Fracture resistance of endodontically treated teeth with different heights of crown ferrule restored with prefabricated carbon fiber post and composite resin core by intermittent loading

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This study evaluated the fracture resistance of endodontically treated teeth restored with prefabricated carbon fiber posts and varying quantities of coronal dentin. Sixty freshly extracted upper canines were randomly divided into groups of 10 teeth each. The specimens were exposed to 250,000 cycles in a controlled chewing simulator. All intact specimens were subjected to a static load (N) in a universal testing machine at 45 degrees to the long axis. Data were analyzed by 1-way analysis of variance and Tukey test ($\alpha = .05$). Significant differences ($P < .001$) were found among the mean fracture forces of the test groups (positive control, 0 mm,1 mm, 2 mm, 3 mm, and negative control groups: 1022.82 N, 1008.22 N, 1292.52 N, 1289.19 N, 1255.38 N, and 1582.11, respectively). These results suggested that the amount of coronal dentin did not significantly increase the fracture resistance of endodontically treated teeth restored with prefabricated carbon fiber post and composite resin core. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e52-e57)**

A persistent problem in clinical dentistry is associated with fractures occurring in endodontically treated teeth. This can be complicated because of the substantial loss of coronal tooth structure and the ability to predict restorative success.

Numerous restoration techniques for endodontically treated teeth have been advocated with criteria for success dependent upon variations in length, diameter, shape and surface configuration, quantity of dentinal structure, and materials and techniques used in reconstruction.[1-3]

Some authors have suggested that metallic posts have a much higher elastic modulus than the supporting dentin. This mismatch in the modulus could lead to stress concentration in the cement lute, leading to failure.[4] Recently, the carbon fiber post has been introduced as an alternative to more conventional materials. The biomechanical properties of these posts have been reported to be close to those of dentin.[5] Teeth restored with carbon fiber posts resist fracture propagation better than teeth restored with metallic posts.[6]

The likelihood of survival of a pulpless tooth is directly related to the quantity and quality of the remaining dental tissue.[7] A post is usually placed in an attempt to strengthen the tooth.[8-10] However, in vitro and in vivo studies have demonstrated that a post does not reinforce the endodontically treated teeth.[11-15]

A key element of tooth preparation when using a post and core is the incorporation of a ferrule.[16-19] The effectiveness of the ferrule has been evaluated by a variety of methods, including fracture testing,[17-19] impact testing,[20] fatigue testing,[21] and photoelastic analysis.[22] Several authors[14,23,24] have suggested that a tooth should have a minimum amount (~2 mm) of coronal structure above the cementoenamel junction (CEJ) to ensure a proper resistance form for a tooth. This coronal structure will provide a ferrule effect with the artificial crown that should prevent fracture of the root and fracture and dislodgement of the post.[14,17,18,25-31] Gegauff[17] evaluated the effect of crown ferrule on the fracture resistance of endodontically treated teeth and found that there was no significant difference between the amount of remaining coronal structure and fracture resistance. However, Pereira

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et al.[18] showed that increasing ferrule length significantly increased the fracture resistance of endodontically treated teeth. Although authors have different opinions about the ideal amount of remaining coronal structure, the results of fracture resistance on endodontically treated teeth restored by cast posts or prefabricated posts found in the literature were acceptable clinically, because they were considerably higher than the maximal physiologic forces acting on the teeth in the oral cavity.[32]

The purpose of the present study was to compare the fracture resistance of endodontically treated teeth using different amounts of coronal tooth structures available for crown treatment while the remaining tooth structure was restored with prefabricated carbon fiber posts and complete metal crowns. The null hypothesis was that there was no significant difference on the effect of remaining coronal structures on fracture resistance.

MATERIALS AND METHODS

Sixty sound maxillary canines (from 73 canines) of comparable root lengths (between 16 mm and 18 mm measured with a millimeter ruler from the apex to the CEJ) were selected for this study. Each tooth was examined under a microscope to ensure the absence of carious lesions, cracks, and microfractures. Selected teeth were stored in distilled water at 37°C throughout the experiment.

The endodontic treatment was done using a standard master apical file #20 (Dentsply Maillefer, Ballaigues, Switzerland) to1 mm before the apex. Conventional step-back technique to file #35 (Dentsply Maillefer) was used. After intermittent rinsing with 2.5% sodium hypochlorite solution (Asfer Industrial Química, São Paulo, Brazil), the canals were dried with paper points (Tanari; Tanariman Industrial, Macaçaruru, Brazil). The roots were obturated with gutta-percha (Tanari) and Sealer 26 eugenol-free sealer (Dentsply Petrópolis, Rio de Janeiro, Brazil). An ISO 35 primary gutta-percha master cone was coated with sealer and seated in the canal to full working length. Lateral condensation with a finger spreader (Dentsply Maillefer) and fine gutta-percha points (Tanari) was performed until the entire canal was obturated. Teeth were inspected for cracks after the endodontic treatment using a ×4 binocular loup (Bio-Art Equipamentos Odontológicos, São Carlos, Brazil).

