Mechanical properties related to the microstructure of seven different fiber reinforced composite posts

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PURPOSE. The aim of this *in vitro* study was to evaluate the mechanical properties (bending strength and hardness) of seven different fiber reinforced composite posts, in relation to their microstructural characteristics. **MATERIALS AND METHODS.** Two hundred eighty posts were divided into seven groups of 40, one group for each type of post analyzed. Within each group, 15 posts were subjected to three-point bending strength test, 15 to a microhardess meter for the Knoop hardness, and 10 to Scanning Electron Microscope in order to determine the diameter of the fibers and the percentage of fibers embedded in the matrix. To compare the flexural strength in relation to the type of fiber, matrix, and the hardness of the posts, a Kruskal-Wallis H test was used. The Jonckheere-Terpstra test was used to determine if the volume percent of fibers in the post influenced the bending strength. **RESULTS.** The flexural strength and the hardness depended on the type of fibers that formed the post. The lower flexural strength of a post could be due to deficient bonding between the fiber and the resin matrix. **CONCLUSION.** According to the results, other factors, besides the microstructural characteristics, may also influence the mechanical properties of the post. The feature that has more influence on the mechanical properties of the posts is the type of fiber. ***[J Adv Prosthodont 2016;8:433-8]***

KEYWORDS. Fiber post; Flexural strength; Hardness; Mechanical properties; SEM-evaluation

INTRODUCTION

Restoration of a tooth with extensive destruction may require a post to retain the restorative material securely and promote an even distribution of forces in the root.[1-4] A post does not strengthen the tooth, thus the decision to use a post is dependent on whether the remaining tooth structure is sufficient to retain the final restoration.[5]

There are two main types of prefabricated posts, a metal post and a fiber reinforced composite (FRC) post.

For optimal results, the post material must have physical and mechanical properties similar to dentin (i.e. be able to join dental structures and be biocompatible).[1,5] In addition, the mechanical properties of the different posts can result in the failure of the restoration.[2] For example, a flexible post may lead to a loss of marginal integrity, with the risk of marginal discoloration, secondary caries, and possible debonding.[6] By contrast, a rigid post can better support a coronal restoration through a more uniform force distribution, but when the tooth is overloaded, due to the post's rigidity and low plastic deformation, a root fracture can occur.[1,4,7,8] The lower elastic modulus of the post, the greater the probability of a restoration failure, but the higher the probability of a root surviving.[9] The FRC posts have a modulus of elasticity similar to dentin while the moduli of the metal posts are much higher.[10] According to Stewardson *et al.*,[10] the FRC posts have a modulus 2 - 6 times, and metal 4 - 10 times, higher than dentin.

The FRC posts usually consist of a matrix of epoxy resin or derivatives into which fibers are embedded to rein-

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Received March 12, 2016 / Last Revision July 26, 2016 / Accepted October 11, 2016

force the structure and improve its properties.[5,7] Through scanning electron microscopy (SEM), numerous authors have found that the average diameter, density, orientation, fiber length, fiber-matrix bond, and matrix type in which the fibers are embedded are factors that influence the mechanical properties of posts.[11-13]

The aim of this *in vitro* study was to assess the mechanical properties (bending strength and hardness) of seven different FRC posts, in relation to their microstructural characteristics.

MATERIALS AND METHODS

The posts used for this study are described in Table 1. Two hundred eighty posts were analyzed. Within each group, 15 posts were subjected to bending strength tests, 15 to hardness tests, and 10 to electron microscopy. The major diameter of the posts ranged from 1.50 mm to 2.20 mm.

In order to determine the diameter of the fibers and the percentage of fibers embedded in the matrix, each post sample was metallized with 15 nm of Au-Pd and studied with a Scanning Electron Microscope (SEM) (JEOL JSM-6400. Jeol, Tokyo, Japan) on cross-sections at 2000× magnification. An approximation of the volume occupied by fibers was determined by adding the surface occupied by all the fibers and dividing by the total surface of the micrograph.[14] The fractured area of the post after being subjected to the bending test was also observed under SEM.

