Original papers

The three-point bending test of fiber-reinforced composite root canal posts

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Abstract

Background. The primary reason for using a post is to retain the core with the objective to restore the missing coronal tooth structure. 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.

Objectives. To characterize the strength parameters of fiber-reinforced composite (FRC) posts with the application of a three-point test. The mean fracture load, flexural strength and flexural modulus were taken into consideration.

Material and methods. For the three-point strength tests, 5 kinds of fiberglass root-posts were used: GC Fiber Post (GC America, Alsip, USA), Mirafit White (Hager Werken, Duisburg, Germany), Innopost (InnoTech, Verona, Italy), Rebilda Post (Voco, Cuxhaven, Germany), and EverStick Post (GC Europe, Leuven, Belgium). For each system, 15 FRC posts were tested. All posts had the same diameter, length and shape. The three-point test was carried out in accordance with ISO 10477:2004, using the Instron-5944 testing machine (Instron, Norwood, USA). The test was carried out until the sample was broken.

Results. The highest force values (67.6 N) were recorded for the GC posts, and the lowest force required to break the sample (29.6 N) was noted for the EverStick Posts. In the case of bending strength, the highest values were also recorded for GC posts (912.4 MPa). Low bending strengths were obtained for the Mirafit White posts (537.2 MPa); however, the EverStick Posts were the weakest (436.2 MPa). Rebilda posts showed the highest modulus of elasticity – 31.1 GPa. The lowest values of the elastic modulus were registered for EverStick Posts – 12.5 GPa.

Conclusions. There were statistically significant differences in fracture loads, flexural strengths and flexural modulus of the FRC-post systems tested. Individually polymerized FRC material showed lower flexural properties than compared prefabricated FRC posts.

Key words: three-point bending test, flexural modulus, flexural strength, fiber-reinforced composite post, individually formed post

Introduction

Posts provide retention for dental materials while the missing coronal tooth structure is being restored. They do not strengthen the tooth.[1,2] To achieve optimum results, the materials that are used for restoration of endodontically treated teeth should have physical and mechanical properties similar to dentin.[3] There is a difference of opinion whether a post should have an elastic modulus close to dentin[4–6] or whether it should be more rigid.[7,8] Posts can be classified based on the elastic modulus, with metallic posts (prefabricated or cast metal posts), ceramic posts and carbon fiber posts presenting high values, and glass fiber posts presenting low elastic modulus.[9,10] Prefabricated and cast metal posts are rigid in nature.[11] The rigidity may pose a risk for root fracture. 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. The biomechanical properties of fiber-reinforced composite (FRC) posts have been reported to be similar to that of dentin.[12–14] Clinical prospective and retrospective studies on the use of fiber posts have reported encouraging results.[15–19]

The first FRC-posts were made of carbon/graphite fibers due to their good mechanical properties. However, they are black in color and thus lack cosmetic qualities. Instead posts made of glass or silica fibers are white or translucent and can be used in situations of higher cosmetic demand.[12,20]

Dental market offers prefabricated and individually formed glass fiber posts. However, prefabricated FRC posts have limitations in their properties, such as poor anatomical fit to the canal. They require preparation of the root canal to fit the shape of the post, which causes loss of dentin and makes the root more vulnerable to root fracture.[21] This emphasizes the importance of trying to preserve the original anatomy of the root canal and minimizing dentin loss throughout the endo-restorative treatment.[22,23] Large root preparation can be avoided by using individually formed FRC posts.[12,24–26] An individually formed FRC post can be polymerized in situ in the root canal, thus precisely following the shape of the canal.[27] The manufacturer's recommendation has been to light-polymerize in 2 phases; first, a short curing is carried out when the post material is placed in the root canal to copy the anatomical shape of the canal. After that the final curing is carried out after removing the post from the canal to ensure complete curing also at the apical parts of the post.

