Original Paper

Fatigue Resistance and Structural Integrity of Different Types of Fiber Posts

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The study aimed at assessing and estimating the fatigue resistance of different fiber posts and to observe their ultrastructures through SEM.

Six types of fiber posts were used: GC Fiber Post (Group 1), ParaPost Fiber White (Group 2), FibreKor (Group 3), DT Light-Post radiopaque (Group 4), FRC Postec (Group 5), and Luscent Anchors (Group 6). Ten out of 15 posts within each group were used for the fatigue test, and the other five were processed for SEM evaluation.

The fatigue test revealed that Groups 1, 4, and 5 performed better than all the other groups, and that their performance differed significantly from the other tested groups from a statistical standpoint. For SEM analysis, Groups 1, 4, and 5 also obtained better results.

Through correlation analysis, an absence of correlation between fatigue resistance and structural characteristics suggested that the latter reflected more of the divergence inherent in the manufacturing process of fiber posts.

Key words: Fiber post, Fatigue test, SEM

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INTRODUCTION

Over the recent years, the development of fiber posts has evolved in leaps and bounds. The introduction of carbon fiber posts in 1990[1)] provided the dental profession with the first true alternative to metal posts, either cast or prefabricated. The material had an elastic modulus much closer to dentin than any of the metal posts[2)], and the clinical trials performed on fiber posts yielded convincing results[3-8)]. However, the posts first produced had some inadequacies with regard to their universal use, as they were radiolucent and difficult to mask under all-ceramic or composite restorations[9)]. Subsequently, radiopaque fiber posts were obtained and more esthetic posts were produced. These improvements brought about a drastic change in the acceptance of fiber posts by the dental profession.

As a consequence of practitioners finding esthetic fiber posts a viable alternative to metal posts[10)], a diverse range of fiber posts were quickly introduced into the market. In response to this surge in the use of fiber posts, many studies have been conducted on the adhesion of fiber posts to root canal substrates[11-13)], on the different luting procedures[14,15)], and the abutment build-up[16-18)]. All these studies favorably demonstrated the quality performance of fiber posts[19,20)].

The rapid influx of these new esthetic fiber posts has fuelled the need for a systematic evaluation of their mechanical properties and clinical performance. To meet these evaluation objectives, scanning electron microscopy (SEM) and fatigue test can provide an indication of which type of post would perform better under clinical conditions. In addition, SEM observation can be useful for assessing the fiber/resin matrix ratio, as well as fiber diameter and the global integrity of the post.

Fatigue is considered as one of the main causes of structural failure in restorative dentistry[21-24)]. It has been reported that dental restorations fail more frequently under cyclic loading tests that are well below the ultimate flexural strength of these materials, *versus* the application of a single, relatively higher, external force[25)]. Fatigue tests can reveal the resistance level of each type of post under cyclic loading, which simulates the normal occlusal and masticatory function[16,26,27)].

On fiber posts, they are in essence composite materials. Therefore, it seems logical to expect their mechanical properties to increase as a result of increased fiber content. The objectives of the present study were to assess the fatigue resistance of six different types of fiber posts, and to acquire an insight of their ultrastructures through scanning electron microscopic observation. The null hypotheses tested were: (1) there are no differences in the structural integrity and in the fiber/resin ratio of the posts; and (2) there are no differences in fatigue resistance among the different kinds of fiber posts.

Table 1 Structural characteristics of the six groups of tested posts

Group	Type of post	Post diameter (mm)	Fiber diameter (μm)	Fiber density (number of fibers per mm^2)	Surface occupied by fibers per mm^2 of post surface (μm/mm^2)
Group 1	GC Fiber Post	2.0	12	34	395
Group 2	ParaPost Fiber White	1.5	6	18	110
Group 3	FibreKor	1.5	18	28	505
Group 4	DT Light-Post radiopaque	2.0	12	32	390
Group 5	FRC Postec	2.0	12	25	300
Group 6	Luscent Anchors	1.7	15	29	195

Table 2 Scoring method to quantify the structural integrity of posts, as assessed under the scanning electron microscope