The bending resistance of the posts was analyzed by submitting them to three-point bending test in a universal testing machine (Suzpecar MEM-103/5. Suzpecar, Madrid, Spain). The load was applied with a loading angle of 90° and a crosshead speed of 0.5 mm/min until fracture. The distance between the two supports was 10 mm. As the investigated posts had different diameters, a central area with a diameter of 1.30 mm was selected as the area of load application. The assessment was made with a digital caliper (Absolute Coolant Proof Caliper 500-731-10. Mitutoyo America Co., Aurora, IL, USA). The flexural strength (σ), in MPa, of the post was computed using the following formula: $\sigma = \frac{8FmL}{\pi D^3}$, where Fm is the maximum load applied at break, L is the span length between the supports (in mm), and D is the diameter of the posts (in mm).

For the hardness test, posts were placed longitudinally into a sample holder with a resin mixture (Bepox 1159. Gairesa, A Coruña, Spain) and were left to set for eight hours. After this step, the sample's surface was polished.

The Knoop hardness (HK) was measured with a microhardness meter (Matsuzawa MXT 50. Matsuzawa, Tokyo, Japan). Ten indentations were made on the polished surface of each sample with a pyramidal diamond point with a rhomboidal base, formed by two mutually perpendicular faces with angles of 172° 30' and 130°. The load applied was 50 g for a load time of 5 seconds. The long axis of the rhomboidal footprint was measured by microscopy. The KH is described by the formula: $HK = \frac{P}{CpL^2}$, where P is the applied load (in Kgf), L is the indentation length along its long axis, and Cp is the correction factor related to the shape of the indenter. The result was multiplied by 10 to obtain a result in MPa.

Nonparametric tests were used because data exhibited a non-normal distribution (Kolmogorov-Smirnov test). To compare the flexural strength according to the type of fiber, matrix, and the hardness of the posts, a Kruskal-Wallis H test was used. The Jonckheere-Terpstra test was used to determine if the volume percent of fibers in the post influenced the bending strength. $P < .05$ was considered statistically significant. All calculations were performed using the statistical software SPSS 21 (SPSS Inc., Chicago, IL, USA).

RESULTS

Examination of post cross sections with SEM revealed different fiber diameters and irregular fiber distributions within

Table 1. Fiber reinforced composite post used in this study

Posts	Manufacturer	Design	Matrix filler	Fibers
Rebilda Post	Voco, Cuxhaven, Germany	cylindrical-conical	dimethacrylate	glass
ParaPost Fiber Lux	Coltène/Whaledent AG., Altstätten, Switzerland	cylindrical	epoxy resin	glass
ParaPost Taper Lux	Coltène/Whaledent AG., Altstätten, Switzerland	cylindrical-conical	epoxy resin	glass
ParaPost Fiber White	Coltène/Whaledent AG., Altstätten, Switzerland	cylindrical	epoxy resin	glass
D.T. Light-Post	RTD, St. Egrève, France	cylindrical-conical	epoxy resin	quartz
Snowpost	Abrasive Technology, Ohio, USA	cylindrical-conical	epoxy resin	silica- zirconium
Carbopost	Abrasive Technology, Ohio, USA	cylindrical-conical	epoxy resin	carbon

the same post (Fig. 1). The results of the diameters of the fibers and the fiber-matrix ratio are shown in Table 2. The posts with the smallest diameter of fibers were ParaPost Fiber White and Carbopost.

In the bending test, the posts with higher resistance were ParaPost Fiber Lux and ParaPost Taper Lux ($P < .05$). The glass fiber post showed a higher resistance to fracture, with statistically significant differences with other types of fibers (quartz, silica-zirconia, and carbon) ($P < .05$). However, no significant difference between the carbon and the silica-zirconium fibers was found ($P = .437$). These two posts had the lowest bending strength. In analyzing the flexural strength in relation to the fibers-matrix ratio, no statistically significant differences were found among the groups ($P > .05$). Between the dimethacrylate matrix and the epoxy resin matrix, there was no statistically significant difference ($P = .672$).

In the analysis of the fracture area with SEM, differences were observed at the junction between the matrix and fibers (Fig. 2). The Carbopost presented very clean fibers, indicating a poor fiber-matrix bond. By contrast, in the ParaPost Fiber White, many adhesions between the two components are observed, indicating a better fiber-matrix bond.

Regarding the KH, the hardest post was Snowpost, which was composed of silica-zirconia fibers, and the least hard post was ParaPost Fiber White, with glass fibers. No statistically significant differences with regard to the matrix compound were found ($P = .619$). However, the post hardness varied depending on the type of fiber (549.2 - 1046.8 MPa), with statistically significant differences among the posts ($P < .05$), except between carbon fiber posts and glass fiber posts, the two types having lower hardness ($P = .673$). The values obtained in each test for the different posts are shown in Table 3.

