DENTAL MATERIALS 23 (2007) 1129–1135

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Flexural properties of endodontic posts and human root dentin

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ARTICLE INFO

Article history:
Received 5 November 2005
Received in revised form
11 April 2006
Accepted 22 June 2006

Keywords:
Endodontic posts
Root dentin
Flexural modulus
Flexural strength

ABSTRACT

Objectives. To evaluate the flexural modulus and flexural strength of different types of endodontic post in comparison with human root dentin.

Methods. Three different types of fiber-reinforced composite (FRC) posts and three metal posts each comprising 10 specimens ($n = 10$) and 20 dentin bars were loaded to failure in a three-point bending test to determine the flexural modulus (GPa) and the flexural strength (MPa). Three randomly selected fiber posts of each group were evaluated using a scanning electron microscope (SEM) to illustrate the differences in mode of fracture. Data were subjected to a one-way ANOVA to determine significant differences between groups and the Bonferroni t-test multiple comparison was applied to investigate which mean values differed from one another with significance levels of $P < 0.05$.

Results. The flexural modulus recorded for the dentin bars was 17.5 ± 3.8 GPa. The values for posts ranged from 24.4 ± 3.8 GPa for silica fiber posts to 108.6 ± 10.7 GPa for stainless steel posts. The flexural strength for dentin was 212.9 ± 41.9 MPa, while the posts ranged from 879.1 ± 66.2 MPa for silica fiber posts to 1545.3 ± 135.9 MPa for cast gold posts. The ANOVA test analysis revealed significant differences between groups ($P < 0.05$) for flexural modulus and flexural strength mean values.

Significance. FRC posts have an elastic modulus that more closely approaches that of dentin while that for metal posts was much higher. The flexural strength of fiber and metal posts was respectively four and seven times higher than root dentin.

1. Introduction

The primary reason for using a post is to retain a core with the objective to restore the missing coronal tooth structure and not to strengthen the tooth, as has been traditionally advocated [1–9].

To achieve optimum results, the materials that are used to restore endodontically treated teeth should have physical and mechanical properties that are similar to that of dentin, should be able to bond to tooth structure and be biocompatible in the oral environment [10].

One of the major reasons that motivated researchers to find alternative solutions to metal posts was to prevent root fracture, which was the main cause of failure with this type of restoration. It has been reported that the rigidity of metal prefabricated posts and the shape and rigidity of cast gold post

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doi:10.1016/j.dental.2006.06.047

and cores may pose a risk and cause root fracture [5,10–14]. Recent reports suggest that the rigidity of the post should be equal or close to that of the tooth to distribute the occlusal forces evenly along the length of the root [15–17].

A recent review by Kinney et al. [18] compared all the values of Young's modulus of dentin that were reported in experiments performed from 1950 to 2003. The mean value was 13.3 GPa with a standard deviation of 4.0 GPa and a range of 10–30 GPa. These differences may be attributed to the structural composition of dentin (dentinal tubules, peritubular dentin and intertubular dentin), which varies between teeth and many other factors. Furthermore, the characteristics of the dentinal tubules (density, direction and dimension) vary depending on their location within the dentin, thus influencing the mechanical properties according to the site of the test.

Thorough knowledge of dentinal properties is important to better understand the effects of a wide variety of restorative dental procedures and the principles that influence successful integration of tooth and restoration.

Fiber-reinforced composite (FRC) root canal posts have been introduced as an alternative to conventional materials [19,20]. The biomechanical properties of FRC posts have been reported to be close to that of dentin [21–23]. Clinical prospective and retrospective studies on the use of fiber posts have reported encouraging results [24–28].

An analysis of the dental literature with respect to *in vitro* studies did not conclusively demonstrate that one system was better than another. Some studies have questioned the mechanical properties of FRC posts reporting rigidity values similar to or even higher than metal posts [14,29,30].