After endodontic treatment, 2 mm of natural root structure was exposed and thinly covered (approximately 60 μm) with a silicone impression material (Aquasil; Dentsply, Konstanz, Germany) to simulate a periodontal ligament.[28] All specimens were embedded in acrylic resin (Clássico; Artigos Odontológicos, São Paulo, Brazil) poured into molds made of the same material (30 mm high, 22 mm in diameter, with an internal opening, located in the center of the mold, with a diameter of 10 mm and a height of 20 mm). The teeth were embedded along their long axes using a surveyor (Bio Art Equipamentos Odontológicos).

The teeth were randomly divided into 6 groups of 10 teeth each by drawing lots. The positive control group was composed of teeth with custom-cast post-and-core without coronal structure (no ferrule). The CP0 group was composed of teeth with a carbon fiber post without coronal structures (no ferrule); CP1, CP2, and CP3 groups were composed of teeth with a carbon fiber post with 1 mm, 2 mm, and 3 mm of remaining coronal tooth structure (1-, 2-, and 3-mm ferrule), respectively. The negative control group was composed of teeth without post and no ferrule.

For the positive control and CP0 groups, the coronal aspect of the teeth was removed at the CEJ perpendicular to the long axis of the tooth. For the CP1, CP2, CP3, and negative control groups, the coronal tooth structure was reduced to a flat plane at a height of 1.0 mm, 2.0 mm, 3.0 mm, and 6.0 mm incisal to the CEJ circumferentially, respectively. The coronal diameter of the root was standardized at 1.5 mm for all dentin walls.

Post preparations were made with a #5 reamer (Largo; Dentsply Maillefer) to remove 12 mm of gutta-percha apical to the CEJ from each filled canal in all groups, except the negative control group which did not receive post preparation.

In the positive control group, the canal of each tooth was restored with a custom-cast post-and-core with the same size and shape as the prefabricated carbon fiber posts. The cores were standardized using a core-forming matrix (TDV Dental, Pomerode, Brazil). The combined core/ferrule height for the groups was 6 mm. A direct technique was used to fabricate the post-and-core patterns in acrylic resin (Duralay; Reliance Dental Mfg. Co., Chicago, IL). A copper-aluminum alloy (NPG, AalbaDent, Cordelio, CA) was used to cast the post-and-core patterns. The patterns were invested (Cristobalite; Whip-Mix Corporation, Louisville, KY) and cast.

The teeth in the CP0, CP1, CP2, and CP3 groups were prepared and restored with prefabricated carbon fiber posts (20 mm in length), parallel-sided (17 mm in length and 1.5 mm in wide) with a tapered end (3 mm in length and 1.1 mm in wide) (Reforpost, Ângelus; Odonto-LógiKa, Londrina, Brasil). All test specimens were cemented with dual-polymerizing adhesive resin luting agent (Rely X ARC; 3M Dental Products Division, St. Paul, MN). The cement mix was prepared according to the manufacturer's instructions. Cement was placed on the post and seated under 5 kg of pressure for 10 min. Excess cement was removed. Then the dentin was etched with 37% phosphoric acid for 30 s and rinsed with water for 30 s. A bonding agent (Scotchbond Multipurpose Plus; 3M Dental Products Division) was placed on the dentin walls and photopolymerizated with a curing light (Ultraled; Dabi Atlante, Ribeirão Preto, Brazil) (110 W) used at a 450 MW/cm^2 light intensity for 20 s. The composite resin cores were standardized using the same core-forming matrix (TDV Dental) used in the control group with a composite resin material (Z100; 3M Dental Products Division). The composite resin was placed using the incremental technique. Each layer had approximately 1.5 mm of thickness (measure obtained with periodontal probe) and was polymerized for 40 s until the coronal core was complete. The same curing light (Ultraled) was used to photopolymerize the composite resin. The tip of the curing light was located 2 cm from the specimens on top of the core. Each specimen was then returned to storage in distilled water.

