An evaluation, using a "three-point bending" test, of the fatigue resistance of certain fiber posts

Simone Grandini DDS, MSC*, Cecilia Goracci, DDS, MS, MSC**, Francesca Monticelli, DDS***, Andrea Borracchini, MD, DDS****, Marco Ferrari MD, DDS, Ph D*****

University of Siena *Chair of Clinical Endodontics
**Chair of Basic Dentistry III
***Chair of Basic Dentistry II
****Chair of Prosthodontics
*****Chair of Dental Materials

CORRESPONDENCE: Marco Ferrari, Piazza Attias 19, 57120 Livorno, Italy
Phone.: +39.0586.892283; Fax: +39.0586.898305;
E-mail: ferrarimar@unisi.it

SUMMARY

Aim *The aim of the present study was to assess the fatigue resistance of different types of fiber posts by using a 3-point bending test and to observe their ultrastructure through scanning electron microscopy (SEM) before and after undergoing the fatigue test.*

Methods *Six types of fiber posts were selected for this study. Easypost (Group 1), Para Post Fiber White (Group 2), FiberKor (Group 3), DT Light-Post radiopaque (Group 4), Luscent Anchors (Group 5) and Snowpost (Group 6). Each group contained 15 posts; 5 posts in each group were observed with a scanning electron microscope, the other 10 were used for the fatigue test. A three-point bending machine, loading at an angle of 90° and a frequency of 3 Hz, was employed for fatigue testing. The test was carried out until 2 million cycles were completed or the post fractured. After the fatigue test had been completed further evaluations were carried out on the fractured posts, or the posts that went to the end of the fatigue cycle with a SEM.*

Results *The fatigue test showed statistically significant differences among the different posts. Group 4 performed better than all the other groups, withstanding the entire load cycles without fractures.*

Conclusions *There are great variations in the responses of different kinds of fiber posts to a fatigue resistance test. Structural integrity is already very different even before undergoing the fatigue test, and this proves that many of the differences noted are due to differences in the manufacturing processes of the fiber posts.*

KEYWORDS

fatigue test, fiber posts, SEM

Fiber posts have undergone significant evolution in recent years. The introduction of carbon fiber posts in 1990[1] gave the dentist the first valid alternative to cast or prefabricated posts. Carbon fiber had an elasticity module that was much more similar to dentine than any other metal post[2], and the clinical trials carried out on fiber posts provided very convincing results[3-8]. In any case the first posts that were produced had the limitation of having a generic use, since they were radiotranslucent and difficult to hide under metal-free restorations, which means under porcelain veneers or full porcelain crowns because of their dark color[9]. Soon after, different radiopaque posts were produced with fibers to obtain 'aesthetic' results, which meant white or transparent ones. These improvements led to a dramatic change in the acceptance of fiber posts by the dental profession.

On the basis of these considerations and of the results of research, fiber posts started being considered as a reliable alternative to metal posts[10] and a growing number of different fiber posts were rapidly introduced into the market. There are many scientific papers concerning adhesion of fiber posts to root substrates[11-13], on different cementation procedures[14,15] and on the abutment restoration[16-18]: all demonstrating the high standard performances of this type of restoration[,20].

The rapid inflow of these new aesthetic posts gave rise to a need for systematic evaluation of their mechanical characteristics and long-term clinical results. For this reason, scanning electron microscopy (SEM) and fatigue tests can provide information on what type of post can better resist these stresses and then retrieve data for a long-term clinical evaluation. SEM observation can also help in the evaluation of the post's integrity before the fatigue cycle and in indicating the type of fracture that can take place under load.

Fatigue is considered one of the principal causes of structural failure in restorative dentistry[21-24]. Conservative restoration fails more often with cyclic loads that are below the mechanical resistance limit of the restoration itself than with the application of a single force, even if relatively greater[25]. Fatigue tests can reveal the resistance level of every single post that undergoes a fatigue cycle (simulating what takes place in the mouth physiologically during normal chewing functions)[16,26,27].

The aim of the present study is to evaluate the fatigue resistance of different posts and to observe the ultrastructures of the posts before and after the fatigue test.