The polymer matrix of individually formed FRC post material consists of both linear and cross-linked phases, which is called semi-interpenetrating polymer network (IPN).[21] This matrix also allows the formation of secondary IPN bonding based on interdiffusion of the resin systems of post and luting cement. The IPN system improves adhesion to composite and increases flexural strength and fatigue strength through the reduction of crack initiation.

Polymer matrix of the FRC post used in the present study is composed of cross-linking monomer system of bisphenol-A-dimethacrylate (Bis-GMA) and linear polymers of polymethyl methacrylate (PMMA) which structurally form semi-interpenetrating polymer networks (semi-IPN).[21] Resiliency of semi-IPN based composites is higher and modulus of elasticity is lower compared to polymer made of crosslinking monomers only.[28,29]

The aim of this study is to:

1) characterize the strength parameters of FRC posts with the application of a three-point test. The mean fracture load, flexural strength and flexural modulus were be taken into consideration.

2) compare the properties of prefabricated FRC posts with custom-made FRC posts in the form of a tape, which achieve full stiffness after the exposure to a polymerization lamp.

3) establish which FRC posts are the most suitable for clinical use.

Material and methods

For this study, 5 different types of endodontic post were selected:

– group 1: GC Fiber Post (GC America, Alsip, USA);
– group 2: Mirafit White (Hager Werken, Duisburg, Germany);
– group 3: Innopost (InnoTech, Verona, Italy);
– group 4: Rebilda Post (Voco, Cuxhaven, Germany); and
– group 5: EverStick (GC Europe, Leuven, Belgium).

Seventy-five endodontic posts, 15 for each group, were tested. All fiber posts were 1.2 mm in diameter, 20 mm in length and had a cylindrical shape with a tapered end. In order to reduce the influence of the conical end of the posts, a 10 mm parallel part of the post was used for the tests.

The EverStick fiber material containing silanized E-glass fibers in light-polymerizable dimethacrylate – polymethylmethacrylate matrix was made into a cylindrical shaped specimen with a diameter of 1.2 mm. EverStick Posts were treated according to the manufacturers' instructions. Tweezers were used to take the post out from the silicone. The length and suitability were checked using electronic caliper. The specimens were polymerized in a light curing lamp for 60 s. A light-polymerizing device (Elipar S10; 3M Espe, Maplewood, USA) with halogen lamp radiating blue light (wavelength 430–480 nm) and with an intensity of 1200 mW/cm² was used.

The three-point bending test according to the ISO 10477 standard (span 10.0 mm, crosshead speed 1.0 mm/min, cross-sectional diameter of loading tip 2 mm) was used to measure the flexural strength and modulus of FRC post specimens. All posts were tested with the material testing machine Instron-5944 (Instron, Norwood, USA). The test was carried out until the sample was broken