Each tooth was prepared with the use of a high-speed handpiece with water spray (Super Torque 625 Autofix; Kavo do Brasil, Joinville, Brazil) and diamond rotary cutting instruments (KG Sorensen, Barueri, Brazil) to achieve a complete metal crown. A #3216 bur was used to prepare the facial and lingual surfaces with uniform reduction. The 1.5 mm chamfer facial line and 0.5 mm chamfer lingual line was prepared at the level of the CEJ. The incisor-gingival dimension was 6 mm for all preparations. The dimensions of the prepared cores were confirmed with a measuring microscope with ×30 magnification and precision of 5 μm (Mitutoyo Co., Tokyo, Japan). An impression was made using vinyl polysiloxane impression material (Aquasil) of the tooth before preparation and used to fabricate the wax pattern. The wax (Kerr Corporation, CA,) was then poured into the impression, the tooth was inserted, the wax was cooled, the impression was removed and the margins were perfected. The wax patterns were sprued, invested (Cristobalite), and cast in a nickel-chromium alloy (Durabond, São Paulo, Brazil). Crowns were luted to the teeth with a dual-polymerizing adhesive resin luting agent (Rely X ARC), according to the manufacturer's instructions.

All specimens were exposed to 250,000 cycles of mechanical fatigue in a controlled chewing simulator (Fig. 1). The force was applied 3 mm below the incisal edge on the palatal surface of the crowns at a frequency of 2.6 Hz. A force of 30 N was chosen. The mechanical loading pattern was equivalent to 1 year of clinical function.[33] The force of 30 N was within previously measured occlusal forces that can occur during mastication and swallowing with restored dentitions.[34] The number of specimens that remained intact (with no fractures, cracks, or microfractures as analyzed with a ×4 binocular loupe [Bio Art Equipamentos Odontológicos]) after fatigue loading was recorded and expressed as survival in percentages.

Fig. 1. Mechanical fatigue in a controlled chewing simulator.

Each intact specimen was positioned in the mounting device and aligned at a 45-degree angle with respect to the long axis of the tooth. A universal testing machine (Kratus K2000 MP; Dinamometros Kratos, São Paulo, Brazil) was used to apply a constant load at a crosshead speed of 0.5 mm/min until failure occurred (Fig. 2). The load was measured in newtons. Failure was defined as the point at which the loading force reached a maximum value by either fracturing the root or core, bending the post, or debonding the cement. After loading, the mode of failure (composite resin core, root, and/or coronal structure and composite resin core) was observed and analyzed with a ×4 binocular loupe (Bio Art Equipamentos Odontológicos).

All data were analyzed statistically with 1-way analysis of variance (ANOVA) to compare the mean loads of the groups, and a Tukey post hoc test was performed to establish which groups were statistically different from the others at alpha equal to .05.

RESULTS

All specimens survived the 250,000 cycles of intermittent loading.

The results of the mean failure load values and standard deviation for the 6 groups are showed in Table

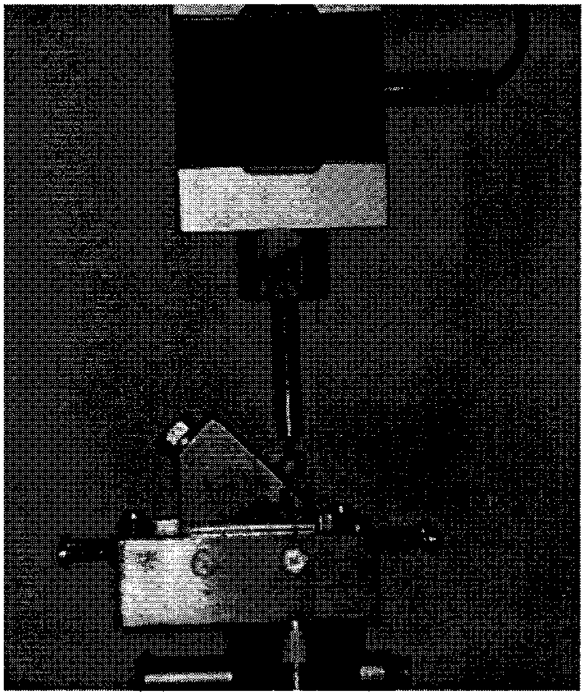

Fig. 2. Static load in a universal testing machine.

Table I. Resistance to failure values of the test specimens

Group	*Mean*	*SD*
Positive control	1,022.88[a]	278.32[a]
CP0	1,008.22[ab]	381.41[ab]
CP1	1,252.92[abc]	444.52[abc]
CP2	1,289.19[abc]	438.25[abc]
CP3	1,255.38[abc]	418.85[abc]
Negative control	1,582.11[c]	523.61[c]

Groups with the same superscripted letters are not significantly different, using the Tukey comparison, at $P < .05$.

