Flexural modulus, flexural strength, and stiffness of fiber-reinforced posts

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ABSTRACT

Background: The radiopacity degree of posts is not enough for adequate visualization during radiographic analyses. Glass fiber post with stainless steel reinforcement has been fabricated in an attempt to overcome this limitation.
Aim: This study was designed to determine the influence of this metal reinforcement on the post mechanical properties.
Materials and Methods: This study evaluated flexural modulus (E), flexural strength (σ), and stiffness (S) of five different fiber post systems (n = 5): RfX (Reforpost Glass Fiber RX; Ângelus, Londrina, PR, Brazil); RG (Reforpost Glass Fiber, Ângelus); RC (Reforpost Carbon Fiber, Ângelus); FP (Fibrekor Post; Jeneric Pentron Inc., Wallingford, CT, USA); and CP (C-Post; Bisco Dental Products, Schaumburg, IL, USA), testing the hypothesis that the insertion of a metal reinforcement (RfX) jeopardizes the mechanical properties of a glass fiber post. Posts were loaded in three-point bending using a testing machine with a crosshead speed of 0.5 mm/min.
Results: The results were statistically analyzed using one-way ANOVA and Tukey's multiple range tests (α = 0.05). Mean and standard deviation values of E (GPa), σ (MPa), and S (N/mm) were as follows: RfX: 10.8 ± 1.6, 598.0 ± 52.0, 132.0 ± 21.9; RG: 10.6 ± 1.0, 562.0 ± 24.9, 137.8 ± 5.5; RC: 15.9 ± 2.4, 680.5 ± 34.8, 190.9 ± 12.9; FP: 10.9 ± 1.4, 586.8 ± 21.9, 122.4 ± 17.3; CP: 6.3 ± 1.7, 678.1 ± 54.2, 246.0 ± 41.7. Carbon fiber posts showed the highest mean σ values ($P < 0.05$). In addition, RC showed the highest mean E value and CP showed the highest mean S value ($P < 0.05$).
Conclusion: The hypothesis was rejected since the metal reinforcement in the glass fiber post (RfX) does not decrease the mechanical property values. Posts reinforced with carbon fibers have a higher flexural strength than glass fiber posts, although all posts showed similar mechanical property values with dentin.

Key words: Endodontic posts, flexural modulus, flexural strength, stiffness

Endodontic treatment of teeth often results in a loss of dental structure. The remaining dental tissue usually requires additional support from a root post to provide retention and stability for direct or indirect restorations.[1-3] The restorative procedure of endodontically treated teeth with metal-free and physiochemically homogeneous materials that have mechanical properties similar to properties of dentin has become a major objective in dentistry.[4] Materials such as metal, carbon, quartz, glass fiber, and other types of ceramics are used in prefabricated posts.[5-7] Metal and zirconia posts can resist to lateral forces without distortion, producing areas of stress concentration in dentin, which is a potential risk for root cracking and fracture.[8] Posts with Young's modulus more similar to dentin, that is about 18 GPa,[9] are desirable because of a more homogeneous stress distribution, reducing the risk of fracture.[10] Laboratory studies have shown that carbon and glass fiber posts have elastic modulus (about 20 GPa) similar to dentin.[8,11-13]

Fiber-reinforced post systems contain a high volume percentage of continuous fibers embedded in polymer matrixes, which are commonly epoxy polymers that keep the fibers together.[14] Carbon fiber posts are manufactured from continuous and unidirectional carbon fibers in an epoxy resin matrix.[15] Glass fiber posts can be made up of different types of glass, such as E-glass (electrical glass), in which the amorphous phase is a mixture of SiO_2, CaO, B_2O_3, Al_2O_3, and some other oxides of alkali metals, and S-glass (high-strength glass), which is also amorphous, but differs in composition. Additionally, glass fiber posts can also be made up of quartz fiber, which is pure silica in a crystallized form[16] and provide better esthetic results.[4]

Commonly, the degree of radiopacity of these posts is not enough for adequate visualization during radiographic analyses.[17] Thus, an experimental glass fiber post with

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stainless steel reinforcement (0.2 mm in diameter) has been fabricated in an attempt to overcome this limitation. However, there is no study reporting the influence of this metal reinforcement on the post mechanical properties. Therefore, the aim of this study was to evaluate the flexural modulus, the flexural strength, and the stiffness of five fiber post systems, testing the hypothesis that the insertion of a metal reinforcement jeopardizes the mechanical properties of a glass fiber post.

