Influence of Ferrule, Post System, and Length on Biomechanical Behavior of Endodontically Treated Anterior Teeth

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Abstract

Introduction: The aim of this study was to evaluate the influence of post system, length, and ferrule on biomechanical behavior of endodontically treated anterior teeth. **Methods:** The investigation was conducted by using laboratory tests and 3-dimensional finite element analysis. Eighty bovine incisors were selected and divided into 8 treatment groups ($n = 10$) with absence of ferrule and 2.0 mm of ferrule, restored with glass fiber post or cast post and core, and 12.0 and 7.0 mm of post length. The specimens were loaded at 135° angle, and the strain was measured by using strain gauge method. Specimens were subsequently loaded until fracture. Strain and fracture resistance results were analyzed by 3-way analysis of variance and Tukey honestly significant difference tests ($\alpha = 0.05$). Three-dimensional models of a maxillary central incisor were generated with the same treatment variations used in laboratory tests. Each model was subjected to 100 N oblique loads. Results were evaluated by von Mises criterion. **Results:** Ferrule was a determining factor in the strain, fracture resistance, and fracture pattern. In the absence of ferrule, the use of fiberglass posts represents a conservative choice from the standpoint of the fracture patterns observed. The length of 7 mm for cast post and cores produced high rates of root fractures. Finite element analysis showed that glass fiber post showed homogeneous stress distribution, whereas cast post showed stress concentration into root canal. **Conclusions:** Post length influenced only the cast post strain and stress distribution. The ferrule groups always showed more satisfactory stress distribution and fracture resistance. *(J Endod 2014;40:119–123)*

Key Words

Endodontically treated teeth, fracture resistance, glass fiber posts, strain-gauge, stress distribution

Endodontically treated anterior teeth are extensively affected by biomechanical failure that is due to caries, endodontic access, and alterations of mechanical, chemical, and physical properties (1–4). Consequently, they may require a post for root rehabilitation (5). Cast metal posts have a high elastic modulus and have been used for several decades in restorative dentistry for restoring them (5, 6). Glass fiber posts showed similar properties to root dentin and are a successful alternative to metal posts (7–9).

The root-filled teeth rehabilitation is related to several factors such as amount and location of dentin walls (8, 10), post system, post cementation length (11), presence of the ferrule (12–14), and final restoration (4, 8). Studies demonstrated that anterior teeth are subject to higher risks of failure (8). Within this context, the choice of inadequate restorative option can cause vertical root fractures (15), leading to tooth extraction. Two hypotheses were tested:

1. Post system and ferrule presence influence the strain, stress distribution, fracture resistance, and fracture mode of root-filled teeth.
2. Shorter post lengths increase the root strain and decrease the fracture resistance of root-filled teeth.

Materials and Methods

Eighty bovine incisors with similar size and shape and absence of cracks were selected by measuring the buccolingual and mesiodistal widths in millimeters, allowing a maximum deviation of 10% from the average (11). The teeth were stored in distilled water and 0.2% thymol (Pharmacia Biopharma Ltda, Uberlândia, Brazil) solution at 37°C. The anatomic crowns of all teeth were sectioned perpendicularly to the long axis by using a water-cooled diamond disk (no. 7010; KG Sorensen, Barueri, SP, Brazil) up to 15.0 mm coronally to the apical limit for the specimens with 2 mm ferrule (F) ($n = 40$) and 13.0 mm from the apical limit for the specimens with absence of ferrule (AF) ($n = 40$).

Root canals were instrumented to the full extension by using no. 2 and 3 Gates Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland), and a no. 4 Gates Glidden drill was used only in the cervical third of the root canal. The canals were rinsed with 1% sodium hypochlorite solution (Asfer; Industrial Química, São Paulo, SP, Brazil). Each canal was filled by using gutta-percha points (Dentsply Maillefer) and calcium hydroxide–based cement (Sealer 26; Dentsply, Petrópolis, RJ, Brazil). Each root was embedded in a polystyrene resin (Cristal; Piracicaba, São Paulo, Brazil) cylinder 2 mm below the cervical limit, and the periodontal ligament was simulated by using a