The aim of this study was to evaluate the flexural modulus and the flexural strength of different endodontic posts and to compare these values to those obtained from root dentin.

2. Materials and methods

For this study six different types of endodontic post were selected (Fig. 1):

- Group 1: carbon fiber posts (Tech 2000, Carbotech, Ganges, France);
- Group 2: silica-zirconium fiber posts (Tech 21 Xop, Carbotech, Ganges, France);
- Group 3: zirconia glass fiber posts (FotoTech, Carbotech, Ganges, France);
- Group 4: type IV gold cast posts (replicas of the carbon fiber posts);
- Group 5: stainless steel posts (Optident, Ilkley, West Yorkshire, UK);
- Group 6: titanium posts (Optident, Ilkley, West Yorkshire, UK).

Sixty endodontic posts, 10 for each group were tested. All fiber posts had a diameter of 1.4 mm, a length of 19 mm and had a cylindrical shape with a tapered end. The stainless steel and titanium posts were parallel and cylindrical with a diameter of 1.14 mm and length of 18 mm. The gold posts were obtained by casting exact replicas of the carbon fiber posts using standard laboratory techniques.

The diameters of the posts were measured with an electronic digimatic 500-311 caliper (Mitutoyo, Tokio, Japan). Measurements were taken at three locations on the cylindrical portion of the posts (coronal, middle and apical) in order to verify whether the diameters corresponded to the information provided by the manufacturers.

Twenty standardized dentin bars (Group 7) measuring 1.2 mm height × 2 mm wide × 16 mm long were obtained from sound freshly extracted completely formed human single rooted premolars that were extracted for orthodontic reasons. A diamond wafering blade (Exact BS310, BioOpticà, Milan, Italy) used with continuous water cooling was used to obtain the bars (Fig. 2a). Twenty samples were selected at random from a pool of dentinal bars and measured to ensure accuracy of dimension using an electronic caliper (Mitutoyo). They were evaluated for cracks, discoloration and defects, under a stereomicroscope at 30× and by means of μCT analysis (Skyscan 1072, Assing s.p.a.; Belgium) (Fig. 2b and c) and stored in normal saline until testing. Samples that did not meet the criteria were replaced.

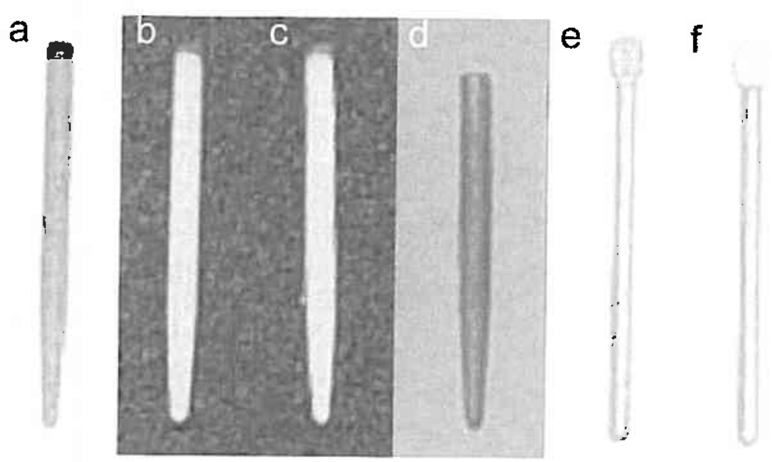

Fig. 1 – The endodontic posts that were tested in the study. (a) Carbon fiber posts (Tech 2000), (b) silica–zirconium fiber posts (Tech 21 Xop), (c) zirconia glass fiber posts (FotoTech), (d) type IV gold cast posts, (e) stainless steel posts, (f) titanium posts.