Score 0	Score 1	Score 2
No voids/bubbles	Microvoids/bubbles (diameter<20 microns)	Voids/bubbles (diameter>20 microns) and/or fiber detachment

MATERIALS AND METHODS

Six types of esthetic posts were selected for this study (Table 1). They were GC Fiber Post (GC, Tokyo, Japan; Group 1, pretensioned glass fibers), ParaPost Fiber White (Coltene/Whaledent, Mawhaw, NJ, USA; Group 2, glass fibers), FibreKor (Jeneric Pentron, Wallingford, CT, USA; Group 3, glass fibers), DT Light-Post radiopaque (RTD, Grenoble, France; Group 4, pretensioned glass fibers), FRC Postec (Ivoclar Vivadent, Schaan, Liechtenstein; Group 5, glass fibers), and Luscent Anchors (Dentatus, New York, NY, USA; Group 6, glass fibers). For each group, 15 posts of the largest available size (Table 1) were collected. Post diameter in the different groups varied from 1.5 mm to 2.0 mm. Ten randomly chosen posts were used for the fatigue test, whereas five more were processed for SEM evaluation.

Fatigue test

Ten posts from each group were tested in a fatigue test machine (Procyon systemes, France). This device had a counter that measured the number of cycles, and that it automatically stopped when the specimen broke (Fig. 1). The three-point bending method of loading was applied, with a loading angle of 90° at a frequency of 3 Hz. All posts were subjected to the same loading conditions. Loading by punch was 20 N at the beginning, and reached 100 N at the end of each cycle. The two supports and the punch had a 3 mm diameter, and distance between the two supports was 9 mm. In tapered posts, the loading punch was positioned on the straight portion of the post. Luscent Anchor posts, which had a conical shape, were loaded at the midpoint of the post length. All the tests were carried out at a room temperature of approximately 22°C. The machine was set to carry out 2,000,000 cycles. The assumption was that teeth normally come into contact once a minute, and therefore this number of cycles would simulate about four years of physiological occlusal and masticatory activity[5,7].

Fig. 1 A post ready to be tested.

For fiber posts that failed prior to reaching the projected number of cycles, the actual number of resisted cycles as counted by the fatigue test machine was recorded. Differences among the tested posts in the number of resisted cycles were tested for statistical significance with one-way ANOVA, followed by the Bonferroni test for multiple comparisons. The level of significance was set at $p<0.05$.

Upon completing the fatigue test, the posts were processed for SEM evaluation. The latter was aimed at verifying whether any changes had occurred in the post structure as a result of loading. Detected modifications were documented through microphotographs.

SEM evaluation

Each post was cross-sectioned into two halves using a diamond saw (Isomet, Buehler, Lake Bluff, NY). One half was used for the observation of the surface exposed by the cross-sectional cut, whereas the other half was again sectioned longitudinally (with the same diamond saw described above) to examine the fibers along their longitudinal axes. The external surface of this half of each sectioned fiber post was also examined.

The specimens were mounted on metallic stubs and sputtered with gold in an ion-sputtering device (Balzers Ltd., London, UK). Then, the specimens were observed using a scanning electron microscope (Philips 505, Eindhoven, The Netherlands), and microphotographs were taken for documenting the morphologic characteristics of the posts. Fiber diameter, the number of fibers per mm^2, and the surface occupied by fibers per mm^2 of post surface were measured. Three microphotographs were taken for the evaluation of each post, and results were obtained by calculating the mean of the scores assigned to the three individual microphotographs. In addition, the presence of voids/bubbles within the post and on its outer surface was assessed and expressed through a score system, which was thus defined (Table 2): 0=no voids or bubbles are visible; 1=microvoids or bubbles can be detected (diameter<20 microns); 2=voids or bubbles (diameter>20 microns) are evident and/or fiber detachment due to a loose bond with the resin matrix.