MATERIALS AND METHODS

Five fiber post systems were used in this study ($n = 5$), and are presented in Table 1 and Figure 1. The glass fiber posts RfX and RG are purported by the manufacturer to contain 57% unidirectional glass fiber and 43% epoxy resin, and RC is purported to contain 62% unidirectional carbon fiber and 38% epoxy resin. FP has a bis-GMA resin matrix and unidirectional glass fiber. CP is composed of 64% carbon fiber and bound in parallel formation in an epoxy matrix.

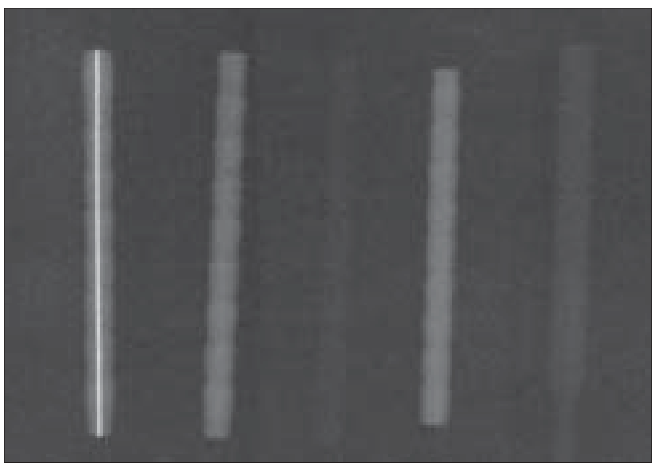

Figure 1: X-ray of the posts. From left to right: Reforpost RX, Reforpost glass fiber, reforpost carbon fiber, Fibrekor post, and C-post

Table 1: Fiber-reinforced post systems used in this study

Group	Post	Composition	Manufacturer	Diameter (mm)
RfX	Reforpost glass fiber RX	Metal-reinforced glass fiber	Ângelus, Londrina, PR, Brazil	1.5
RG	Reforpost glass fiber	Glass fiber	Ângelus, Londrina, PR, Brazil	1.5
RC	Reforpost carbon fiber	Carbon fiber	Ângelus, Londrina, PR, Brazil	1.5
FP	Fibrekor post	Glass fiber	Jeneric Pentron Inc., Wallingford, CT, USA	1.5
CP	C-post	Carbon fiber	Bisco Dental Products, Schaumburg, IL, USA	2.1

Posts were loaded to failure in three-point bending in accordance with the ISO 10477 standard (10.0-mm span, 0.5 mm/min crosshead speed, 2-mm cross-sectional diameter of the loading tip) with a 500 N load cell, using a universal testing machine (EMIC DL 2000, São José dos Pinhais, PR, Brazil). Flexural modulus (E), flexural strength (σ), and stiffness (S) were calculated as follows:

$E = 4F_{max}L^3/(D3\pi d^4)$ (in GPa)

$\sigma = 8F_{max}L/\pi d^3$ (in MPa)

$S = F/D$ (in N/mm),

where F_{max} is the maximum load point of the load-deflection curve (in N), L is the distance between the support rollers (10.0 mm), d is the diameter of the specimens (in mm), and D is deflection (in mm) at F_{max}[16] at a point in the straight-line portion of the trace. The stiffness was defined as the force necessary to deflect the post.[5] The diameter and length were measured with a digital caliper (S235, Sylvac, Switzerland). In order to eliminate the influence of the conical end of the posts, a short span length (10.0 mm) was used to obtain support for the post within the cylindrical part of the post. The parallel-sided cylindrical part of the post was considered to be the specimen.[16]

