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Resistance to fracture and structural characteristics of different fiber reinforced post systems

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ABSTRACT

Objectives. The aim of this study was to investigate the ultrastructure and resistance to fracture of eight different types of fiber post, and to verify the existence of a correlation between structural characteristics and flexural strength.

Methods. Eight types of fiber post were selected for this study. Fiber Kor (Jeneric-Pentron), Para Post Fiber White (Coltène), Luscent Anchor (Dentatus), Twin-Luscent Anchor (Dentatus), Style Post (Metalor), DT White-Post (VDW), DT Light-Post (VDW) and ER Dentin Post (Brasseler). Ten posts of each experimental group were selected for a three-point bending test, and one was processed for SEM evaluation. A universal testing machine loading at an angle of 90° was employed for the three-point bending test. The test was carried out until fracturing of the post. After fracture testing, the posts with the highest and the lowest values of flexural strength of each system were additionally processed for SEM analysis. SEM evaluation was performed using a PC-measurement program to assess the fiber/matrix ratio and fiber dimensions.

Results. The fracture load of the tested systems ranged from 60 to 96 N and the flexural strength from 565 to 898 MPa. DT White-Post and DT Light-Post (898 and 842 MPa, respectively) had significantly higher flexural strengths than the other posts. Style Post (565 MPa) showed a significantly lower flexural strength than all other posts. The differences in fiber diameter ranged from 8.2 to 21 μm and for the fiber/matrix ratio from 41 to 76%. Of the various structural characteristics investigated, only the fiber/matrix ratio showed a significant correlation to the flexural strength ($r = 0.922$, $p = 0.003$).

Significance. The FRC-posts investigated displayed significant differences with regard to fracture load and flexural strength. A strong and significant linear correlation between the fiber/matrix ratio and the flexural strength was found.

1. Introduction

For 15 years endodontic posts made out of fiber reinforced composites (FRC) have been described in the literature [1,2]. Glass-, silica- and carbon fiber reinforced materials especially, have been marketed and provided the dental profession with the first true alternative to cast or pre-fabricated metal posts [3–6]. FRC-posts contain a high percentage of continuous reinforcing fibers embedded in a polymer matrix. Matrix polymers are commonly epoxy resins or other polymers with a high degree of conversion and a highly cross-linked structure [7–9]. The elastic moduli of fiber posts are closer to dentin than that of any metal post [10]. The first clinical trials reported promising results [3,4,11,12]. Laboratory studies examined different

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luting procedures [13], FRC-post-based abutment build-ups [14,15] and the adhesion of fiber posts to root canal substrates [16–18].

A linear correlation between the diameter of posts and their resistance to fracture load was shown in an investigation involving 17 different FRC-posts [19]. Just recently, another study [9] tested the hypothesis that the fiber diameter and the surface occupied by fibers per square millimeter of post surface – the so called fiber/matrix ratio – is related to the physical properties of a fiber post. However, the study was not able to detect a statistically significant correlation.

Therefore, it is still not clear how the structural properties of FRC-posts influence their flexural strengths. To investigate the relationship between flexural strength and the structural characteristics of FRC-posts the combination of scanning electron microscopy (SEM) and fracture testing can be used. SEM observations can provide the information to assess the fiber/resin matrix ratio and the fiber diameter and look at the interface between the fibers and the matrix.

As fiber posts are basically composite materials, it can be assumed that their mechanical properties are improved with an increase in the fiber portion. The objectives of the present study were to assess the resistance to fracture of different types of fiber posts, and to test the hypothesis that there is a correlation between the resistance to fracture and the structural characteristics of the FRC-posts.