MATERIALS AND METHODS

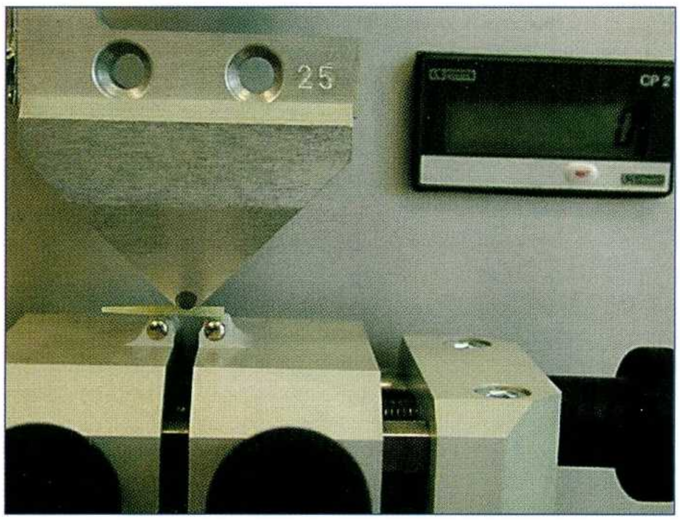
Six types of post were chosen for this study (table 1): Easypost (Krugg, Milan, Italy; Group 1, carbon fiber), Para Post Fiber White (Coltene/Whaledent, Mawhaw, NJ, USA; Group 2, glass fiber), FiberKor (Jeneric/Pentron, Wallingsford, CT, USA; Group 3, glass fiber), DT Light-Post radiopaque (RTD, Grenoble, France; Group 4, pre-tensioned glass fiber), Luscent Anchors (Dentatus, New York, NY, USA; Group 5, glass fiber), Snowpost (Carbotech, Ganges, France, Group 6, silicon fiber). In each group 15 posts were chosen with the greatest diameter possible (table 1). Post diameter varied between 1.5 and 2 mm. Ten of these, chosen at random, underwent fatigue tests, the others were prepared to be observed with the SEM.

SEM EVALUATION

Each post (out of the five per group selected for SEM analysis) was sectioned transversally into two halves. One of the two halves was

Table 1. **Structural characteristics of the 6 groups of tested posts**

Group	Type of post	Diameter of the post (mm)	Diameter of the fiber (μm)	Density of the fiber (number of fibers per mm²)	Surface occupied by the fiber per mm² of post surface (μm/mm²)
Group 1	Easypost	1.6	12	29	360
Group 2	Para Post Fiber White	1.5	6	18	110
Group 3	FiberKor	1.5	18	28	505
Group 4	DT Light-Post radiopaque	2.0	12	32	390
Group 5	Luscent Anchors	1.7	15	29	195
Group 6	Snowpost	1.6	7	36	250



1. The post ready for the test.

further sectioned longitudinally. For this procedure, a diamond saw was utilized (Isomet, Buehler, Lake Bluff, NY). The sectioned parts were prepared for SEM observation (Philips 505, Eindoveen, Holland). Microphotographs were taken of each section in order to evaluate the diameter, density and surface occupied per mm² of the fibers and to record the morphological characteristics of the post examined. The presence of bubbles and empty spaces within the post (obviously before the fatigue cycle) was also evaluated. After the fatigue test had been completed some of the fractured posts or the posts that had resisted the entire fatigue cycle were prepared for SEM observation by means of the above-mentioned procedure, and were observed in order to evaluate the bond between the fibers and the resin matrix and any structural changes that took place after the fatigue test.

FATIGUE TEST

Ten posts in each Group underwent a fatigue test by means of a special machine (Procyon Systèmes, France). This machine has a counter that measures the number of cycles and that stops when and if the sample breaks (figure 1). A three-point bending machine, loaded at an angle of 90° and a frequency of 3 Hz, was employed for fatigue testing. Because the posts of the 6 groups had different diameters, a mathematical formula was used to calculate the force to apply on the different posts in accordance with the diameter of the post and therefore, proportionally to it. The two supports and the punch had a diameter of 3 mm, and the distance between the two supports was 9 mm. All the tests were carried out at room temperature, approximately 22°C. The machine was calibrated to reach 2,000,000 cycles: it was observed that teeth touch once a minute on average and that therefore this number simulated four years of clinical functioning of the post, which means of physiological chewing functions[5,7].