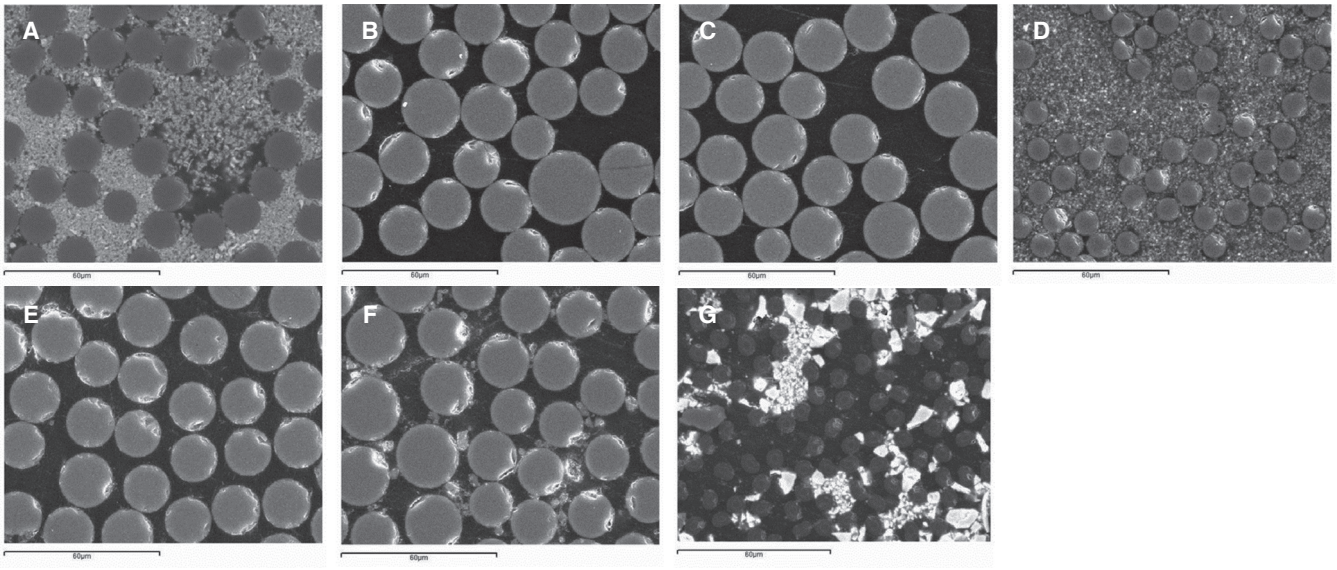

Fig. 1. SEM micrographs of the cross sections of the fiber posts. (A) Rebilda Post, (B) ParaPost Fiber Lux, (C) ParaPost Taper Lux, (D) ParaPost Fiber White, (E) D.T. Light-Post, (F) Snowpost, and (G) Carbopost.

Table 2. Diameters of fibers and fiber-matrix ratio of the FRC posts obtained with the analysis of the SEM photographs

Post	Diameter of fibers (μm)	Fibers/matrix ratio (%)
Rebilda Post	14.76 (0.86)	75
ParaPost Fiber Lux	16.97 (0.75)	55
ParaPost Taper Lux	19.15 (3.30)	55
ParaPost Fiber White	8.83 (0.83)	40
D.T. Light-Post	17.63 (0.60)	75
Snowpost	17.46 (1.90)	55
Carbopost	6.57 (0.15)	65