The scoring method allowed for a quantitative evaluation of the structural integrity of the posts, as well as for a statistical evaluation of the differences among the various types of posts. SEM scores were assigned by two different operators, who separately examined the microphotographs taken from the specimens. Where disagreement arose between the two investigators on the score assigned to a specimen, the worse score was chosen for the statistical analysis. The observations were repeated twice to verify interexaminer reliability. Differences in scores recorded for the six groups of posts were tested for statistical significance with Kruskall-Wallis ANOVA by ranks, followed by Mann-Whitney U test for multiple comparisons. Level of statistical significance was set at $p<0.05$.

Correlation analyses

A further objective of the investigation was to verify the existence of a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics, namely fiber diameter, fiber density, and the surface occupied by fibers per mm^2 of post surface. For this purpose, the strength of correlation between the number of resisted cycles and each of the abovementioned structural variables of the posts was measured by calculating the Pearson's correlation coefficients. Statistical significance of the correlations was also assessed ($p<0.05$).

RESULTS

Fatigue test

Table 3 lists the means and standard deviations of the numbers of cycles that the different types of posts were able to withstand before breaking. Results of the statistical analysis performed on these data are summarized in Table 4.

Highest resistance to cyclic loading was exhibited by GC Fiber Post and DT Light-Post (Groups 1 and 4), followed by FRC Postec (Group 5). None of the specimens from GC Fiber Post and DT Light-Post broke after two million cycles, whereas among the FRC Postec posts only one failure occurred. From a statistical standpoint, the results given by these three groups were similar (Table 4).

On the other hand, FibreKor, Luscent, and

Table 3 Means and standard deviations of the numbers of cycles that each type of post withstood before breaking

Group	Type of post	Shape	Mean number of resisted cycles	Standard deviation	Minimum number of resisted cycles	Maximum number of resisted cycles
Group 1	GC Fiber Post	Double-tapered	2,000,000	0	2,000,000	2,000,000
Group 2	ParaPost Fiber White	Cylindrical with serrations	84,915.7	59325.4	15,968	373,882
Group 3	FibreKor	Cylindrical with serrations	29,687.8	24327.5	3,297	82,375
Group 4	DT Light-Post radiopaque	Double-tapered	2,000,000	0	2,000,000	2,000,000
Group 5	FRC Postec	Double-tapered	1,910,513.7	282,980.5	1,105,137	2,000,000
Group 6	Luscent Anchors	Conical	807,242.9	213,567.7	467,421	989,640

Table 4 A star sign indicates that the difference between the groups was statistically significant. The minus sign indicates that the difference between the two mean values was negative

ParaPost, FibreKor	*vs*	*(−)Light-Post, Postec, GC Fiber Post, Luscent Anchors
Luscent Anchors	*vs*	*(−)Light-Post, Postec, GC Fiber Post *FibreKor, ParaPost
FRC Postec, DT Light-Post, GC Fiber Post	*vs*	*FibreKor, ParaPost, Luscent Anchors

Table 5 Median values of the scores assigned to the different types of posts, providing an estimate of each post's structural integrity, as shown by scanning electron microscopy

Group	Type of post	Scores		
		Cross-section of post	Longitudinal section of post	External surface of post
Group 1	GC post	0	0	0
Group 2	ParaPost Fiber White	2	2	1
Group 3	FibreKor	0	1	1
Group 4	DT Light-Post radiopaque	0	0	0
Group 5	FRC Postec	0	0	0
Group 6	Luscent Anchors	1	2	1

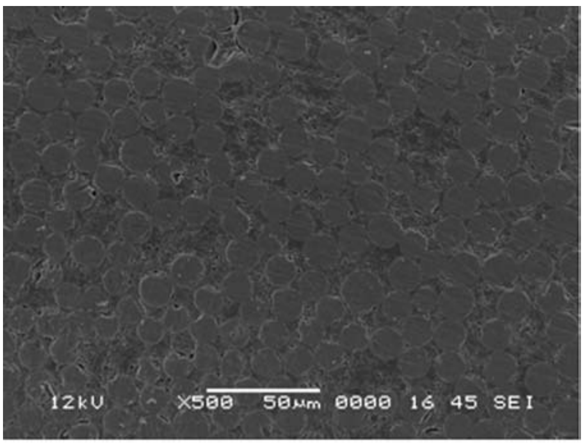

Fig. 2 Surface of Group 1 sample after the cross-sectional cut.

