, D: Fracture of monolithic zirconia crown (complete fracture), E: Root fracture >2 mm below cementoenamel junction of a tooth with monolithic zirconia crown, F: Root fracture <2 mm below cementoenamel junction of a tooth with metal ceramic crown, G: Root fracture <2 mm below cementoenamel junction and post decementation of a tooth with monolithic zirconia crown, H: Root fracture of a tooth with metal ceramic crown

fractures were more frequent (40%). Repairable fractures were also observed in this group with 40% crown fracture, and 10% post or crown decementation. Veneer chipping was also observed at 40% of cases. Under oblique loading a high percentage of endodontically treated premolars presented abutment fracture (70%) while 30% had a root fracture greater than 2 mm below cementoenamel junction. In the metal ceramic crowns group an irreversible root fracture was observed in 4 cases (40%), and a reversible in another 4 (40%). One post (10%) and
were significantly higher in the groups of teeth loaded vertically, elucidating the disastrous effect of non-axial loading of teeth, that leads to stress concentration at the cervical region in vitro increasing the probability of root fracture. In agreement to the present study, Hayashi et al. reported no significant difference in fracture strength between the prefabricated stainless steel post core and fiber post groups under cast gold crowns of two-rooted maxillary premolars, and significantly lower fracture strength for both types under oblique loading. Similarly, Fokkinga et al. found no significant difference regarding the fracture strength between the two post types under oblique loading of single-rooted maxillary premolars restored with cast Cr-Co crowns, while also favorable fracture patterns were correlated to the teeth restored with glass-fiber posts. These findings agree with those of Habibzadeh et al. who used monolithic zirconia crowns and single-rooted premolars with either fiber glass or cast Ni-Cr metallic posts, and Forberger and Göhring who used lithium disilicate crowns and fiber glass or cast gold metallic crowns. Only one study, by applying a different configuration of non-axial loading, found lower flexural strength for glass-fiber posts compared to prefabricated titanium posts. The similar behavior of both post types under oblique loading can be explained by the adhesive cementation applied in all studies.

Root fracture was the primary fracture mode of teeth loaded with non-axial forces, with the crack being present on the buccal side, 3 mm below cementoenamel junction. Higher stresses are generated under oblique loading as the load generates bending moments. During oblique forces, stresses from the cervical margin of the crown are transmitted to the root and post-dentin interface, so tensile stresses are also transmitted to the cement layer. This leads to early loss of cementation, which then exerts uncontrolled stresses that cause root fracture. The concentration of these stresses on post-dentin interface and not on the crown-core interface, may further explain the law amount of the observed crown decementation in the present study.

On the other hand, similar or even higher flexural strength has been reported for glass-fiber posts and monolithic zirconia restorations under axial loading compared to metal posts and metal ceramic restorations, opposing the results of the present study. The results of these studies were explained through the modulus of elasticity of glass-fiber posts that resembles that of dentin, and make the posts bending along with the tooth under axial loading, which results in even loads transmitted throughout the root, avoiding root fracture. However many studies suggest exactly the opposite, and state that posts with a high modulus of elasticity enhance bending strength of teeth, while the low modulus of fiber posts makes teeth bending under lower occlusal loads and transferring the loads to the dental tissues, increasing the incidence of root fracture. The results of a systematic review, however, suggest that there is no statistically significant difference in fracture strength between metallic and non-metallic posts. The increased fracture strength under axial loading observed in the present study, may be attributed to the adhesive cementation of both metal post and metal ceramic crown, that due to the greater affinity of the involved materials’ modulus of elasticity, the whole complex behaves as a bonded tooth-post-core-crown “monobloc” restoration. Although adhesive cementation may have created the same “monobloc” in the case of glass-fiber posts and monolithic zirconia crown, the inherent lower strength and brittleness of zirconia, may have led to lower strength values. This is further confirmed by the complete zirconia crown fractures occurred under axial loading in the present study. The higher modulus of elasticity of prefabricated posts, which is even higher than that of dentin (15–25GPa), may have resulted to higher transmitted forces, leading to a slightly higher percentage of irreparable fractures under axial loading. It has been observed that the highest tensile stresses on dentin are observed with stiffer posts under axial loading, while when a less stiff post is applied less circumferential tensile stresses are exerted, minimizing the probability of root fracture. On the other hand, fracture strength of control endodontically treated teeth was significantly lower compared to crown restored teeth, independently of their type, an expected finding, as crown placement has been correlated to increased survival rates of endodontically treated teeth.

Occlusal loads in the premolar region vary between 220 and 540 N. From this perspective, the values recorded in the present study suggest that both treatment modalities are acceptable for endodontically treated premolars, although compared to other studies they are lower. This is attributed to the single root premolars used in the present study compared to double rooted premolars investigated in the study of Lin et al., who reported higher fracture strength. However, our values disregard this treatment option in patients with bruxism or purafunctional habits, where the occlusal loads can be up to six times higher.

In the present study, all teeth attained a circumferential ferrule which has been considered as one of the most important factors for the long term survival of post restored endodontically treated teeth. Contradictory results related to the presence, location and height of ferrule exist, due to variations in methodology, or even the presence of human teeth that present different physical and mechanical properties, pulp morphology and aging characteristics. Differences in elastic modulus of included materials (epoxy resin, posts, composite resins, crown materials and luting cements), make impossible the generalization of the results from different studies, and thus only differences elucidated from different post and core combinations within the same study should be taken into comparative evaluation. Thus, future research should include monolithic zirconia-restored teeth with varying amount of ferrule or remaining dentinal walls, to clarify in what extend fiber post insertion has a protective effect under a rigid monolithic zirconia crown.

In this study a tetragonal monolithic zirconia was
used for the fabrication of the ceramic crowns. However, current monolithic zirconia ceramics present great variety in composition and mechanical properties. As a consequence, the results of the present study should not be generalized to all monolithic zirconia formulations, as new translucent zirconia ceramics present lower strength values and their behavior under the experimental conditions of this study is expected to be significantly different. Furthermore, the use of other fiber posts, luting cements or other occlusal design of the metal ceramic restorations, would have provided different outcomes to the effect of the specific testing parameters on fracture strength. In this study, human teeth were used instead of metal or plastic to closer simulate clinical situation. Attention was paid to the selection of teeth with comparable sizes, to ensure standardization. However, differences in dental tissues’ properties that have been reported to vary according to age, pulp vitality before extraction, and the storing media, may have affected the fracture patterns. Another limitation of the present study was that crowns were tested without being aged in water or other simulated oral fluid and no cycling performance was performed, that could have a different impact on the materials strength. It is well known that tetragonal zirconia is prone to hydrothermal degradation that diminishes its mechanical properties at least in vitro, and thus different results could be observed due to phase transformations. In the present study ten specimens were constructed per subgroup which has been considered as adequate in many studies, however, larger sample size and thermal cycling should be included in future studies to clarify whether there is actually a vulnerability of zirconia materials after hydrothermal treatments in regards to fracture strength.

Under the limitations of the present study, the following conclusions can be drawn:

1. Crown placement significantly improved the fracture strength of endodontically treated premolars irrespectively of post and crown type.
2. The fracture strength of premolars restored with metal post and metal ceramic crowns was higher compared to premolars restored with glass-fiber posts and monolithic zirconia, under axial loading, but not under oblique forces.
3. Fracture mode did not present significant differences among the experimental groups, although differed depending on the applied loading mode, with the primary mode being root fracture for oblique loading.

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