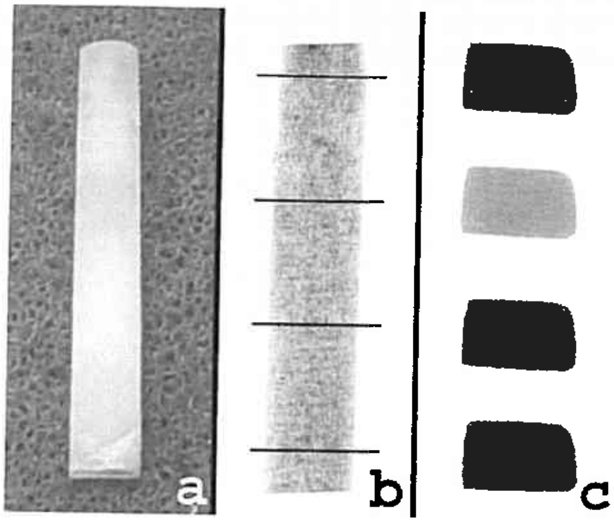

Fig. 2 – (a) Dentin bar specimen; (b) longitudinal section obtained by means of μCT scanning and reconstruction procedures; (c) four cross-sections obtained by means of μCT scanning and reconstruction procedures corresponding to the different levels as showed in 2b.

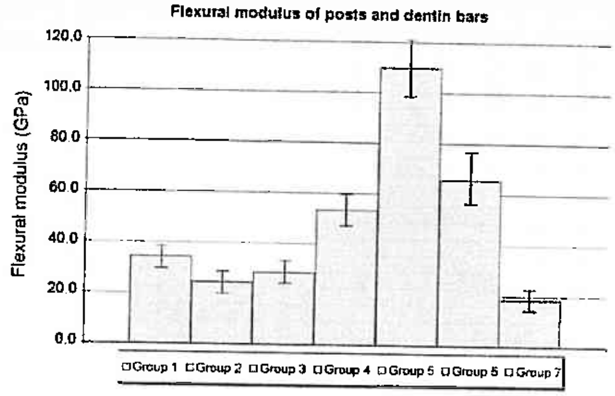

Fig. 3 – Flexural modulus of the test specimens. The bars represent the mean values expressed in GPa (S.D.).

A three-point bending test with 10.0 mm span distance, 2 mm loading tip cross-sectional diameter, 1.0 mm/min crosshead speed, was used to measure the flexural modulus and flexural strength values of all specimens.

For mechanical testing an electronic dynamometer (Lloyd Instruments Ltd., LR30K, Fareham, England) equipped with a 500N ± 0.5% load cell was used. All dentin samples were kept moist during testing with normal saline and were positioned with the dentin tubules oriented as parallel as possible to the direction of the stress applied. The direction of the load application was on the 1.2 mm cross-section. The load–deflection curves were obtained by means of Nexygen Mt v4.5 PC-software (Lloyd Instruments Ltd., UK) and the flexural modulus (GPa) and flexural strength (MPa) mean values with the relative standard deviations were calculated, according to EN ISO 178:2003 [31]. At the start of each post and dentin bar testing, Nexygen asked about specimen dimensions.

In order to reduce the influence of the conical end of the posts, a 10 mm span length was used to ensure testing of only the parallel portion of the post.

Three randomly selected fiber posts of each group were selected to analyze the fracture mode. They were mounted on a metal stub, gold coated by evaporation and observed using a Scanning Electron Microscope (SEM) (Philips SEM 515, Eindhoven, The Netherlands) operated at 15 KV at a working distance of 10 cm. Micrographs were made at 50×, 462× and 1420× magnifications.

Data analysis was performed using SPSS software (Statistical Package for the Social Sciences, SPSS Inc., Ill, USA) and subjected to one-way ANOVA to determine significant differences between groups. When the overall F-test showed a significant difference, the multiple comparison Bonferroni t-test procedure was applied to determine which mean values differed from one another with a significance level of $P<0.05$.