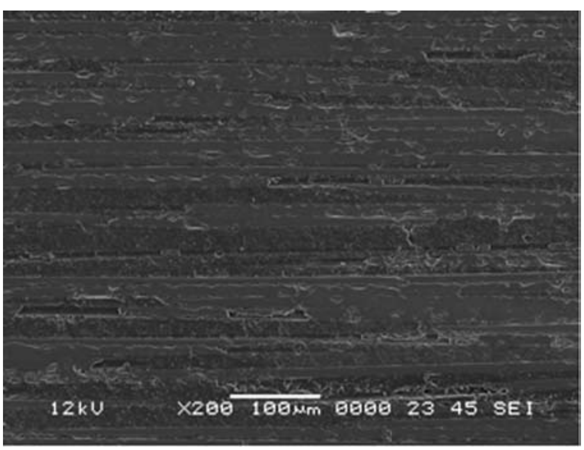

Fig. 3 Surface of Group 1 sample after the longitudinal cut.

Fig. 4 A sample from Group 3, whereby post was fractured after fatigue test.

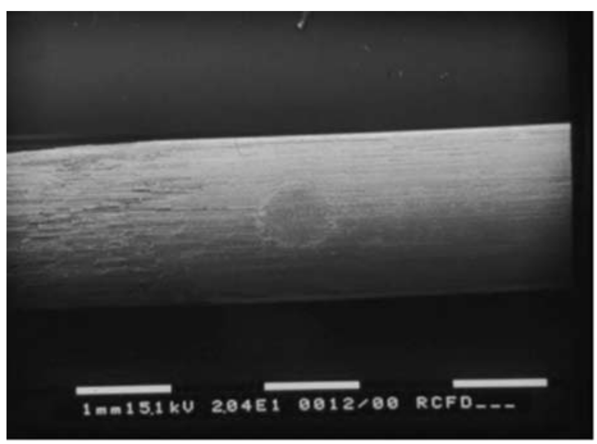

Fig. 5 A sample from Group 4, whereby the post remained unbroken after 2,000,000 cycles. Contact area with the loading punch is evident.

Table 6 Strength and statistical significance of the correlation between posts' fatigue resistance and their structural characteristics

Variable		Variable		
		Fiber Diameter	Fiber Density	Surface occupied by fibers per mm^2 of post surface
Mean number of resisted cycles	Pearson's correlation coefficient	r = 0.128	r = 0.028	r = 0.112
	Statistical significance	p = 0.257	p = 0.806	p = 0.322

ParaPost (Groups 3, 6, and 2 respectively) showed fatigue resistance levels that were significantly lower than the other tested posts (Table 4).

Structural integrity
The scores assigned to the different types of posts in order to quantify their structural integrity, as revealed by SEM observation, are summarized in Table 5. Specimens from ParaPost and Luscent groups (Groups 2 and 6 respectively) exhibited voids and/or bubbles within the post structure on both the cross- and longitudinal sections. The ParaPost group recorded scores significantly higher than the other tested posts ($p<0.05$). Only specimens from DT Light-Post (Group 4), FRC Postec (Group 5), and GC Fiber Post (Group 1) neither exhibited visible structural defects on the cross and longitudinal sections (Figs. 2 and 3) nor on the outer surface of the posts. The scores assigned to these three types of posts were significantly lower than the other tested groups ($p<0.05$).

When the posts that were fractured after load cycling were observed under SEM, their loss of structural integrity was evident (Fig. 4). On the other hand, the DT Light-Post, GC Fiber Post, and FRC Postec posts, which were able to withstand the fatigue test, exhibited only a small circumferential depression at the area of contact with the loading punch (Fig. 5).

Correlation analysis
Data expressing the strength of correlation between fatigue resistance and structural characteristics of the posts are summarized in Table 6. No correlation was found to be statistically significant ($p>0.05$).