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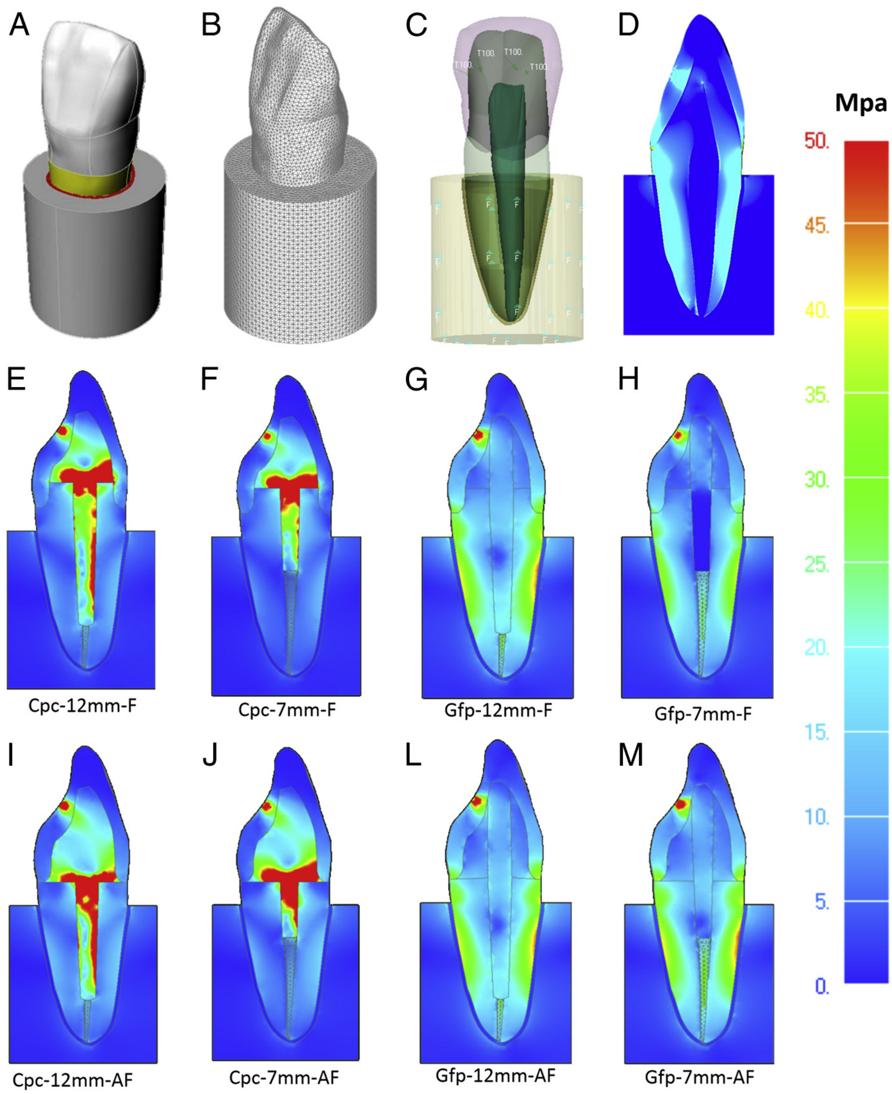

Figure 1. Generation of 3-dimensional finite element models. (*A*) Bio-CAD model of sound incisor, (*B*) finite element mesh, (*C*) load and boundary conditions, and (*D*) stress distribution by von Mises criteria of sound incisor. Stress distribution by von Mises criteria of experimental models: (*E*) model Cpc-12 mm-F, (*F*) model Cpc-7 mm-F, (*G*) model Gfp-12 mm-F, (*H*) Gfp-7 mm-F, (I) Cpc-12 mm-AF, (*J*) Cpc-7 mm-AF, (*L*) Gfp-12 mm-AF, and (*M*) Gfp-7 mm-AF.

polyether impression material (Impregum Soft; 3M ESPE, St Paul, MN) (16). Groups F and AF were divided randomly into 2 subgroups of 20 specimens each for treatment with glass fiber posts (Gfp), and cast post and cores (Cpc). Finally, each of the subgroups was further divided into 2 additional subgroups (n = 10) with designated post lengths of either 7.0 or 12.0 mm.