3. Results

Measurements of the diameters of the fiber posts corresponded rather precisely to the dimensions specified by the manufacturer with slight variations in the range of 0.01–0.02 mm. The stainless steel and titanium posts had exactly the diameters as specified. The diameters of the gold cast posts were similar to those of the original carbon fiber posts with an error ranging from 0.01 to 0.02 mm.

The mean and standard deviation of flexural modulus (GPa) and flexural strength (MPa) are illustrated in Table 1 and in Figs. 3 and 4. ANOVA test showed significant differences between groups ($P<0.05$) in flexural modulus and flexural strength mean values (Tables 2 and 3).

The lowest flexural modulus was registered for the silica–zirconium fiber post (24.4 ± 3.8 GPa) followed by the

Table 1 – Mean (S.D.) of the flexural properties of the specimens tested

Group	Posts type	Flexural modulus (GPa)	Flexural strength (MPa)
1	Carbon fiber posts	34.4 (3.6)	978.2 (65.9)
2	Silica–zirconium fiber posts	24.4 (3.8)	879.1 (66.2)
3	Zirconia glass fiber posts	28.2 (3.4)	961.4 (43.1)
4	Gold cast posts	53.4 (4.5)	1545.3 (135.9)
5	Stainless steel posts	108.6 (10.7)	1436.1 (83.1)
6	Titanium posts	66.1 (9.6)	1280.7 (23.9)
7	Dentin bars	17.5 (3.8)	212.9 (41.9)

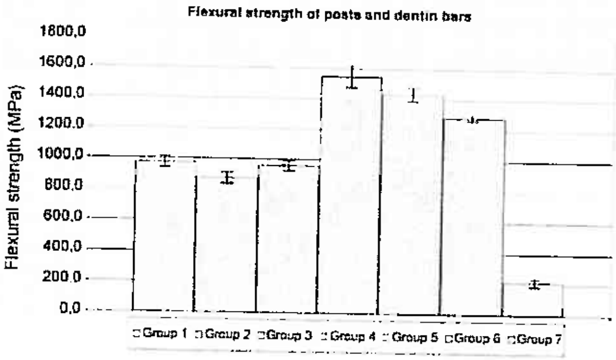

Fig. 4 – Flexural strength of the test specimens. The bars represent the mean values expressed in MPa (S.D.).

zirconia glass fiber post (28.2 ± 3.4 GPa), carbon fiber post (34.4 ± 3.6 GPa), gold cast post (53.4 ± 4.5 GPa), titanium post (66.1 ± 9.6 GPa) and the stainless steel post (108.6 ± 10.7 GPa). The Bonferroni t-test multiple comparison showed a statistically significant difference ($P < 0.05$) between all groups, except the zirconia glass fiber post compared to the carbon fiber post ($P = 0.382$) and the silica–zirconium fiber post ($P = 1.000$).

The highest flexural strength value was obtained with the gold cast post (1545.3 ± 135.9 MPa), followed by the stainless steel post (1436.1 ± 83.1 MPa), titanium post (1280.7 ± 23.9 MPa), carbon fiber post (978.2 ± 65.9 MPa), zirconia glass fiber post (961.4 ± 43.1 MPa) and the silica-zirconium fiber posts (879.1 ± 66.2 MPa). The Bonferroni *t*-test multiple comparison showed a statistically significant difference ($P < 0.05$) among all groups except for the three fiber posts amongst themselves ($P > 0.05$).

The flexural modulus value obtained for human root dentin was 17.5 ± 3.8 GPa and the flexural strength was 212.9 ± 41.9 MPa. The Bonferroni t-test multiple comparison showed a statistically significant difference ($P < 0.05$) between the dentin samples and all the other groups with regards to flexural modulus and to flexural strength.

SEM analysis of the fractured surfaces of the fiber posts showed a similar failure mode. The fibers separated at random from the resin matrix in which they were embedded. At higher magnification it was observed that the fractured surface of the silica-zirconium and the zirconia glass fibers was clean and straight (Fig. 5), while the carbon fibers showed an irregular and beveled appearance (Fig. 6).