2. Materials and methods

Eight types of esthetic FRC-posts of different brands with continuous unidirectional glass or quartz fibers were selected for this study, namely Fiber Kor (FK), Para Post Fiber White (FW), Luscent Anchor (LA), Twin-Luscent Anchor (TA), Style Post (SP), DT White-Post (WP), DT Light-Post (LP) and ER Dentin Post (ER) (Table 1). From each group 11 posts of small or medium size were collected. Ten of them, randomly chosen, were used for the three-point bending test and one was used for SEM evaluation without being fractured. In addition, the two posts with the highest and the lowest values of flexural strength in each group were processed for SEM evaluation after testing.

2.1. *Three-point bending test*

The three-point bending method was conducted according to the DIN-EN 843-1 in a universal testing machine (Zwick BZ010/TN 2A, Zwick, Ulm, Germany). The load was applied to standard posts with a loading angle of 90° and a crosshead speed of 0.5 mm/min until fracture. The two supports and the central loading anvil had a 2-mm cross-sectional diameter and the distance between the two supports was 8 mm. All the tests were carried out at a room temperature of approximately 22 °C.

As the post systems investigated had different diameters and different designs (conical, cylindrical, cylindrical–conical), a central area with a diameter of 1.15 mm, which all post systems had in common in a certain section, was selected as the area of load application. This point was assessed using an electronic sliding caliper, marked on the post and was placed in the midst of the two supports (Fig. 1).

The load-deflection curves were registered with PC-software (TestXpert, Zwick, Ulm, Germany) and fracture load and flexural strength were determined. All values were analyzed by performing one-way ANOVA (Statgraphics V 4.1, Statistical Graphics Corp., Rockville, Maryland, USA). To reveal the statistical differences between the different post systems the Bonferroni-test was subsequently applied. The statistical significance was set at $p < 0.05$.

2.2. *SEM analysis*

To prepare the allocated specimens for SEM-analysis the cross-sectional surface of each post was wet-ground (Unipolisher, Metaserv Ltd., Betchworth, Surrey, UK) with 4000 grit (FEPA). Then the samples were fixed on metallic stubs and sputtered with gold in an ion-sputtering device (Balzers Ltd.,

Table 1 – Post systems tested in the study, their characteristics and group codes

Product name and manufacturer	Abbreviation	Size	Mean post diameter (mm)	Post design	Fiber material
Fiber Kor, Jeneric-Pentron, Wallingsford, CT, USA	FK	M	1.15	Cylindrical	Glass
Para Post Fiber White Coltene-Whaledent, Mawhaw, NJ, USA	FW	M	1.15	Cylindrical	Glass
Luscent Anchor, Dentatus, New York, NY, USA	LA	M	1.25	Conical	Glass
Twin-Luscent Anchor, Dentatus, New York, NY, USA	TA	M	1.25	Conical	Glass
Style Post, Metalor Technologies, Stuttgart, Germany	SP	M	1.225	Cylindrical–conical	Glass
DT Light-Post, VDW, Munich, Germany	LP	S	1.225	Conical	Quartz
DT White-Post, VDW, Munich, Germany	WP	S	1.225	Conical	Quartz
ER Dentin Post, Brasseler, Lemgo, Germany	ER	M	1.35	Cylindrical–conical	Glass

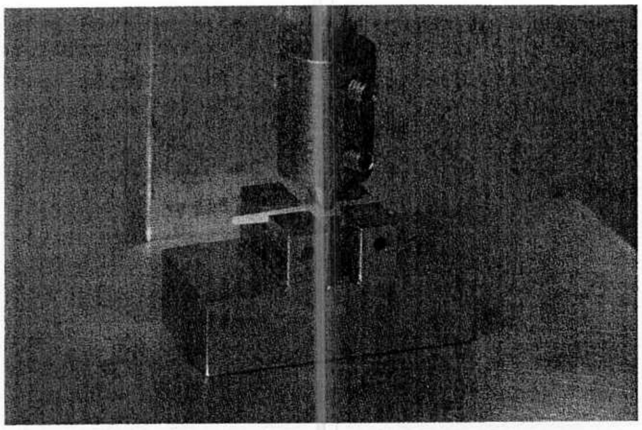

Fig. 1 – Test set up with a conical post. The load was applied at the area in which a diameter of 1.15 mm was measured.