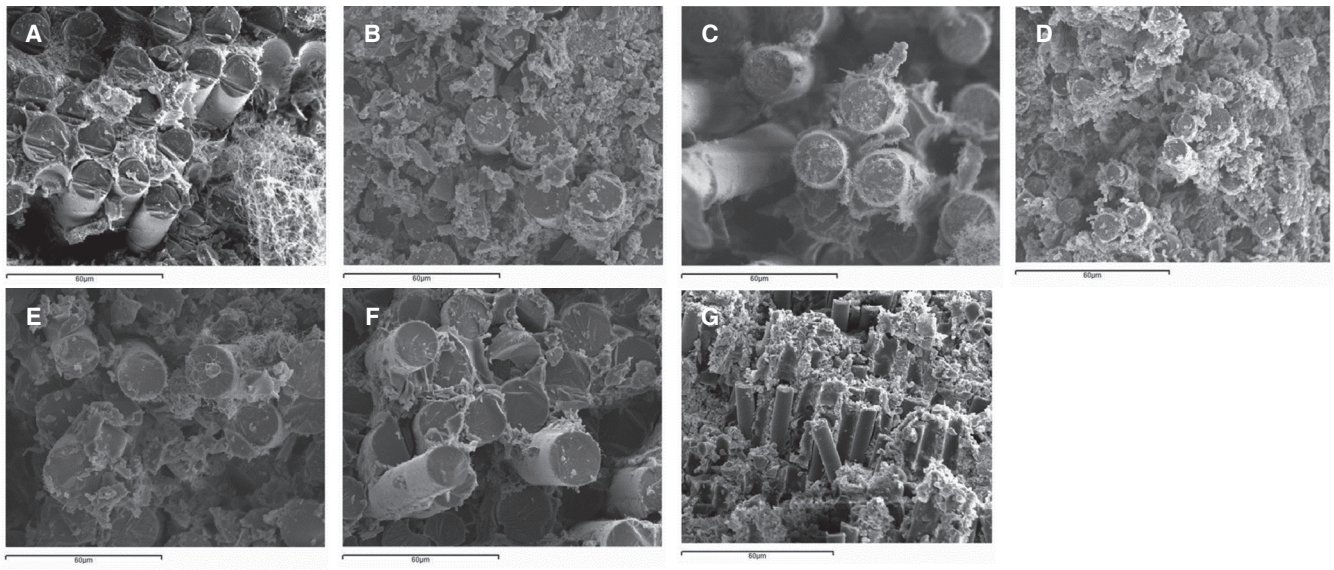

Fig. 2. SEM micrographs of the failure area of the fiber posts. (A) Rebilda Post, (B) ParaPost Fiber Lux, (C) ParaPost Taper Lux, (D) ParaPost Fiber White, (E) D.T. Light-Post, (F) Snowpost, and (G) Carbopost.

Table 3. Mean (standard deviation in parenthesis) physical properties of the different posts, and according to the type of fiber, matrix, and the fiber-matrix ratio (%)

	Flexural strength (MPa)	Hardness (MPa)
Post		
Rebilda Post	871.7 (242.1)	637.6 (115.9)
ParaPost Fiber Lux	1622.5 (370.6)	581.9 (86.9)
ParaPost Taper Lux	1181.4 (118.2)	699.3 (145.9)
ParaPost Fiber White	813.8 (124.9)	376.5 (102.3)
D.T. Light Post	838.4 (212.1)	798.4 (124.8)
Snowpost	705.5 (69.4)	1046.8 (162.7)
Carbopost	664.3 (140.4)	549.2 (64.3)
Materials		
Dimethacrylate	871.7 (242.1)	637.6 (115.9)
Epoxi Resin	962.4 (385.4)	676.9 (243.2)
Carbon fiber	664.3 (140.4)	549.2 (64.3)
Glass fiber	1122.3 (397.7)	573.6 (166.6)
Quartz fiber	838.4 (212.1)	798.4 (124.8)
Silica-Zirconium fiber	705.5 (69.4)	1046.8 (162.7)
40% fiber-matrix ratio	813.8 (124.9)	376.5 (102.3)
55% fiber-matrix ratio	1027.3 (439.7)	722.8 (233.0)
65% fiber-matrix ratio	871.7 (242.1)	637.6 (115.9)
75% fiber-matrix ratio	838.4 (212.1)	798.4 (124.8)

DISCUSSION

It has been explained that the mechanical properties of a fiber-reinforced composite post depend on structural characteristics such as the direction of the fibers, the volume ratio of the fibers,[7,11-13] the bonding between the matrix resin and the fibers, and the individual properties of the fibers and the matrix.[11-13,15] Related to the results obtained, besides the microstructural characteristics, there are other factors that influence the mechanical properties of the post.

The *in vitro* bending test better simulates and predicts what may happen to materials *in vivo*.[16] Usually, the fatigue test used for this purpose is the three-point bending test,[17] as used in this study.