4. Discussion

Many studies investigating the flexural properties of root canal posts have been published reporting results that varied greatly [14,21,29,30]. The flexural modulus parameter defines the flexibility of a sample and higher values indicate more stiffness, while lower values indicate more flexibility. The flexural modulus is calculated by taking into account the elastic behavior of a sample within a load range that will not cause plastic deformation.

The flexural strength parameter determines the resistance to fracture of a sample. Higher values indicate that a sample is more resistant to fracture, lower values that it is less so. The flexural strength is determined by the highest load a sample can withstand and depends on the specimen configuration.

The present study showed similar mechanical characteristics for the three different fiber posts, both with regards to their flexibility (flexural modulus) ($P > 0.05$) as well as their

Table 2 – Multiple comparison Bonferroni t-test between the different groups for flexural modulus

P	Carbon	Silica–zirconium	Zirconia glass	Gold cast	Stainless steel	Titanium	Dentin bars
Carbon fiber posts	–						
Silica-zirconium fiber posts	0.005	–					
Zirconia glass fiber posts	**0.382**	**1.000**	–				
Gold cast posts	0.000	0.000	0.000	–			
Stainless steel posts	0.000	0.000	0.000	0.000	–		
Titanium posts	0.000	0.000	0.000	0.000	0.000	–	
Dentin bars	0.000	0.000	0.000	0.000	0.000	0.000	–

In bold no significant difference between the groups ($P > 0.05$).

Table 3 – Multiple comparison Bonferroni t-test between the different groups for flexural strength

P	Carbon	Silica–zirconium	Zirconia glass	Gold cast	Stainless steel	Titanium	Dentin bars
Carbon fiber posts	–						
Silica-zirconium fiber posts	**0.050**	–					
Zirconia glass fiber posts	**1.000**	**0.226**	–				
Gold cast posts	0.000	0.000	0.000	–			
Stainless steel posts	0.000	0.000	0.000	0.018	–		
Titanium posts	0.000	0.000	0.000	0.000	0.000	–	
Dentin bars	0.000	0.000	0.000	0.000	0.000	0.000	–

In bold no significant difference between the groups ($P > 0.05$).

Fig. 5 – Scanning electron micrograph of the fractured surface of a specimen of Group 2. Fractured fibers that were sheared perpendicular to their long axis, can be seen protruding from the resin matrix. The mode of failure indicates a brittle fracture. Original magnification 462×.

resistance to fracture (flexural strength) ($P > 0.05$). Just the carbon fiber posts and the silica–zirconium fiber posts showed statistically significant differences ($P = 0.005$), even if the values were in a similar range. This can be explained by the low standard deviation registered. The tooth-colored posts (silica–zirconium fiber posts and zirconia glass fiber posts) were found to be slightly more flexible than the carbon fiber posts.

The metal posts that were tested were found to be more rigid than the fiber posts ($P < 0.05$). The stainless steel posts were almost twice as rigid as the titanium posts ($P < 0.05$) and more than twice as rigid as the gold cast posts ($P < 0.05$). All

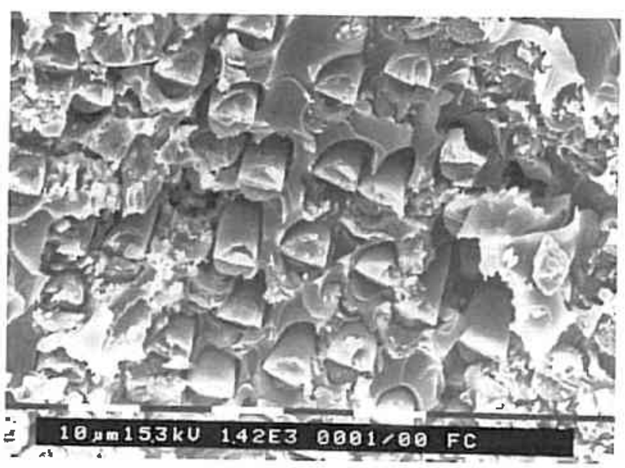

Fig. 6 – Scanning electron micrograph of the fractured surface of a specimen of Group 1. During load application the fibers deformed the resin matrix causing separation, followed by fracture of the fibers. The fractured fiber surfaces appear to be bevelled rather than perpendicular as was seen with the silica–zirconium samples. Original magnification 1420×.