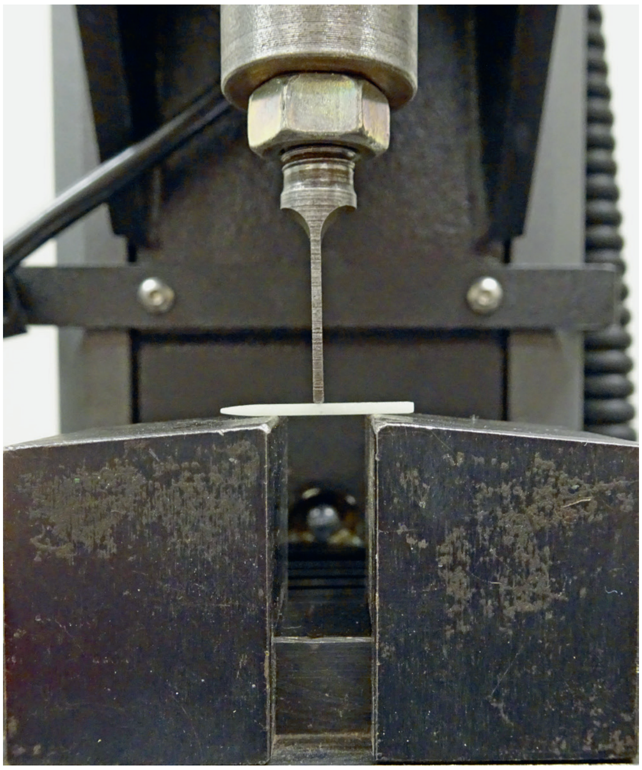

Fig. 1. The post during three-point bending test

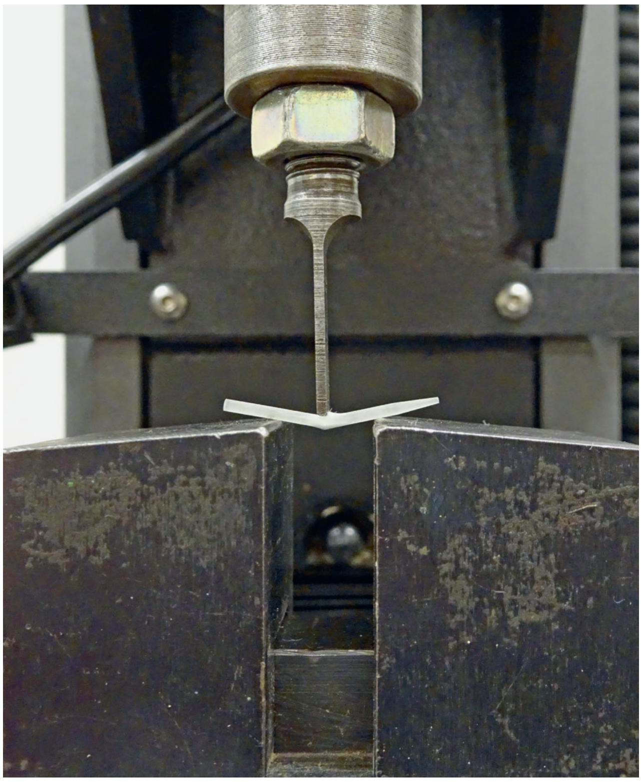

Fig. 2. The broken post after three-point bedning test

(Fig. 1,2). All the tests were carried out in temperature about 22°C. Fracture load of post was measured. Flexural strength (σ) and flexural modulus (E) were calculated from the formula:

$$\sigma = 8F_{max}\,L/\pi d^3\ [\text{MPa}]$$

$$E = 4F_{max}\,L^3/(D3\pi d^4)\ [\text{GPa}],$$

where: F_{max} is the maximum load point of the load-deflection curve [N], L is the distance between the support rollers (10.0 mm), d is the diameter of the specimens [mm], and D is deflection [mm] at Fmax [16] at a point in the straight-line portion of the trace.

The differences between specimens were evaluated using Kruskal–Wallis nonparametric analysis of variance (ANOVA) and the median test. The probability level was set at 0.05.

Results

In the conducted three-point test, the values of maximum forces that caused damage to the FRC post were observed (Table 1). The ANOVA revealed significant differences ($p = 0.05$) in fracture loads, flexural strengths and flexural modulus of the FRC-post systems tested. The highest force values (67.6 N) were recorded for the GC Fiber Posts and the lowest force required to break the sample (29.6 N) was noted for the EverStick Posts (Fig. 3). In the case of bending strength, the highest values were also recorded for GC Fiber Posts – 912.4 MPa (Fig. 4). Low bending strengths were obtained for the Mirafit White posts (537.2 MPa); however, the EverStick Posts were the weakest (436.2 MPa). The elastic modulus was also calculated. Rebilda posts showed the highest modulus of elasticity – 31.1 GPa (Fig. 5). Slightly lower modulus was recorded for GC Fiber Posts – 30.9 GPa; however, the lowest values of the elastic modulus were registered for Mirafit White posts and EverStick Posts – 21.7 GPa and 12.5 GPa, respectively. The elastic module of EverStick Posts proved to be lower than the dentine elasticity modulus, which was 17.5 ±3.8 GPa.