DISCUSSION

Fiber-reinforced materials, as composite materials, owe their mechanical properties not only to the characteristics of fibers and matrix, but also to the strength of the bond at the interface between these components and to the geometry of reinforcement. The addition of fibers to a polymer matrix leads to a significant increase in fracture toughness, stiffness, and fatigue resistance of the material. In the fabrication of endodontic posts, glass, quartz, carbon, and ceramic fibers have been used[2,10,28].

The posts produced by GC, RTD, and Ivoclar Vivadent contained silanized glass fibers and an epoxy resin. In particular, during the manufacturing process of GC and RTD posts, the fibers were pre-stressed in tension and then soaked in resin, which was finally polymerized. On the final cure of the resin, the tension in the fibers was released and, as a result, the resin surface was placed under compression. For this reason, when the post was subjected to a flexural force, the tensile stresses which were introduced could easily be absorbed. For the Ivoclar Vivadent posts, they were made following the Vectris technology[29].

The methods of fabrication of GC Fiber Post, DT Light-Post, and FRC Postec could provide an explanation for the significantly higher resistance to fracture under cyclic bending forces as demonstrated in the present study. Unfortunately, the manufacturers did not disclose the modulus of elasticity of the resin employed for the resin matrices of these posts. This is because this parameter might play an influential role in the determination of the fatigue resistance of the posts. Another important factor was whether the fibers were silanized prior to embedding in the resin matrices. This could also affect both the resistance of the fiber posts to the fatigue test, as well as the structural integrity of these posts. At this juncture, it must also be highlighted that good interfacial bonding can ensure efficient load transfer from the matrix to the reinforcement, and is a primary requirement for effective use of reinforcement properties. In his scholar thesis, Gu[30] stated that '…a fundamental understanding of interfacial properties and a quantitative characterization of interfacial adhesion strength can help in evaluating the mechanical behavior and capabilities of composite materials…'.

During daily normal occlusal and masticatory function, both the natural and restored teeth are subjected to a number of cyclic loads. Failure due to fatigue stress is a phenomenon of paramount importance from a clinical standpoint[19-21]. In the explanation of the occurrence of this type of failure, it is assumed that failure commences from a small structural defect within the material. When subjected to cyclic functional loading, a line of fracture can gradually propagate from this weak area through the material, finally culminating in catastrophic failure[31]. Potential areas of weakness in a fiber-reinforced post can be seen in the voids present within the resin or in the discontinuities along the interfaces between fibers and matrix. Therefore, a solid (with fibers evenly distributed) structure of the fiber-reinforced posts seems to be critical for their clinical success.

Areas of potential weakness also refer to sections of the post subject to abrupt changes[22]. For this reason, the addition of a notch on the post for retention purpose did not seem to augur well for the post's fatigue resistance. In the context of the present study, this might account for the relatively low resistance to cyclic loading exhibited by ParaPost Fiber White and Fibrekor, with serrations present in both posts. In addition, the conical shape might have a negative bearing on the Luscent Anchor post, resulting in lower fatigue resistance in comparison with the double-tapered GC Fiber Post, DT Light-Post, and FRC Postec posts. Consequently, SEM observation of ParaPost Fiber White, Fibrekor, and Luscent Anchor posts — with significantly lower fatigue resistance — showed loss of their structural integrity after they fractured under load.

In a fatigue test, as in any repeated masticatory action, the load varies between a minimum (Kmin) and a maximum (Kmax). Theoretically, the moment in which a rapid fracture occurs has to be related to the Kmax value. On the other hand, the difference between the maximum and minimum values (K) corresponds to cyclic energy dissipation, which provides more insight to the fatigue phenomenon. Nonetheless, the two different values (Kmax and K) combined should provide us with important information on what is really happening in the mouth[32].

In the present study, a load ranging from 20 to 100 N was applied at a frequency of 3 Hz. With the 20-N force, the loading unit was kept in stable contact with the specimen. With regard to the highest-level force in a fatigue test, its magnitude does not exceed 50% of the ultimate strength of the material on trial[17]. Similarly, this criterion was applied in the present study, and the results showed that specimen failure occurred even when a cyclic force as low as one-half of the material's ultimate strength was exerted.