Results were analyzed by one-way ANOVA and Tukey's test ($\alpha = 0.05$). Representative images of the sectioned surfaces were recorded using scanning electron microscopy (SEM) (LEO 435 VP, LEO Electron Microscopy, Cambridge, UK). For SEM analysis, the fractured specimens were mounted in aluminum stubs and sputter coated (MED 010, Balzer, Balzers Union, Liechtenstein) with gold for 3 min, at $10^{-}1$ mmHg vacuum, producing a gold coat of 100 Á.

RESULTS

One-way ANOVA showed significant differences for all properties analyzed among groups [Tables 2-4]. Mean and standard deviation values of E (GPa), σ (MPa), and S (N/mm)

Table 2: One-way ANOVA ($P < 0.05$) – Flexural modulus

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	231.737	4	57.934	20.548	0.000
Within groups	56.389	20	2.819		
Total	288.126	24			

Table 3: One-way ANOVA ($P < 0.05$) – Flexural strength

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	59791.918	4	14947.979	9.395	0.000
Within groups	31820.593	20	1591.030		
Total	91612.510	24			

Table 4: One-way ANOVA ($P < 0.05$) – Stiffness

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	54509.200	4	627.300	25.066	0.000
Within groups	10873.146	20	543.657		
Total	65382.345	24			

are presented in Table 5. The statistical analysis indicated significant differences for the mechanical properties evaluated between the carbon fiber post groups (RC and CP) and the glass fiber post groups (RX, RG, and FP). Glass fiber posts did not present any statistical difference between them. The two carbon posts (RC and CP) showed statistical differences regarding flexural modulus and stiffness.

Table 5: Mean and standard deviation values of *E*, σ, and *S*, and the statistical groupings

Group	Flexural modulus (*E*) (GPa) (SD)	Flexural strength (σ) (MPa) (SD)	Stiffness (*S*) (N/mm) (SD)
RfX	10.83 (1.58)[b]	597.63 (52.04)[b]	131.60 (21.94)[c]
RG	10.59 (0.97)[b]	562.33 (24.92)[b]	137.84 (5.52)[c]
RC	15.87 (2.42)[a]	680.55 (34.79)[a]	190.93 (12.90)[b]
FP	10.87 (1.36)[b]	586.84 (21.90)[b]	122.41 (17.33)[c]
CP	6.26 (1.72)[c]	678.07 (54.18)[a]	246.02 (41.71)[a]

Different letters in the columns mean statistically significant differences ($P < 0.05$), SD - Standard deviation

Representative SEM images of the posts' fractured surfaces are presented in Figures 2-4 which show the interaction between fibers, matrix, and metal reinforcement.

DISCUSSION

The mechanical properties of fiber-reinforced composite posts depend on factors such as the direction[18] and volume fraction of the fibers, impregnation of the fibers by the resinous matrix, polymerization shrinkage of the resin, individual properties of fibers and matrix,[19,20] and the bonding between the resinous matrix and fibers, which is one of the most important factors that may influence the post strength.[11] If interfacial bonding between the fiber and the matrix is not adequate, no improved mechanical