Table 1. The fracture load and flexural properties

Group	Posts type	Fracture load [N]	Flexural strength [MPa]	Flexural modulus [GPa]
Group 1	GC Fiber Post	67.6 ±3.9	992.4 ±58.3	30.9 ±0.9
Group 2	Mirafit White	36.5 ±3.2	537.2 ±47.3	21.7 ±0.9
Group 3	Innopost	52.5 ±4.3	773.5 ±59.6	23.5 ±1.6
Group 4	Rebilda Post	65.3 ±3.3	962.1 ±48.6	31.1 ±1.1
Group 5	EverStick Post	29.6 ±5.1	436.2 ±75.9	12.5 ±2.7

Discussion

Many studies investigating the flexural properties of root canal posts have been published, reporting results that varied greatly.[2,12,30–32] The flexural modulus parameter

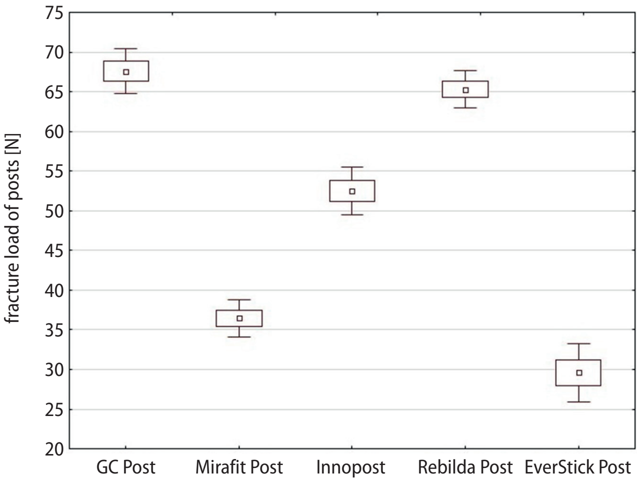

Fig. 3. The fracture load of posts

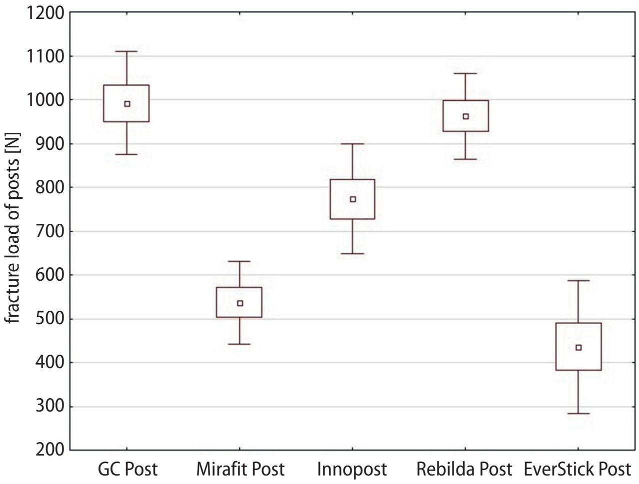

Fig. 4. The flexural strength of posts

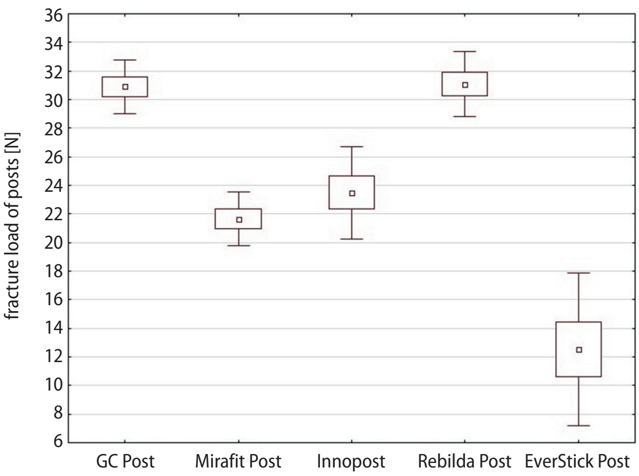

Fig. 5. The flexural modulus of posts

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

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,[2,30,33,34] it has been demonstrated that within the tooth, the behavior of posts is comparable to that of dry posts.[14,32] Lassila et al. revealed that thermocycling for FRC posts had a significant effect on the fracture load and flexural strength.[12] In general, thermocycling decreased the flexural modulus of the tested FRC posts by about 10%. Strength and fracture load decreased by about 18%. Thermocycling slightly decreased the bond strength at the fiber post–core interface.[35]