$$\delta = \frac{8}{\pi} \times \frac{F \times I}{d^3}$$

δ = *stress* (N/mm = MPa)
F = *load or force* (Newton)
I = *span* (mm)
d = *diameter* (mm)

Load applied on the basis of the diameter of the post:

$$F = \frac{\delta \times \pi}{\pi} \times \frac{d^3}{I}$$

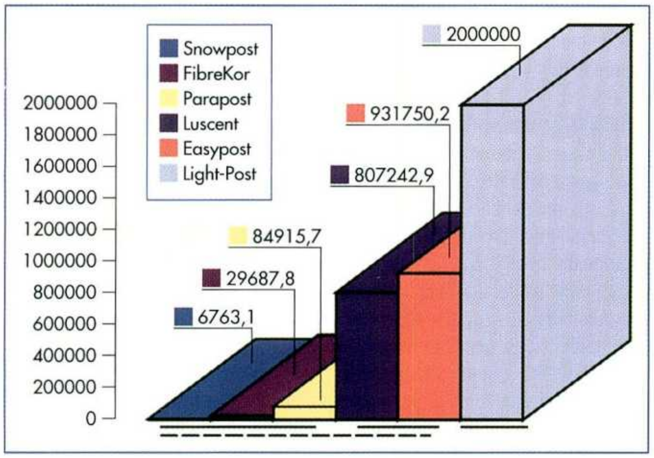
As regards the fiber posts whose failure took place before the test was over, the counter stopped as soon as the sample fractured. In order to evaluate the differences between the various posts in relation to the number of completed cycles a statistical analysis was carried out (One-Way ANOVA), followed by a Bonferroni test for multiple comparisons. The significance level was set at $p<0.05$.

RESULTS

Table 2 shows the averages and the standard deviation of the number of cycles withstood by the different types of post. The results of the statistical analysis were summarized in figure 2.
The highest resistance to the test was shown by the DT Light-Post group (Group 4). None of the samples belonging to this group fractured after two million cycles. From a statistical point of view, none of the other five groups provided similar results (figure 2). On the other hand, Snowpost, FiberKor, and Para Post (respectively Groups 6, 3, and 2) showed resistance values to fatigue that were significantly lower than all the other groups that were tested (figure 2).

Table 2. **Average and standard deviation of the number of cycles that each post withstood before fracture**

Group	Type of post	Average cycles withstood	Standard deviation
Group 1	Easypost	931750.2	829005.8
Group 2	Para Post Fiber White	84915.7	106039.0
Group 3	FiberKor	29687.8	24327.5
Group 4	DT Light-Post radiopaque	2000000	0
Group 5	Luscent Anchors	807242.9	2008
Group 6	Snowpost	6763.1	780



2. Graph showing the average number of cycles that the posts in the 6 groups withstood. The columns underlined by the same line did not display any statistically significant differences.

SEM EVALUATION

The microphotographs of the 6 groups of posts showed significant differences both regarding the overall morphological structure of the posts and the diameter, density and surface occupied by the fibers (table 1). The samples coming from Groups 1, 2, and 5 showed hollow spaces and bubbles inside the post structure and in the longitudinal and transversal cuts before undergoing the fatigue test. Besides this the samples in Group 1 showed hollow spaces between the fibers and the resin matrix, in particular in the marginal area and on the external surface of the post. The samples in Group 4 (DT Light-Post) showed excellent integrity on the external surface and a uniform distribution of the fibers, which were definitely uniform in the diameter and surface occupied per mm^2. The samples of the other groups, on the contrary, presented less fiber uniformity and lower density.

Once the posts fractured during the fatigue test the loss of structural integrity became evident. In different ways and to different extents separation between the fibers and the matrix (figures 3 and 4) became evident in Groups 1, 2, 3, 5 and 6. On the contrary, the samples in Group 4 showed a small circumferential depression on the external surface, at the point where pressure was applied by the punch, without other apparent morpho-structural variations (figure 5).