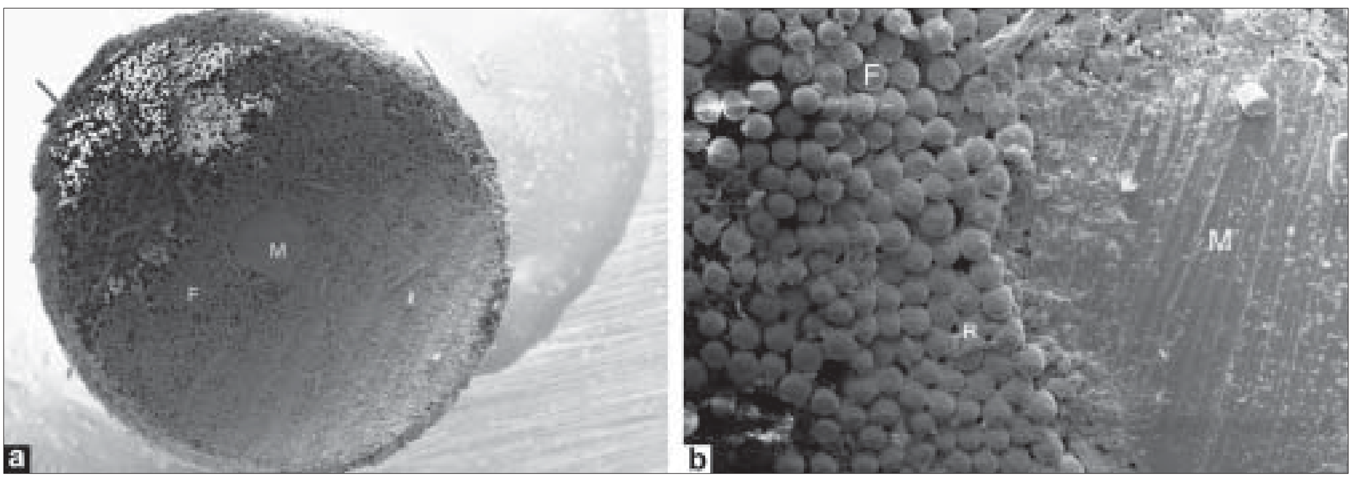

Figure 2: Representative SEM micrographs from the fractured surface of RfX post: (a) showing the metal reinforcement (M) surrounded by the glass fibers (F) (magnification 131×). (b) The magnified image shows the interaction between the glass fibers (F), the resin matrix (R), and the metal reinforcement (M) (magnification 1000×)