Post spaces were made with heated pluggers to remove the gutta-percha to either 7.0 or 12.0 mm. Post preparations were completed to these same lengths by using a conical drill supplied in the post system (Whitepost DC no. 3; FGM, Joinville, SC, Brazil). Prefabricated polycarbonate patterns (Nucleojet; Angelus, Londrina, PR, Brazil) were used to standardize the coronal portion. The patterns were aligned by using autopolymerizing acrylic resin (Duralay; Reliance Dental Mfg Co, Aslip, IL) in the post space. A Ni-Cr alloy (FIT CAST-SB Plus; Curitiba, PR, Brazil) was used to cast the post and core patterns. The glass fiber posts (White Post DC no. 3; FGM) were treated with a silane coupling agent (Prosil; FGM) for 60 seconds. The post space was cleaned with 0.5% sodium hypochlorite, rinsed for 10 seconds with water spray, and dried with paper points (Dentsply Maillefer). Self-adhesive resin cement (RelyX Unicem; 3M ESPE) was manipulated according to manufacturer's instructions and used for cementation. Each incisal, vestibular, and palatine surface was light polymerized for 40 seconds with a LED polymerization unit (Radii-Cal; SDI, Victoria, Australia). The composite resin cores of the glass fiber post groups were made by the incremental technique (11).

All specimens were prepared with a tapered rounded-end diamond rotary cutting instrument (no. 4138; KG Sorensen) in a high-speed handpiece with air-water spray (ExtraTorque 605C; Kavo do Brasil Ind Com Ltd, Joinville, SC, Brazil). Teeth were prepared with 1.5 mm of axial reduction and 6° of axial convergence, and the cervicoincisal height remained at 8.0 mm for all specimens. An impression of the specimens was made by using polyether impression material (Impregum Soft; 3M ESPE). Then the impressions were poured with type IV stone (Durone IV; Dentsply). All specimens were restored with Ni-Cr cast metal crowns.

Strain Gauge Test

Five specimens of each subgroup were selected for the strain gauge measurements. Two strain gauges (PA-06-040AB-120LEN; Excel Sensores, São Paulo, SP, Brazil) were attached in specimens. One gauge

TABLE 1. Mean Strain Values (μS) (standard deviation) and Ranking of Tukey Honestly Significant Difference Tests (n = 5)

	12 mm		7 mm	
Groups	AF	F	AF	F
Buccal				
Cpc	619 (189) Ba	149 (71) Aa	130 (53) Aa	295 (134) Aa
Gfp	666 (231) Ba	398 (138) ABa	639 (252) Bb	319 (144) Aa
Proximal				
Cpc	153 (30) Aa	179 (106) ABa	359 (20) BCb	547 (181) Cb
Gfp	135 (81) Aba	294 (140) Ba	108 (68) ABa	88 (20) Aa

Different uppercase letters indicate significant differences in rows; different lowercase letters indicate significant differences in columns; Tukey honestly significant difference test (P < .05).

was placed at the buccal surface, parallel to the long axis, and the other at the proximal surface in a transverse direction; both were placed 1.0 mm below the cervical limit of the root. Each specimen was placed in a custom apparatus that allowed the wedge-shaped tip to be positioned at 135° to the long axis of the specimen. The specimens were subjected to a nondestructive ramp-load from 0 to 100 N at this orientation and a crosshead speed of 0.5 mm/min by using a mechanical testing machine (EMIC DL2000; São José dos Pinhais, PR, Brazil), and strain was recorded.

Fracture Resistance and Fracture Pattern

The specimens were subject to 135° oblique compressive load at a 0.5 mm/min crosshead speed in a mechanical testing machine (EMIC DL2000). The force required to fracture a specimen was recorded. Fracture resistance data were analyzed by 3-way analysis of variance, followed by Tukey honestly significant difference test (α = 0.05). The fractured specimens were evaluated to determine the fracture patterns by using a classification system proposed by Santos-Filho et al (11):

I = Post or core fracture
II = Root fracture in the cervical third
III = Root fracture in middle third
IV = Root fracture in the apical third
V = Vertical root fracture