London, UK). The visual examination of the surfaces was performed with a scanning electron microscope (Philips XL 30 CP, Philips, Eindhoven, The Netherlands).

Two microphotographs of each surface were taken for documentation. The first one was taken with a magnification of 200× to serve as an overview. The area with the most characteristic fiber-distribution was chosen for a second microphotograph with a magnification of 2000×. It enclosed an area of 87 μm × 100 μm. The diameter of the fibers, the number of fibers in the investigated surface area and the fraction of the investigated surface area occupied by fibers (=fiber/matrix ratio) were measured and recorded using PC-software (Leica IM50 V 4.0, Leica Microsystems, Cambridge, UK). Based on the measurements, the number of fibers per square millimeter and the overall circumference of fibers per square millimeter (representing the total interface between fibers and matrix in a cross-sectional area of one square millimeter) were calculated.

To evaluate possible correlations between the physical properties recorded in the three-point bending test and the structural characteristics of the SEM-analysis a linear-regression test was used (Statgraphics V 4.1, Statistical Graphics Corp., Rockville, Maryland, USA). The statistical significance of the correlations was set at $p < 0.01$.

3. Results

The mean fracture loads and flexural strengths of the post systems tested are presented in Table 2. The Bonferroni test revealed a segmentation of the eight post systems into four groups which gave statistically similar results (Fig. 2). The highest values for fracture load were recorded for DT White-Post (95.8 N) and DT Light-Post (89.8 N) (group 1). Groups 2 and 3 included five post systems with values ranging from 82.1 N for the ER Dentin Post to 71.7 N for the Para Post Fiber White. The lowest values were recorded for the Style Post system (60.3 N) which formed group 4. The outcome of the analysis on flexural strength showed an analogous distribution into four statistically similar groups with the highest values obtained by DT White-Post with 898 MPa and the lowest value for Style Post with 565 MPa (Fig. 2).

Table 2 – Summary of the mean physical properties and structural characteristics of the eight post systems (standard deviations in parentheses)

Type of post	SP	FW	FK	TA	LA	ER	LP	WP
Fracture load (N)	60.3 (5.8)	71.7 (5.2)	74.2 (5.0)	75.5 (3.6)	75.9 (4.2)	82.1 (4.5)	89.8 (7.5)	95.8 (2.9)
Flexural strength (MPa)	565 (55)	672 (49)	695 (46)	708 (34)	711 (39)	770 (43)	842 (71)	898 (27)
Diameter of fiber (μm)	21.0[a] (5.0)	8.8 (0.5)	8.8 (0.4)	14.8 (0.2)	16.4 (0.3)	12.5 (1.2)	13.3 (0.5)	8.2 (0.2)
Fiber/matrix ratio (%)	57.5[a] (9.8)	40.9 (14.9)	41,5 (7.8)	53.7 (3.1)	51.6 (6.4)	70.1 (2.4)	71.8 (2.5)	75.9 (2.0)
Number of fibers per square millimeter	2671[a]	7915	8333	4186	3158	6583	6240	14612
Overall circumference of fibers per square millimeter (mm)	55[a]	218	230	191	162	260	260	377

Group codes are listed in Table 1.

[a] Mean values for the structural characteristics of the Style Post were calculated from the examination of the area containing the fibers with larger diameter (Fig. 4).

