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

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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[3-5]. 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[6]. 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[7] and a growing number of fiber post types was rapidly introduced into the market. There are many scientific papers concerning adhesion of fiber posts to root substrates[11-13] on different cements and procedures[14,15] and on the abutment restoration[16-18], all demonstrating the high standard performances of this type of restoration[19].

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 fiber 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 (Krug, Milan, Italy; Group 1, carbon fiber), Para Post Fiber White (Coltene/Whaledent, Mawah, 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), Lucent 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 2.2 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

<table>
<thead>
<tr>
<th>Group</th>
<th>Type of post</th>
<th>Diameter of the post (mm)</th>
<th>Diameter of the fiber (µm)</th>
<th>Density of the fiber (number of fibers per mm²)</th>
<th>Surface occupied by the fiber of post surface (µm²/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Easypost</td>
<td>1.6</td>
<td>12</td>
<td>29</td>
<td>360</td>
</tr>
<tr>
<td>Group 2</td>
<td>Para Post Fiber White</td>
<td>1.5</td>
<td>6</td>
<td>18</td>
<td>110</td>
</tr>
<tr>
<td>Group 3</td>
<td>FiberKor</td>
<td>1.5</td>
<td>18</td>
<td>28</td>
<td>505</td>
</tr>
<tr>
<td>Group 4</td>
<td>DT LightPost radiopaque</td>
<td>2.0</td>
<td>12</td>
<td>32</td>
<td>390</td>
</tr>
<tr>
<td>Group 5</td>
<td>Lucicent Anchors</td>
<td>1.7</td>
<td>15</td>
<td>29</td>
<td>195</td>
</tr>
<tr>
<td>Group 6</td>
<td>Snowpost</td>
<td>1.6</td>
<td>7</td>
<td>36</td>
<td>250</td>
</tr>
</tbody>
</table>

1. The post ready for the test.

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.

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 5, 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

<table>
<thead>
<tr>
<th>Group</th>
<th>Type of post</th>
<th>Average cycles withstood</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Easypost</td>
<td>931750.2</td>
<td>829005.8</td>
</tr>
<tr>
<td>2</td>
<td>Para Post Fiber White</td>
<td>84915.7</td>
<td>106039.0</td>
</tr>
<tr>
<td>3</td>
<td>FiberKor</td>
<td>29687.8</td>
<td>24327.5</td>
</tr>
<tr>
<td>4</td>
<td>DT LightPost radiopaque</td>
<td>2000000</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Luscent Anchors</td>
<td>807242.9</td>
<td>2008</td>
</tr>
<tr>
<td>6</td>
<td>Snowpost</td>
<td>6763.1</td>
<td>780</td>
</tr>
</tbody>
</table>

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.

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.

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 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. 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. Hollow spaces and bubbles inside the resin matrix or irregularities along the interface between the resin and the fibers may
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. For this reason the insertion of a notch to help retention does not seem to be favourable for the overall resistance of the post. 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. 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. 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. 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. 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. 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 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 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 be 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 initial small fracture line propagates until it becomes complete and macroscopic fracture. 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