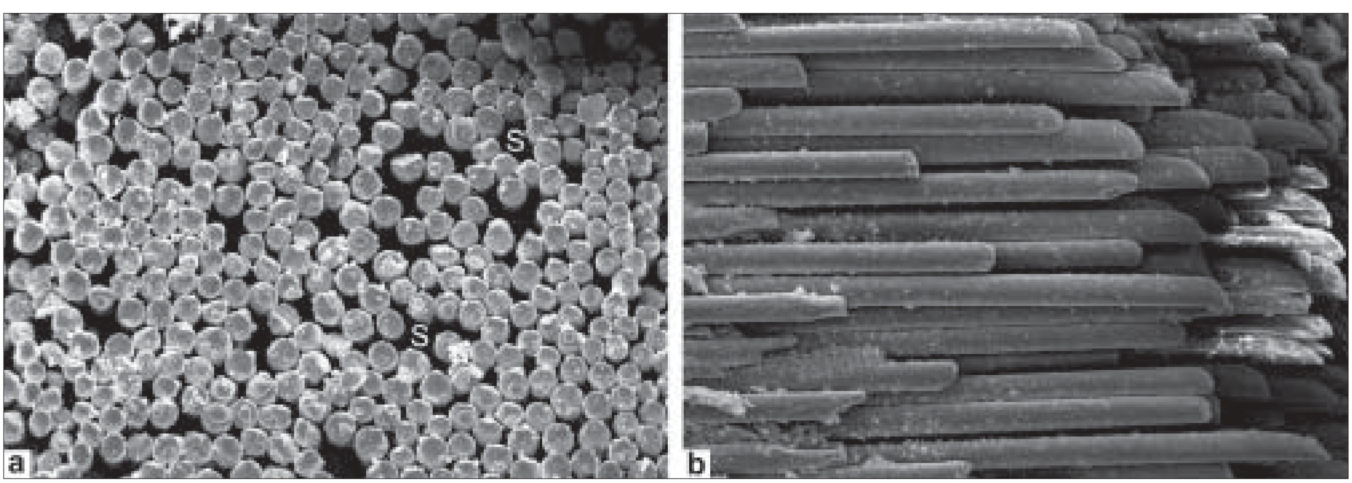

Figure 3: Representative SEM micrographs from the glass fiber post (RG). (a) Cross section of the glass fibers revealing empty spaces among the fibers (S) (magnification 1000×). (b) Fibers' long-axis section confirmed the inadequate interaction with the resin matrix (magnification 1000×)

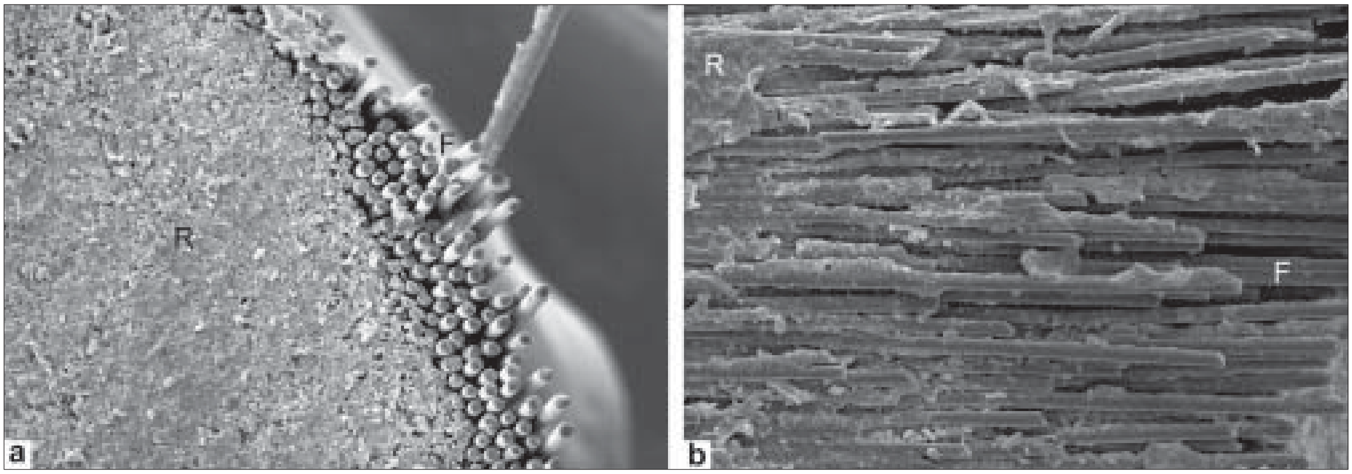

Figure 4: Representative SEM micrographs from the carbon fiber post (CP). (a) Cross section of the carbon fibers showing the peripheral (F) and central fibers covered with the resin matrix (R) (magnification 1000×). (b) Fibers long-axis section showing carbon fibers (F) impregnated with the resin matrix (R) (magnification 1000×)

properties are acquired.[16]

The experimental glass fiber posts (RfX) showed no difference in mechanical properties in comparison with the others glass fiber post systems (RG and FP), rejecting the hypothesis tested. The metal reinforcement (RfX) did not significantly influence the mechanical properties of the glass fiber post probably because of its minimal diameter, in comparison with the total diameter of the post [Figure 2]. The stainless steel filament inside the fiber post is not used as reinforcement, but their radiopaque appearance permits to recognize radiographically the real post position and length of the post in the root canal, since the fiber reinforced posts are radiolucid. On the other hand, this type of post does not allow one to distinguish it from the cement because both fiber post and resin cement have in their composition polymer materials, which are similar in radiopacity. In the case of retreatment, the removal of the post with metal reinforcement probably will be more difficult than a normal fiber post because of the presence of a metal filament; however, this was not a variable of this study, and must be assessed in future work.