With respect to the number of cycles that were applied to simulate fatigue loading, Wiskott *et al.*[32] indicated that it should be at least one million cycles. In the present study, a maximum of two millions cycles were applied, with the intention of simulating about four years of normal occlusal and masticatory activity[5,7]. It should be pointed out that the cyclic fatigue test, as it was performed in this study, most probably exposed the specimens to higher tensile stresses than those actually transmitted to an endodontic post cemented inside a root, as failure of the bonded cement could have occurred prior to post fracture. Taking this consideration into account and with an unwavering intention of having a fatigue resistance appraisal that would be as close as possible to clinical reality, the same study should be repeated on roots with cemented posts instead of mere posts. This would then require a completely different study design that does not involve a three-point bending test.

From a statistical standpoint, Groups 1, 4, and 5 showed better results than all the other tested groups. In terms of physical considerations, any fiber direction deviating from the longitudinal axis of the post results in a stress transmission to the matrix. For this reason, posts with parallel fibers should, at least theoretically, withstand loading more efficiently than posts containing obliquely-oriented fibers. When a compressive force is exerted on a post or when forces are directed obliquely or diagonally to the post's longitudinal axis, the stress acts on the matrix particularly. The high stresses on the fiber-resin interface are responsible for a gradual inelastic behavior, which occurs due to detachment occurring at the interface between the fibers and the matrix. Besides, plastic deformation of the matrix and resin microcracking also occur. Such stresses are minimum in the equidistant areas of the fibers, and maximum immediately next to the same fibers[33].

Fibers represent the stiffer component in a post as compared with the resin matrix. Therefore, the post that exhibits a higher fiber density would be expected to exhibit a greater fracture resistance than that with a lower amount of fibers[28]. In the present study, GC Fiber Post, DT Light-Post, and FRC Postec fiber posts were the ones with higher fiber density values. In recent clinical evaluations of DT Light-Post and FRC Postec fiber posts, it was shown that neither a post nor root fracture occurred over a two-year period of clinical service. These data thus soundly supported the clinical use of translucent fiber posts for the restoration of endodontically treated teeth[3-8]. With regard to the other types of posts tested in this study, no data are yet available on their clinical performance. However, noting the mechanical and structural characteristics of GC Fiber Post samples tested in this study, it can be safely and rationally assumed that they will likewise render satisfactory performance when used under clinical conditions.

Apart from efficiently holding up under fatigue stress, GC Fiber Post, DT Light-Post, and FRC Postec posts were also among those that exhibited the highest degree of structural homogeneity when evaluated under SEM. The other posts showed different degrees of structural defects and a limited survival to fatigue loading.

In any bid to understand the quality of a post, it is also necessary to investigate the adhesion between the fibers and the resin matrix as it is an important parameter. However, it is a variable that is difficult to measure. As such, the strength of the adhesion bonds at the fiber-resin interface can only be speculated by examining the results of the fatigue test, the SEM scores regarding structural integrity, and the SEM images of the fractured posts. In some cases, catastrophic failures were evident with fibers spread out and separate from each other and absence of any bond between the fibers and the resin matrix.

Regarding the fracture mode of a post, it is speculated that when failure commences under compression the more brittle fibers break due to variability in individual fiber surface defects. This leads to interfacial slip between the broken fiber and the matrix, and consequently stress magnification in the adjacent fibers. As the interfacial bond is probably still effective, tensile stress in the broken fiber along the bond transfer length will gradually build up. If the bond strength is exceeded, delamination of the fiber from the matrix will commence and propagate[33]. With loss of interfacial bond, progressive fiber fracture will occur, leading to overall catastrophic failure. Further detailed fractographic analysis should be performed to validate the results of this study.

Given the results of this study, GC Fiber Post, DT Light-Post, and FRC Postec can be expected to function efficiently against fatigue stress. This property augments the reliability of these materials when used clinically for the restoration of endodontically treated teeth.

CONCLUSIONS

Both of the null hypotheses tested in this study were rejected. When subjected to a fatigue resistance test, different kinds of fiber posts gave different results, possibly accounted for by the variability in their ultrastructural characteristics. Moreover, no correlation existed between the fatigue resistance and structural characteristics of the posts investigated in this study.

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