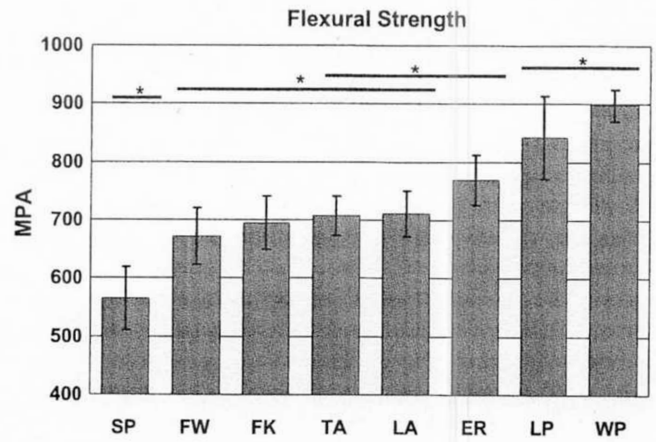

Fig. 2 – Mean flexural strengths of the tested post systems. Standard deviations are indicated by vertical lines. The horizontal lines connecting groups indicate which groups do not differ statistically at $p = 0.05$. Group codes are listed in Table 1.

Table 2 shows the structural characteristics obtained by the SEM-evaluation of the cross-sectional post surfaces for the eight post systems. The results are based on the investigation of three posts: one unfractured post and the two posts that showed the highest and the lowest values of resistance to fracture, respectively.

The diameter of the fibers ranged from 8.2 μm for the DT White-Post up to 21.0 μm for the Style Post. Also, substantial differences were found for the fiber/matrix ratio of the different post systems. Fiber Kor and Para Post Fiber White showed the lowest ratio with approximately 41% whereas for ER Dentin Post, DT White-Post and DT Light-Post the fiber/matrix ratio was above 70%. The other three systems ranged between 50 and 60%. These results are illustrated in the SEM micrographs of Fig. 3, in which the differences in fiber diameter and fiber/matrix ratio are visible.

Of all eight post systems investigated only the Style Post included fibers of widely varying diameters which were inhomogeneously distributed (Fig. 4). Therefore, the Style Post system was excluded from the correlation analysis. To further evaluate the interrelation between fiber diameter and fiber/matrix ratio the number and the overall circumference of fibers per square millimeter were calculated (Table 2).

Of the four structural characteristics investigated only the fiber/matrix ratio showed a strong and significant correlation ($p = 0.003$; Pearson's correlation-coefficient $r = 0.922$) with the flexural strength (Fig. 5). A correlation between diameter, number or overall circumference of fibers per square millimeter and the results of the three-point bending test was not detected. Therefore, the hypothesis that there is a correlation between the resistance to fracture and the structural characteristics of the FRC-posts was only partially approved.

4. Discussion

Besides the post diameter and the post design, several other factors might influence the mechanical properties of FRC-posts, i.e. the mean diameter of fibers, number of fibers (fiber-density) in a certain area, fiber-orientation, length of the embedded fibers, type of matrix polymer and the strength of the interfacial bonding [20].

The matrix of modern FRC-post systems generally consists of synthetic resins or bisGMA polymers and only a few systems also contain PMMA chains of a high molecular weight (>220 kDa). While fibers in FRC-posts are meant to be the component with high tensile strength, the matrix should be considered to be the part which withstands compressive stresses, due to the high portion of macro- and microfillers in the resin matrix. Another function of matrix composites is the absorption of emerging stresses in the overall post system. Due to the different elastic moduli of glass/silica fibers and matrix composites stresses normally develop at the interface between the fibers and the matrix, and propagate along the surfaces of the fibers when the posts are loaded. Structural failures such as voids, cracks or micro bubbles, which might occur during the manufacturing process, will weaken the post [9]. Therefore it can be assumed that not only an increase of the fiber/matrix ratio alone, but also an increase of the total interface area, will lead to higher stiffness and a higher elastic modulus.

However, laboratory studies showed that it is not always desirable to raise the stiffness of FRC-posts to maximum values. The highest fracture strengths of restored teeth were obtained using posts with elastic moduli which were close to the elastic modulus of dentin. High values of elastic modulus often lead to unfavourable root fractures [21,22]. PMMA chains with a high molecular weight might plasticize the stiff highly cross-linked bisGMA matrix and reduce stress formation in the fiber–matrix interface during deflection [19]. This could be an explanation for the moderately good values of Para Post Fiber White, which contained the least amount of fibers.