The flexural modulus (E) of carbon fiber posts (RC and CP) showed statistically different values, while in posts reinforced with glass fiber this did not happen. These results may be explained by the difference in the diameter of the carbon fiber posts (1.5 and 2.1 mm) and because E was obtained from the load deflection trace during flexural strength testing.[21] This test model may also explain the lower E values reported in this study, which could be measured as the dynamic modulus, and, therefore, is a limitation of this study. When the three-point bending test is used to measure the flexural properties of posts, the results are related to the ratio of the span length and diameter of the sample set-up.[16] In a study by Lassila *et al.*,[16] to investigate the flexural modulus of different types of fiber-reinforced posts, it was shown that the modulus increases as the post diameter decreases, agreeing with this study's results. So the diameter of the post, as demonstrated by the results of the present study, should be taken into account.

Flexural strength (σ) is the mechanical property selected by the International Standards Organization for screening resin-based filling materials (ISO1992), considering it a more discriminatory and sensitive test for subtle changes in a material substructure.[21] The carbon fiber posts had higher flexural strength (σ) than the glass fiber posts. SEM images show a more intimate contact between the carbon fibers and the resin matrix [Figure 4] in comparison with the glass fibers, which showed empty spaces between fibers [Figure 3], suggesting a better bonding interaction between the resin matrix and the carbon fibers.

Considerable differences in the stiffness (S) were found among the posts investigated, where the S of glass fiber posts was smaller than that of carbon posts. This is probably related to the differences in post composition and bonding between the fiber and the matrix, in addition to the type, concentration, and orientation of fibers. Fibers represent the stiffer component of a fiber-reinforced post; hence, the higher the fiber volume fraction, the higher the S value.[18] In relation to fiber orientation, fibers diverging from the post longitudinal axis result in stress transmission to the matrix. Therefore, posts with parallel fibers should withstand loads better than those with obliquely oriented fibers.[18] The S of a material is related to Young's modulus and specimen geometry. A low modulus material allows greater bending under load. When strain exceeds the yield point, the material is irreversibly deformed even after the load has been removed. When a load is applied to a structure composed of dissimilar materials, such as a post-bonded- to-dentin system, the material with the higher modulus deforms less, producing areas of stress concentration before the material is permanently deformed.[22]

The placement of endodontic posts creates an unnatural restored structure, because it fills the root canal with a material that has stiffness unlike that of the pulp and it is not possible to recreate the original stress distribution within the tooth.[23] Nevertheless, it is necessary to have materials whose mechanical properties closely resemble the properties of dentin (E = 18 GPa).[8] According to Galhano *et al.*,[11] posts reinforced with fibers have an E of approximately 20 GPa, while cast metal alloy posts and prefabricated metal posts have an E of about 200 GPa and ceramic posts about 150 GPa.[11] Thus, posts reinforced with fibers have mechanical properties similar to dentin, which show a flexural modulus of about 18 GPa.[9] Akkayan and Gülmez[4] evaluated the resistance to fracture of endodontically treated teeth restored with different posts systems, and concluded that teeth restored with posts that have properties closer to those of the dental structure, such as the glass fiber posts, showed favorable fractures; however, those restored with titanium and zirconia's posts demonstrated catastrophic fractures.[4]

The mechanical properties of posts are fundamental for restorative procedures. However, other clinically relevant aspects, like cementation, ferule effect, and quantity of the remaining tooth structure are also important. So, the dentin- bonded-to-post structure should be investigated before the clinical use of a system, which should be the focus of future investigations.

CONCLUSION

In accordance with the methodology used and within the limitations of this study, it can be concluded that

- Posts reinforced with carbon fibers have a higher flexural strength than posts reinforced with glass fibers.
- The diameter of the posts influences their properties and should be taken into account.
- The mechanical properties of the new metal-reinforced glass fiber posts (RfX) are similar to ones obtained by the regular glass fiber posts (RG and FP).

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