3-dimensional Finite Element Method

Nine 3-dimensional finite element models were created, representing each experimental group and a sound tooth. The models were constructed from a contact scanning of a maxillary central incisor. The *.STL files generated were imported to CAD software (Computer Assisted Design, Rhinoceros 3D 4.0; McNeel North America, Seattle, WA). On the basis of this file, non-uniform rational Bazier spline surfaces and solids were created by using Bio-CAD techniques (Fig. 1*A*). The models were exported in STEP files CAE software (Computer Assisted Engineering, Femap 10.1; Velocity Series, Siemens PLM Software, Plano, TX), and meshing of each structure was performed by using solid quadratic tetrahedral elements of 10 nodes (Fig. 1*B*). A total load of 100 N was applied at 135° angle, with the longitudinal tooth and a nodal displacement constraint applied at the bottom and lateral surfaces of the support cylinder (Fig. 1*C*). A linear structural analysis was performed, and all materials were considered linear, isotropic, and homogeneous except for the orthotropic glass fiber post. Applied mechanical properties, elastic modulus (MPa), and Poisson ratio were the following: enamel: 84.1 × 10^3/0.33 (17); dentin: 18.0 × 10^3/0.31 (18); pulp: 0.02 × 10^3/0.45 (19); polyether: 50/0.45 (20); polystyrene resin: 13.5 × 10^3/0.31(20); composite resin: 15.8 × 10^3/0.24 (21); Ni-Cr alloy: 205 × 10^3/0.33 (22); glass fiber post (23): EX: 37,000, EY: 9500, EZ: 9500; ηXY: 0.34, ηYZ: 0.27, ηXZ: 0.34; Gxy: 3544.8, Gxz: 1456.7, Gxz:3544.8, respectively (E = elastic modulus; = Poisson ratio; G = shear modulus; x, y, z = specific orthogonal plane directions). Models were then exported to the FE processing software (NEi Nastran 9.2; Noran Engineering, Westminster, CA), and the solution of each model was run. Von Mises equivalent stresses were determined for stress assessment.

Results

Buccal and proximal root strain (means and standard deviations) are summarized in Table 1. Letters identify statistically different groups (P < .05). The decrease of post length produced high strain values for Cpc groups on the proximal surface. The Gfp strain values were similar for both lengths. Groups restored with glass fiber post showed higher strain values on the labial surface for all samples without ferrule.

The analysis of the stress distribution was conducted by von Mises criteria. The finite element analysis showed that the groups with cast post and cores showed elevated stress levels in the ferrule (Fig. 1*E*) and post dentin interface (Fig. 1*E*, *F*, and *I*). On the other hand, the Gfp (Fig. 1*G*, *H*, *L*, and *M*) distributed stresses to the external surface, similar to the untreated tooth (Fig. 1*D*). Reduction in post length only influenced stress distribution for the Cpc, with higher stress concentrated in a smaller area of the canal (Fig. 1*F* and *J*). Gfp stresses were distributed similarly for both post lengths.

The results of the fracture resistance tests (means and standard deviation) are summarized in Table 2. Letters identify statistically different groups (P < .05). The fracture resistance of the ferrule groups (F) was significantly higher than AF groups. Post length was not influenced by the fracture resistance values regardless of post system. The fracture pattern is shown in Figure 2. Gfp groups produced fractures

TABLE 2. Mean Fracture Resistance Values (N) (Standard Deviation) and Ranking of Tukey Honestly Significant Difference Tests (n = 10)

	12 mm		7 mm	
Groups	AF	F	AF	F
Cpc	724 (82) Ba	1026 (240) Aa	668 (133) Ba	909 (67) Aa
Gfp	607 (64) Ba	918 (112) Aa	682 (89) Ba	913 (145) Aa

Different uppercase letters indicate significant differences in rows; different lowercase letters indicate significant differences in vertical columns; Tukey Honestly Significant Difference test (P < .05).