Embedding of fibers in a resin matrix is the reason for the improvement of the mechanical properties of all the post systems examined. However, the material and the manufacturing process of the fibers in these posts are obviously not identical. Commonly used posts usually contain e-glass fibers (electric glass/e-modulus = 73 GPa) that consist of SiO_2, CaO, B_2O, Al_2O and a few other oxides of alkali metals in its amorphous phase. R-Glass (86 GPa) and S-glass (high-strength-glass/87 GPa) are also amorphous but differ in composition [19]. The filament diameters of R- and S-glass are smaller which enhances the matrix ability to spread between the fibers and leads to an increase in interlaminar tightness. A similar quartz-glass used in DT Light-Post and DT White-Post is made out of pure silica. Its elastic modulus does not differ much from the other types of glasses but its low coefficient of thermal expansion seems to benefit the structural integrity during thermal alteration [9,23].

Another re-enforcing effect of fibers can be created during the manufacturing process of posts. Pre-stressed fibers are soaked with resin and released after curing. This procedure causes compression of the glass fibers which are able to absorb tensile stresses while the post is exposed to flexural forces. Pre-treatment of fiber surfaces by sandblasting [24] or silanization techniques are other methods essential in improving the strength of the fiber/matrix interface [25].

The present study aimed to show a correlation between mechanical properties and structural characteristics of selected FRC-post systems. This correlation could be detected between fiber/matrix ratio and flexural strength for seven of