The EverStick Posts were polymerized in a light-curing lamp (Elipar) for 60 s. Cacciafesta et al. claimed that oven post-curing does not increase the flexural strength values of FRC EverStick Posts compared with conventional hand light-curing.[36]

In the case of prefabricated conventional FRC posts, the location of the post in the center of the root – in the neutral axis of tubular structure – is not optimal to provide effective reinforcing effect by the fibers of the post for the root-core-crown system.[21] In addition, by using the prefabricated FRC posts, the free space of the coronal root canal opening is filled only with weaker particulate filler composite resin cement. In the individually formed, also called custom-made, FRC posts, the fiber volume at the coronal part of the root canal is high and it fills the entire available root canal space. This increases the stiffness and strength of that part of the post and forms a strong support for the core. By considering the mechanics of tubular structure of a tooth and post system, the individually formed posts also provide fiber location closer to the outermost surface of the root, where the high functional stresses are located. Stress distribution in dentin is related to bone height level.[37] Singh et al. assessed that the stress in the dentin, post and the cement was much higher in the tooth with the alveolar bone height of 4 mm from cementoenamel junction (CEJ) compared to the tooth with bone support of 2 mm alveolar bone height from the CEJ.[37]

Lassila et al. claimed that EverStick in their studies presented the highest flexural strength values.[12] Their study investigated the flexural properties of different types of FRC posts (Snowpost, Carbopost, Parapost, C-post, Glassix, and Carbonite) and compared those values with a FRC material for dental applications (EverStick). A three-point bending test (span: 10 mm) was used to measure the flexural strength and modulus of FRC post specimens. The highest flexural strength was obtained with the control material (EverStick). They claimed that this unexpected finding could be explained by the optimization of the polymer matrix and fiber properties to function as a composite material. More precisely, the difference in the polymer matrix of EverStick compared to the matrices of other tested FRCs is based on the existence of poly(methyl methacrylate) (PMMA) chains in the cross-linked polymer matrix. The PMMA chains with a molecular weight of 220 KD plasticize the cross-linked BisGMA-based matrix of the EverStick FRC and reduce stress formation in the fiber–matrix interface during deflection. This may be assumed to contribute to the higher strength of EverStick FRC material.[38]

A different study examined the flexural strength of 2 different fiber post-resin cement systems and the results showed significant differences between the flexural strength of the prefabricated GC Fiber Posts and the individually formed EverStick Posts.[39] A four-point bend test was carried out till failure on all groups. The highest flexural strengths were found for the GC Fiber Posts without silane pretreatment and the second-highest flexural strengths were found for the GC Fiber Posts with silane pretreatment, both of which were higher than the flexural strengths of the EverStick Posts.

Cagidiaco et al. assessed whether the amount of residual coronal dentin and the placement of a prefabricated (DT Light Post) or a individually formed (EverStick Post) have a significant influence on the three-year survival of endodontically treated premolars.[40] Teeth restored with prefabricated DT Light Posts had a three-year survival rate higher (90.9%) than those restored with individually formed EverStick Posts (76.7%).

Conclusions

The following conclusions can be drawn from the study:

1. There were statistically significant differences in fracture loads, flexural strengths and flexural modulus of the FRC-post systems tested.

2. Prefabricated FRC posts exhibit favorable mechanical properties in comparison to individually polymerized FRC. Therefore, their application may result in enhanced clinical performance of endodontically treated teeth.

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