Table II. Types of failure, number (%) of teeth

	Location of failure		
Group	*Composite resin core*	*Root*	*Coronal structure and composite resin core*
Positive control	—	10 (100%)	—
CP0	10 (100%)	—	—
CP1	5 (50%)	—	5 (50%)
CP2	4 (40%)	—	6 (40%)
CP3	—	—	10 (60%)
Negative control	—	—	10 (100%)
Total	19 (31.6%)	10 (16.6%)	31 (51.8%)

I. One-way ANOVA indicated that there was a statistically significant difference among the groups ($P < .04$). Further analysis with the Tukey test indicated that the negative control group fracture resistance was significantly greater than the positive control and CP0 groups (Table I).

Differences regarding the mode of failure among the groups were observed and analyzed as described in Table II.

DISCUSSION

The present study supported the null hypothesis, which was that there is not a significant difference in the effect of remaining coronal structures on the fracture resistance of endodonticaly treated teeth restored with prefabricated carbon fiber posts subjected to intermittent loading.

The results of the investigation showed that none of the specimens failed during the intermittent loading test, because the differences in the elastic moduli of carbon fiber post and dentin are minimal.[5] Isidor et al.[21] suggested that a post should have the same modulus of elasticity as root dentin to distribute forces along the length of the post.

The positive control group preserved the root structure as much as possible, and the negative control group retained the maximum quantity of coronal structure to distribute the loading, and this may explain why both groups survived the intermittent loading test.[14,17,18,25-31]

After static loading, the present study showed that increasing ferrule length did not significantly increase the fracture resistance of endodontically treated teeth in all groups. This could be explained because of the minimal differences in the elastic moduli of carbon fiber post and dentin, such that the forces could be distributed along the length of the post similarly for all groups restored with carbon fiber post and composite resin core independently from ferrule height.[5,21] However, the presence of, at least, 1 mm of coronal structure increased the fracture resistance of the tooth in 24.5% of the study subjects. This, in combination with a study by Zhi-Yue and Yu-Xing,[30] supports the idea that the loss of structural integrity associated with access preparation may lead to a higher occurrence of fractures in endodontically treated teeth. The findings of the present study are in agreement with Sorensen and Engelman,[14] who found that 1 mm of remaining coronal tooth structure was able to resist compressive load. Yet, in another study, Sorensen and Martinoff[13] showed that 1.0 mm of remaining coronal tooth structure nearly doubled the fracture resistance of the endodontically treated teeth. Pereira et al.[18] and others[1,6,20,22,27] concur that fracture resistance was highest in specimens with the longest ferrules.

When the ferrule was not present, the fracture resistance of the teeth restored with cast post-and-core (positive control group: 1022.88 N) was not significantly different than those restored with prefabricated carbon fiber posts (CP0: 1008.22 N). This may suggest that the strength of the tooth was directly related to the remaining bulk of dentin and is more important than the type of material that the core and post are made from.[11-15]

However, it is important to note that the forces responsible for failure in the present study were considerably higher than the maximal physiologic forces acting on the teeth intraorally.[32] Lyons and Baxendale[32] observed that the mean force applied on an upper canine was 215 N. In the presence of parafunctional loading, those authors noted that the force increased to 254.8 N and that the maximum forces were between 343 and 362.6 N.

The most common cause of failure when using the direct technique (prefabricated carbon fiber post) is fracture of the restorative material or the coronal structure. When the cast post-and-core was used, the most common failure was root fracture,[16,18] as observed in the present study.

Despite its lower resistance, the technique using prefabricated posts and composite resin with or without remaining coronal structure or composite resin with remaining coronal structure may be appropriate, because no root fractures were detected. Therefore, the direct method appears to protect the tooth structure.[16,18]

The limitations of the present study include the fact that it was an in vitro investigation, which could not fully replicate oral conditions. For more clinically relevant results, in vivo studies should be performed.

CONCLUSIONS

Within the limits of this study, the following conclusions were drawn:

1. The presence of ferrule effect did not significantly ($P < .05$) increase the fracture resistance of endodontically treated teeth for all groups.
2. When the ferrule was not present, the fracture resistance of the teeth restored with cast post-and-core was not significantly ($P < .05$) different from those restored with prefabricated carbon fiber posts.
3. The negative control group was significantly more resistant than the positive control and CP0 groups.
4. The groups restored with the prefabricated post–and–composite resin core showed coronal structure or composite resin core failure before root fracture occurred. In contrast, the cast post-and-core specimens typically showed root fracture.

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