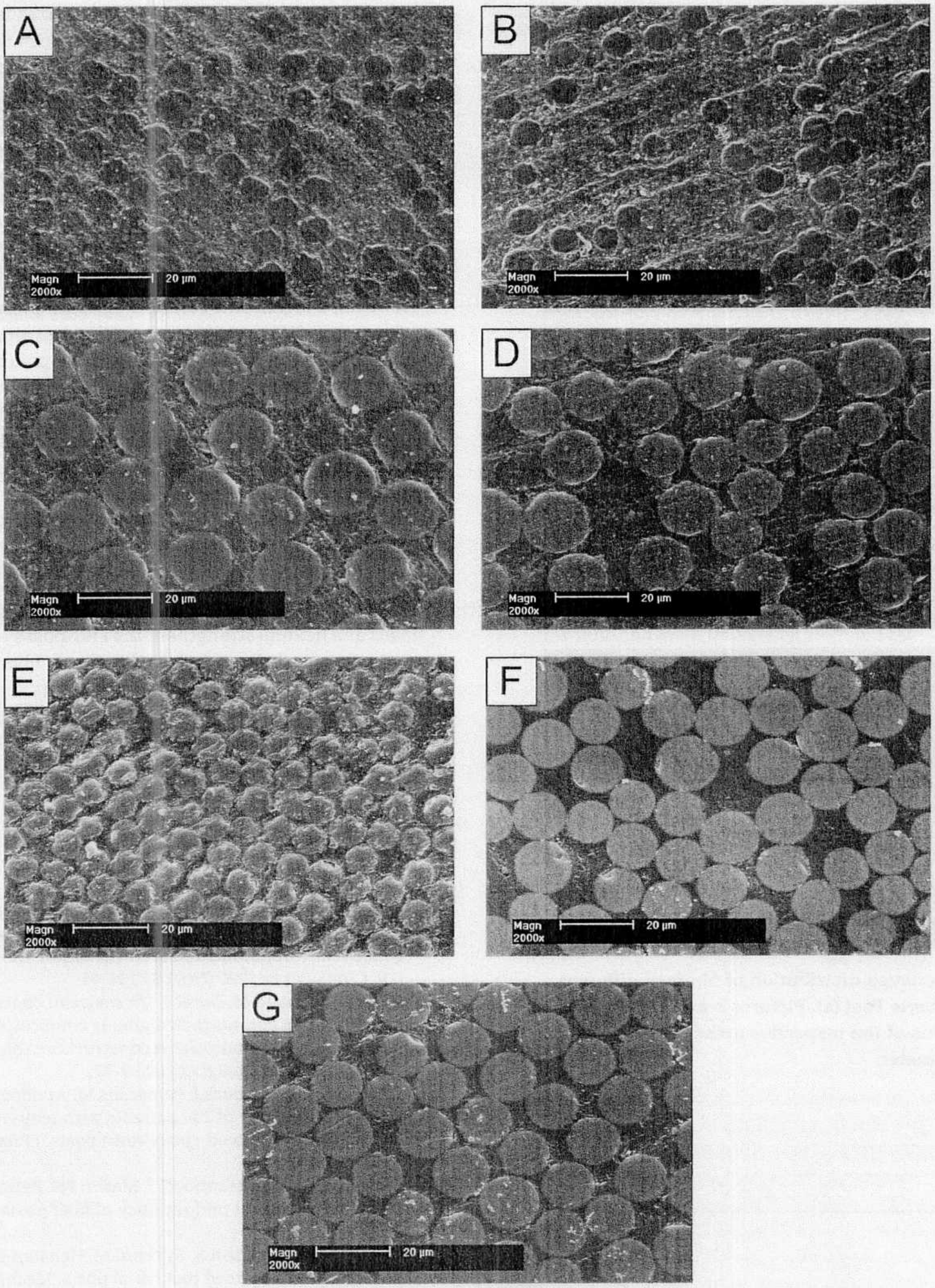

Fig. 3 – SEM microphotographs of seven post systems showing differences in fiber diameter and fiber/matrix ratio: Fiber Kor (a), Para Post Fiber White (b), Luscent Anchor (c), Twin-Luscent Anchor (d), DT White-Post (e), DT Light-Post (f) and ER Dentin Post (g).

the systems tested, while the Style Post system was excluded from this analysis because it showed an inhomogeneous distribution of fibers with widely varying diameters (Fig. 4). Fig. 3a and b shows the surfaces of two posts with low values for flexural strength: Fiber Kor (a) and Para Post Fiber White (b) and Fig. 3e and f shows the surfaces of two posts with high values: DT White-Post (e) and DT Light-Post (f). A possible explanation for the significantly lower flexural strength of the Style Post could be a weak interfacial bonding caused by irregularities produced during the manufacturing process, as other post systems like the Twin-Luscent Anchor (Fig. 3d) with a comparable fiber/matrix ratio had a considerably higher flexural strength.