metal posts were more resistant to fracture than the fiber posts ($P < 0.05$).

The gold cast posts showed most flexibility of the metal posts tested. It is of interest to note that despite there being a statistically significant difference in flexural modulus between gold cast posts and fiber posts ($P = 0.000$), the flexibility of the gold cast posts was more similar to the flexibility of the fiber posts than the stainless steel posts. Furthermore, the gold cast posts exhibited the highest flexural strength of all the posts tested ($P = 0.000$), demonstrating that this material, even showing good flexural properties, can support high stresses during the elastic phase resulting in a high flexural strength value.

However, *in vitro* static loading tests demonstrated a significantly higher fracture resistance of teeth restored with a cast gold post and core than for carbon FRC posts and resin composite core [32,33]. Nevertheless, it has been reported that more unfavorable fractures occur in teeth restored with cast post and cores than with carbon fiber posts, the latter showing more fractures that involve the core only, which can be repaired [32–34]. An analysis of the results of the present study offer support for the hypothesis that the difference in performance under fracture load may be more related to the wedging effect determinated by the tapered shape of the cast posts than by the flexural modulus of the metal [35,36].

The results of the present study are mostly in agreement with previously published studies [21–23,37]. On the other hand, some studies have shown that fiber posts have the same or sometimes even less flexibility than metal posts [14,29,30,37]. In some cases [30,38] these results could be explained by the test that was carried out. For instance the axis along which the load was applied had an angle of 45° compared to the long axis of the posts in contrast to the 90° used in the three-point bending test. The fiber-reinforced composite materials are anisotropic and it can be surmised that the more parallel the forces are to the long axis of the post, the higher the flexural modulus will be.

In this study the posts were tested dry at room temperature and even though the authors agree with published reports that humidity can alter the mechanical properties of fiber posts [14,39,40], it has been demonstrated that within the tooth the behavior of posts is comparable to that of dry posts [23,30].

All dentin specimens exhibited sudden brittle fracture upon incremental loading. The results of previous studies using the same test showed flexural modulus values ranging from 8.5 ± 2.8 to 52 ± 11 GPa and flexural strength values ranging from 87 ± 25 to 198 ± 66 MPa [41–43]. The results of the present study are similar to those reported by Sim et al. [42] with regards to the dentin flexural modulus value (15.1 ± 2.1 GPa). The flexural strength values, however, were slightly higher than what has been reported in other studies [41–43].

The elastic properties of dentin have been indirectly obtained in either tensile or compressive measurements [18]. The flexural modulus of root canal posts found in previous studies [14,21,29,30] derived from flexural tests could not therefore be directly compared to Young's dentin modulus obtained with other tests. In the present study the flexural properties of root canal posts and root dentin obtained by the same test indicate that FRC posts have an elastic modulus more similar to that of dentin. On the other hand, the metal posts showed higher differences for flexural modulus when compared to dentin. Furthermore, the flexural strength of fiber and metal posts appears to be very different when compared to the flexural strength of root dentin.

Within the limitations of this study, it may be concluded that FRC root canal posts exhibited flexural properties more similar to those of dentin than metallic posts, confirming previous observations.

Gold cast post with the same shape and dimensions as preformed FRC posts showed a flexibility that approached that of fiber posts more closely than stainless steel posts. Gold cast posts exhibited the highest flexural strength of all posts tested ($P = 0.000$).

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