DISCUSSION

Fiber-reinforced materials, like composite materials, owe their mechanical properties not only to the characteristics of the single components (fibers and resin), but also to the bonding strength in the interface of the two components and to the reinforcing geometry. The addition of fibers to a polymeric matrix causes a significant increase in the material's resistance to fractures, hardness and fatigue resistance. Different types of fiber are used in manufacturing the endodontic posts[2,10,28].

In particular, during the manufacturing process of the RTD posts (Group 4), the fibers are pre-tensioned and then a resin matrix that is later polymerized is inserted, 'shot' inside the fibers. Once the entire polymerization process is completed the fibers are released and, as a result, the resin surface is compressed. For this reason, when a post of this type is bent the tensile loads that have been introduced can be easily absorbed. This manufacturing procedure can explain the great difference in the results obtained with the fatigue test. The elasticity module of the resin matrix probably also plays an important role in the determination of fatigue resistance, but unfortunately manufacturers do not always disclose this information. Another important factor is fiber silanization, which is a type of bond between the fibers and resin matrix. In point of fact, a good bond between these two components could ensure the optimal and homogeneous transfer and distribution of loads, and all in all this is of great importance for the posts' final fatigue resistance and structural integrity performance. Indeed a good bond at the interface can ensure the transfer of loads from the matrix to the fibers and vice versa, and this is a fundamental specification for an effective strengthening of the system through the fibers. In his doctorate thesis, Gu[29] asserts that "...it is fundamental to understand the properties at the interface and quantitatively characterize the adhesion at the interface, in order to evaluate the mechanical behaviour of composite materials that are reinforced with fibers ...".

During the normal occlusal and chewing function both natural teeth and teeth that have undergone endodontic treatment are subject to a certain number of cyclical loads. Failure due to fatigue is a very important phenomenon from a clinical point of view[19-21]. To explain how these failures take place it is necessary to start from the assumption that they start with a small structural defect inside the material. From the weaker area, as the result of a cyclical load, a fracture line can propagate and, in the end, become a catastrophic fracture[30]. Hollow spaces and bubbles inside the resin matrix or irregularities along the interface between the resin and the fibers may

3. Sample of Group 6 after the fracture following the fatigue test. The separation between the fibers and the resin matrix is evident.

4. Sample of Group 2. Here too the fracture shows the failure of the bond between the fibers and the resin matrix.

5. Sample of Group 4. After 2,000,000 cycles the post is still intact. The point at which the load was applied is evident, with a small depression in the middle of the post, which in any case remains perfectly intact from a structural point of view.

represent areas of potential weakness inside a fiber post. Therefore the fact of having a post with a 'solid' structure, with well-divided and equally distributed fibers, seems to be crucial for the clinical success of this type of restoration. The areas in which there is a sudden change of the section diameter are also critical points[22]. For this reason the insertion of a notch to help retention does not seem to be favourable for the overall resistance of the posts. SEM observation of the fractured posts clearly indicates that stress distorted the structure, confirming what just stated above.

In this study, a load ranging from 20 to 100 Newton was applied with a 3 Hz frequency. In the fatigue test applied load normally represents approximately 50% of the fracture load, which is the maximum stress that is withstood by the posts[17]. In fact the results of this study confirm that a fracture caused by a fatigue test can also take place with loads that are less than 50% of the fracture load.

Regarding the number of cycles to apply to simulate fatigue, Wiskott et al.[31] suggested that there should be at least a million. In this study the Authors applied a maximum of two million cycles to simulate a normal occlusal and chewing load[5,7]. It must also be highlighted that a fatigue test like the one carried out in this study might have loaded the post even more than happens in the mouth, where the residual teeth structures and cement can act as a cushion and absorb part of the load. For this reason, it could be interesting to repeat the same study with posts cemented in the roots, instead of with posts only. From a statistical point of view the posts in Group 4 returned better performances than the other groups. Probably this is due to the manufacturing process (pre-tensioned fibers) and to the good bond between the resin matrix and the fibers. Since fibers represent the most rigid component in a post, posts having a greater number of fibers seem to be destined to have a greater resistance to the fatigue test. This does not seem to be completely true since a recent study gives greater importance to the type of bond between the two system components, the fibers and the matrix, provided by a good bonding agent[28,32].