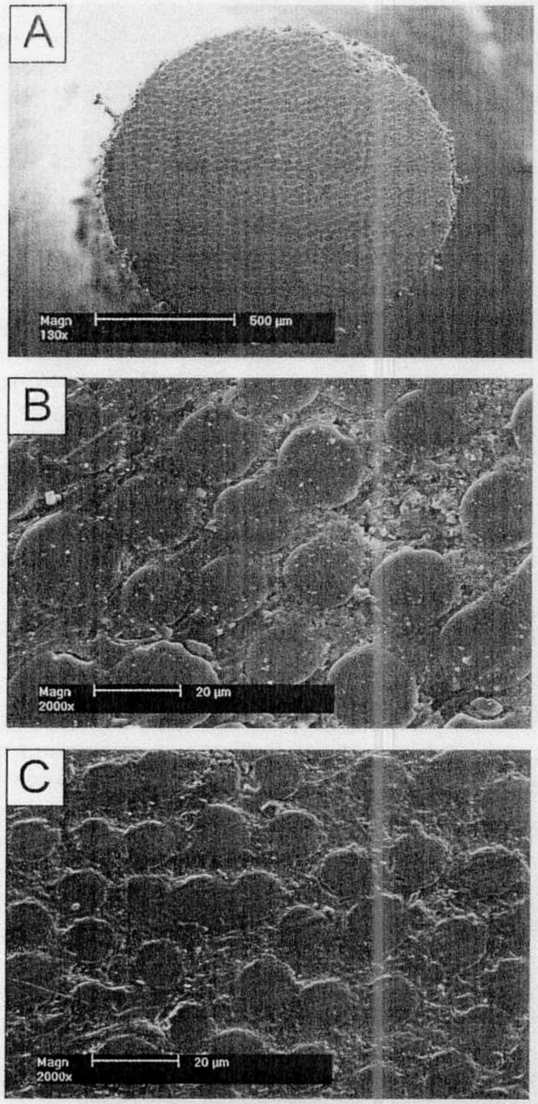

Fig. 4 – The uneven distribution of fibers of different diameter of Style Post (a). Pictures b and c show higher magnifications of the respective areas with fibers of different diameter.

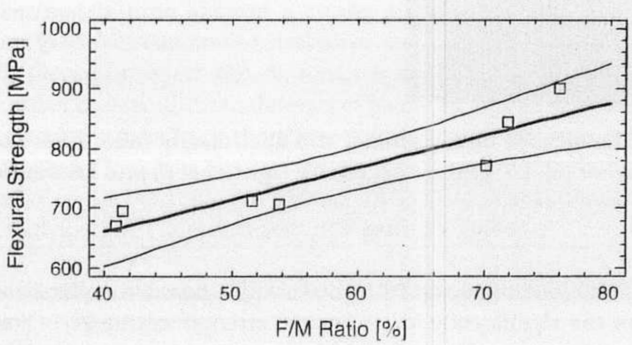

Fig. 5 – The chart shows a strong and significant correlation ($p = 0.003$; Pearson's correlation-coefficient = 0.922) between the fiber/matrix ratio and the flexural strength.

This assumption is supported by clearly visible voids and bubbles found in the Style Post (Fig. 4b). It has been described that these voids and bubbles can negatively influence the mechanical properties of posts [9]. Another reason for the relatively low flexural strength of the Style Post might be the large diameters of its fibers which eventually limit the regular spread of matrix polymers between the fibers. In addition, the fiber distribution in this post system was found to be inhomogeneous compared to the other systems (Fig. 4a–c). The presence of very small diameter fibers located next to an area of very large diameter fibers was remarkable.

However, a significant correlation between the overall circumference of all fibers per square millimeter representing the interfacial area and the results of the three-point bending test was not found. An explanation might be that increasing the fiber surface area – an increased number of small fibers leads to a greater overall fiber surface – only increases the fracture load if the interfacial bonding between the fibers and the resin matrix works perfectly.

Under the limitations of the study the following conclusions can be drawn:

1. There were statistically significant differences in fracture loads and flexural strengths of the FRC-post systems tested.
2. A strong correlation was found between fiber/matrix ratio and flexural strength of FRC-post systems.
3. Data on the clinical outcome of specific FRC-post systems are needed before they can be recommended for clinical application.

REFERENCES

[1] Duret B, Reynaud M, Duret F. Un nouveau concept de reconstitution corono-radiculaire: le composiposte (1) [new concept of coronoradicular reconstruction: the composipost (1)]. Chir Dent Fr 1990 (Nov);60:131–41.

[2] Duret B, Reynaud M, Duret F. Un nouveau concept de reconstitution corono-radiculaire: le composiposte (2) [new concept of coronoradicular reconstruction: the composipost (2)]. Chir Dent Fr 1990 (Dec);60:69–77.

[3] Fredriksson M, Astback J, Pamenius M, Arvidson K. A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. J Prosthet Dent 1998;80:151–7.

[4] Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. Am J Dent 2000;13:9B–13B.