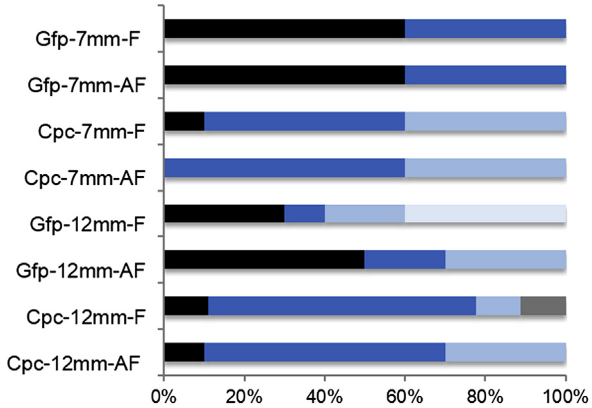

Figure 2. Resulting failure types found in fracture resistance tests.

involving the core and coronal third of the root. Cpc samples showed a high incidence of catastrophic failures with the reduced post length, whereas the Gfp exhibited fewer irreparable failures. Ferrule groups had fractures involving the coronal and middle third of the root. On the other hand, group AF had fractures involving the core and coronal third of the root predominate.

Discussion

The first hypothesis was accepted; the post system had an influence on strain, stress distribution, fracture resistance, and failure mode. The second hypothesis was partially accepted; decreased post length increased the root strain but did not influence the fracture resistance of the root-filled teeth.

In the biomechanical analysis in dentistry, destructive mechanical tests used to determine fracture resistance are important means of analyzing the tooth biomechanical behavior (20). However, they do present limitations when obtaining information on the internal behavior of the tooth-restoration complex. Therefore, it is important to associate destructive tests with nondestructive methodologies such as strain gauge test and finite element analysis and its relation with fracture resistance and fracture mode (12, 18, 24).

According to the results of this study, there was a definite correlation between post length and the root fractures. Although there was no statistical difference in the values of fracture resistance, reduced post length caused high rates of strain on the proximal surface of the Cpc groups, contributing to increased fractures in the middle third (Fig. 2). The finite element analysis also showed that post length reduction increased levels of stress (25) in a lower surface of the root dentin, increasing the likelihood of failure of that region (15, 26). On the other hand, the use of fiber glass posts, irrespective of cementation length, produces low strain values on the proximal surface. Assuming the same factor, finite element analysis showed similar stress patterns for models (Fig. 1*H* and *M*) compared with sound incisor (Fig. 1*D*).

The strain on the proximal surface also evidences the influence of the ferrule on biomechanical behavior of root-filled teeth. There are 2 major changes in strain at the root dentin associated with the presence of ferrule: a decrease in the compressive stress on dentin cervical levels below the compressive strength of dentin and increase of tensile stress in the palatal cervical dentin to a value near the tensile strength of dentin (13). This fact explains the higher strain values at the proximal surface in the groups that had lower fracture resistance. In addition, ferrule presence associated to the use of materials with mechanical properties closer to dentin contributes to better stress distribution and fracture resistance (27).

The results of the present study demonstrated that the ferrule presence increases the fracture resistance for endodontically treated teeth regardless of the post system. Several studies also reported these findings (13, 14, 28–35). The finite element analysis and laboratory test results of the F/Gfp groups showed better biomechanical behavior than cast post and core groups because of their unfavorable failure modes (36), which was demonstrated by their distribution (Fig. 2). In this situation, the Cpc groups showed higher percentage of unfavorable failures because of the high stress concentrations within the root canal being transferred to the origin of the crack (15, 26). Furthermore, the high stress concentration can lead to microgaps in the cement-dentin interface or cement-post interface, resulting in bacterial colonization and periapical lesions. This is in accordance with the study by Sterzenbach et al (37). Thus, the use of glass fiber posts can be justified because the low elastic modulus decreases the risk of adhesive failures because of the low stress values at the post/cement interface, and teeth restored with glass fiber posts are less likely to fail because the risks of fracture in the composite core and post are higher than in the root (9, 38).

Within the limitations of this study, it was concluded that the presence of ferrule is a determining factor on the strain, stress distribution, fracture resistance, and failure mode. In the absence of ferrule, the use of fiberglass post represents a conservative choice because of the non-catastrophic fracture patterns observed. When a cast post and core are used, the post should be as long as possible, whereas the biomechanical performance of a glass fiber post was less sensitive to post length.

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The authors deny any conflicts of interest related to this study.

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