Recently, some fiber posts have been evaluated with perspective and retrospective clinical studies. No root or post fracture was seen with translucent radiopaque DT posts after two years of clinical service. This data supports the use of translucent posts to restore teeth that have undergone endodontic treatment[3-8]. Tests are not available regarding the clinical performance of other types of posts that were tested in this study.

In this study no evaluation was carried out after a thermal test. In view of the sudden changes of temperature normally seen in the mouth, it could be interesting to combine thermal stress with the fatigue test for an evaluation of this type of posts. In point of fact some studies show[10] that after a temperature change dimensional changes can take place inside the matrix, with negative consequences on overall mechanical resistance.

The brief and unstructured SEM evaluation that was carried out in this study seems to indicate that the posts in Group 4, which are those that gave the best results, also a good surface structure, a good bond between the fibers and the resin and the absence of structural defects. In another study[32] it was noticed that the above-mentioned factors, if compared with one another, are a good indication of whether they can or cannot withstand the fatigue test. Indeed, the posts with evident structural defects gave quite negative results. Adhesion between fibers and matrix, which seems to be very important to determine fatigue resistance, is difficult to evaluate. Some speculation can made from the images of the posts that are fractured or not, where it is evident how the strength of the bond between the fibers and the matrix is different in the 6 groups that were examined and greatly influences the final result. In some cases, after the fracture, it was clear that this bond was almost completely absent (figures 3-5).

Regarding post fracturing processes, the Authors hypothesize that under the effect of a load, in the presence of bubbles, hollow spaces, structural defects or areas of poor bonding between the fibers and the matrix, a breakage in continuity is seen at first and then an initially small fracture line propagates until it becomes a complete and macroscopic fracture[33]. A further fractographic analysis will be necessary to confirm the results of this study.

After our observations during the fatigue test, the DT Light-Posts can be expected to function in line with their ability to withstand the fatigue test. This factor adds up to the clinical reliability of these materials, proved by clinical studies carried out in endodontically treated teeth.

CONCLUSIONS

Different types of fiber posts give very dissimilar results when undergoing a fatigue test. From a statistical point of view, the DT Light-Post resists the fatigue test significantly better than the other posts tested in this study. A correlation can probably be made between the fatigue test and the structural integrity of the post.