[5] Torbjörner A, Karlsson S, Syverud M, Hensten-Pettersen A. Carbon fiber reinforced root canal posts. Mechanical and cytotoxic properties. Eur J Oral Sci 1996;104:605–11.

[6] Sieber C, Thiel N. Eine lichtoptische Möglichkeit—Spinell/Luminaries. Quintessenz Zahntech 1994;20:1041–51.

[7] Behr M, Rosentritt M, Scharnagl P, Leibrock A, Loose M, Handel G. Faserverstärkte Kunststoffe in der Zahnmedizin. Zahnärztliche Welt – Zahnärztliche Rundschau – Zahnärztliche Reform 1998;107:588–92.

[8] Terry DA, Triolo PT, Swift EJ. Fabrication of direct fiber-reinforced posts: a structural design concept. J Esthet Restor Dent 2001;13:228–40.

[9] Grandini S, Goracci C, Monticelli F, Tay FR, Ferrari M. Fatigue resistance and structural characteristics of fiber posts:

three-point bending test and SEM evaluation. Dent Mater 2005;21:75–82.

[10] Rosentritt M, Furer C, Behr M, Lang R, Handel G. Comparison of in vitro fracture strength of metallic and tooth-coloured posts and cores. J Oral Rehabil 2000;27:595–601.

[11] Malferrari S, Monaco C, Scotti R. Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts. Int J Prosthodont 2003;16:39–44.

[12] Ferrari M, Vichi A, Garcia-Godoy F. Clinical evaluation of fiber reinforced epoxy resin posts and cast post and cores. Am J Dent 2000;13:15B–8B.

[13] Grötsch G. Glasfaserverstärkte Kunststoffe. Allgemeines und Probleme um glasfaserverstärkte Kunststoffe (GFK). Quintessenz 1965;16:47–9.

[14] Hornbrook DS, Hastings JH. Use of bondable reinforcement fiber for post and core build-up in an endodontically treated tooth: maximizing strength and aesthetics. Pract Periodontics Aesthet Dent 1995;7:33–42.

[15] Mannocci F, Ferrari M, Watson TF. Microleakage of endodontically treated teeth restored with fiber posts and composite cores after cyclic loading: a confocal microscopic study. J Prosthet Dent 2001;85:284–91.

[16] Ferrari M, Mannocci F, Vichi A, Cagidiaco MC, Mjör IA. Bonding to root canal: structural characteristics of the substrate. Am J Dent 2000;13:255–60.

[17] Chappell RP, Cobb CM, Spencer P, Eick JD. Dentinal tubule anastomosis: a potential factor in adhesive bonding. J Prosthet Dent 1994;72:183–8.

[18] Purton DG, Chandler NP, Qualtrough AJ. Effect of thermocycling on the retention of glass–fiber root canal posts. Quintessence Int 2003;34:366–9.

[19] Lassila LV, Tanner J, Le Bell AM, Narva K, Vallittu PK. Flexural properties of fiber reinforced root canal posts. Dent Mater 2004;20:29–36.

[20] Callister WD. Materials science and engeneering: an introduction. Composites. 3rd ed. New York: Wiley; 1997. p. 513–541 [chapter 17].

[21] Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002;87:431–7.

[22] Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89: 360–7.

[23] Tezvergil A, Lassila LV, Vallittu PK. The effect of fiber orientation on the thermal expansion coefficients of fiber-reinforced composites. Dent Mater 2003;19: 471–7.

[24] Piesold JU. Vergleichende Untersuchungen zur Eignung von Stiftsystemen mit glatter und strukturierter Oberfläche für die transdentale Fixation. Quintessenz 1991;11: 1817–24.

[25] Gu W. Interfacial adhesion evaluation of uniaxial fiber-reinforced–polymer composites by vibration damping of cantilever beam. PhD Thesis. Virginia Polytechnic Institute and State University; 1997. p. 11–3.