There have been several studies in which the flexural strengths of fiber posts were analyzed with tests similar to those used in this evaluation, giving variable results.[12-14,18] The discrepancy in flexural strengths reported for similar materials can be attributed to differences in experimental design, method of specimen preparation, and thickness and shape of the posts.[7,19]

The results implied that the compound of the matrix did not affect the mechanical properties of the posts. Drummond and Bapna concluded that the bending force was not affected by the composition of the reinforcing fibers in the posts, as they all had approximately the same elastic modulus.[11] However, in this study, the flexural strength of the post showed statistically significant differences depending on the type of fiber. The carbon fiber post and the silica-zirconium fiber post achieved the lowest values of flexural strength, like in another study.[18] Even though one study showed the quartz-fiber post having greater flexural strength values than the glass fiber post,[13] this study's

results showed the highest flexural strength in glass fiber post.

Taking into account that the primary function of posts is to retain the core,[1,5] a high flexural strength is essential to enhance the durability of the restoration during function. Also, a low flexural modulus may avoid stress concentration and effectively prevent root fractures.[19] Teeth restored with less rigid posts tend to have fewer catastrophic failures,[20,23] which are more likely to be restorable.[24] Therefore, according to the results of flexural strength, glass fiber posts should be chosen.

No statistically significant difference was found in the flexural strength among different fiber-matrix ratios. It has been published that the higher content of glass fibers in the post contributed to the greater strength displayed.[20,25] However, other authors argued that the fiber density contributed only partly to mechanical performance[15] or that it did not affect flexural strength.[19] Perhaps in this study, there were not differences among the posts because the analyzed posts differed in more characteristics than the fiber-matrix ratio. One study analyzed only the fiber-matrix ratio, in the same unidirectional glass fiber reinforced composite, finding that it influenced the mechanical properties.[26]

The KHs of the carbon fiber and glass fiber posts are similar, showing the lowest values; however, glass fiber posts have significantly more resistance to flexion than carbon fiber posts. Therefore, the hardness does not seem to influence the bending strength of these posts. The lowest hardness values have also been associated with the smallest diameters of the reinforcing fibers,[15] a statement that is corroborated by our results.

Cross-sectional examination with SEM revealed different fiber diameters and irregular fiber-matrix distribution within the same post, a finding which has also been reported by other authors.[13,15,19] However, fiber diameters are homogenous, as seen from the value of the standard deviations.[15] When comparing different posts with glass fibers, it is observed that the greater the fiber diameter and the fiber-matrix ratio, the greater the flexural strength.[15] The relationship between the matrix and the fibers in the fracture zone varies depending on the post. Carbon and silica-zirconia fibers are separated from the matrix, as noted by Plotino *et al*.[18] The lower flexural strength of a post could be due to deficient bonding between the fiber and the resin matrix[12-14] because it has been seen that failure begins at the interface between matrix and fibers.[26] Glass and quartz fibers remain attached to the matrix after fracture, and the posts made of them have higher flexural strength. Achieving a good interfacial bonding allows load transfer from the matrix to the fibers.[12,25,27] By contrast, an inappropriate adhesion causes voids, increasing water sorption, and reducing the mechanical properties.[28] Accordingly, the interfacial adhesion between fibers and matrix[11,19,27,29] or the manufacturing process[12,13] may contribute to the flexural strength of glass fiber posts.

With elastic posts, the tooth, cement, and post will all deform during function.[6,30] Failure will appear at the weakest point, which seems to be the adhesive joints at the core-dentin and post-cement-dentin interfaces.[30] By the factors mentioned above, the most frequent failures of teeth restored with FRC posts are post and core debonding.[31-33] Some authors demonstrated that the bond strength between dentin walls, luting resin, and FRC post was more affected by the rigidness of FRC post than the type of luting agent used.[34,35]

Future investigations would determine the influence of fiber-matrix ratio and fiber diameter within the same glass fiber posts on the fatigue resistance, as well as the ideal flexural strength that permit the flexion and avoid debonding of the post-core system.

CONCLUSION

Besides the microstructural characteristics, the mechanical properties of the posts are influenced by other factors such as the adhesive interface between the matrix and fibers. The feature that has more influence on the mechanical properties of the posts is the type of fiber. The hardness of the glass fiber post does not affect the bending strength. Within the limitations of this *in vitro* study, the posts with the most adequate properties for the clinical use are the glass fiber posts.

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