References

1. Duret B, Reynaud M, Duret F. Un nouveau concept de reconstitution corono-radiculaire: le composiposte (1). Chir Dent France 1990;540: 131-41.
2. Asmussen E, Peutzfeldt A, Heitmann T. Stiffness, elastic limit, and strength of newer types of endodontics posts. J Dent 1999;27:275-8.
3. Fredriksson M, Astback J, Pamenius M, et al. A retrospective study on 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 clinical performance of fiber posts. Am J Dent 2000;13:9B-13B.
5. Ferrari M, Vichi A, García-Godoy F. Clinical evaluation of fiber-reinforced epoxy resin posts vs. cast posts and cores: a four year recall. Am J Dent 2000;13:15B-18B.
6. Malferrari S, Baldissara P, Arcidiacono A. Translucent quartz fiber posts: a 20 months in vivo study. IADR 80th General Session, S. Diego, 2002, abstract n° 2656.
7. Scotti S, Malferrari S, Monaco C. Clinical evaluation of quartz fiber posts: a 30 months results. IADR 80th General Session, S. Diego, 2002, abstract n° 2657.
8. Dallari A, Rovatti L. Six years of in vitro/in vivo experience with Composipost. Compendium 1998;20:S57-S63.
9. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque posts. J Prosthet Dent 2000;83:412-7.
10. Drummond JL, Toepke RS, King TJ. Thermal and cycling loading of endodontic posts. Eur J Oral Sci 1999;107:220-4.
11. Nakabayashi N, Pashley DH. Hybridization of dental hard tissue. Berlin: Quintessence Co. Publ., 1998.
12. Chappel RP, Cobb CM, Spencer P. Dentinal tubule anastomosis: A potential factor in adhesive bonding? J Prosthet Dent 1994;72:183-8.
13. Mjör IA, Nordhal I. The density and branching of dentinal tubules in human teeth. Archs Oral Biol 1996;41:401-12.
14. Ferrari M, Mannocci F, Vichi A, Cagidiaco MC, Mjor IA. Bonding to root canal: Structural characteristics of the substrate. Am J Dent 2000;13:380-6.
15. Vichi A, Grandini S, Ferrari M. Comparison between two clinical procedures for bonding fiber posts into a root canal: a microscopic investigation. J Endod 2002;28:355-60.
16. Gateau P, Sabek M, Dailey B. Fatigue testing and microscopic evaluation of post and core restorations under artificial crowns. J Prosthet Dent 1999;82:341-7.
17. Cohen BI, Pagnillo MK, Condos S, Deutsch AS. Four different core materials measured for fracture strength in combination with five different designs of endodontic posts. J Prosthet Dent 1996;76:487-95.
18. Freedman GA. Esthetic post and core treatment. Dent Clin North Am 2001;45(1):103-16.
19. Dietschi D, Romelli M, Goretti A. Evaluation of post and cores in the laboratory: rationale for developing a fatigue test and preliminary results. Compend Contin Educ Dent Suppl 1996;20:S65-S73.
20. Dietschi D, Romelli M, Goretti A. Adaptation of adhesive posts and cores to dentin after fatigue testing. Int J Prosthodont 1997;10:498-507.
21. Hsu YB, Nicholls JI, Phillips KM, Libman WJ. Effect of core bonding on fatigue failure of compromised teeth. Int J Prosthodont 2002;15:175-8.
22. Baran G, Boberick K, McCool J. Fatigue of restorative materials. Crit Rev Oral Biol Med 2001;12:350-6.
23. Fan P, Nicholls JI, Kois JC. Load fatigue of five restoration modalities in structurally compromised premolars. Int J Prosthodont 1995;8:213-20.
24. Yamamoto M, Takahashi H. Tensile fatigue strength of light cure composite resins for posterior teeth. Dent Mater J 1995;14:175-84.
25. Kahn FH, Rosenberg PA, Schulman A, Pines M.. Comparison of fatigue for three prefabricated threaded post systems. J Prosthet Dent 1996; 75:148-53.
26. Cohen BI, Pagnillo MK, Newman I, Musikant BL, Deutsch AS. Cyclic fatigue testing of five endodontic post designs supported by four core materials. J Prosthet Dent 1997;78:458-64.
27. Reagan SE, Fruits TJ, Van Brunt CL, Ward CK. Effects of cyclic loading on selected post-and-core systems. Quintessence Int 1999;30:61-7.
28. Ferrari M, Mannocci F. Bonding of an esthetic fiber post into root canal with a 'one-bottle' system: a clinical case. Int J Endodont 2000; 33:397-400.
29. Gu W. Interfacial Adhesion Evaluation of Uniaxial Fiber-Reinforced-Polymer Composites by Vibration Damping of Cantilever Beam. PhD thesis at Virginia Ploytechnic Institute and State University, 1997:11-3.
30. Griffith AA. The phenomena of rupture and flow in solids. Philosophical Transactions of the Royal Society of London (Series A) 1920; A221:168-98.
31. Wiskott HW, Nicholls JI, Belser UC. The effect of tooth preparation height and diameter on the resistance of complete crowns to fatigue loading. Int J Prosthodont 1997;10:207-15.
32. Grandini S, Goracci C, Monticelli F, Tay F, Ferrari M. Fatigue resistance and structural integrity of fiber posts: three-point bending test and SEM evaluation. Accepted for publication, Dental Materials, 2004.
33. Grandini S, Balleri P, Ferrari M. Scanning electron microscopic investigation of the surface of fiber posts after cutting. J Endod 2002 Aug;28(8):610-2.

IL DENTISTA MODERNO - PERIODICO MENSILE DI UTET SPA - DIVISIONE SCIENZE MEDICHE, CORSO RAFFAELLO 28, 10125 TORINO
REDAZIONE: VIALE TUNISIA 37, 20124 MILANO - TEL. 02/6241171 - REG. TRIBUNALE DI MILANO N. 206 DEL 22/5/1982
ESTRATTO DAL NUMERO 3/2004 - DIRETTORE RESPONSABILE: CORRADO TREVISAN - STAMPA: GRAF 3 SPA, ROZZANO (MI)