Confocal and Scanning Electron Microscopic Study of Teeth Restored with Fiber Posts, Metal Posts, and Composite Resins

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Forty-two single-rooted lower premolars, extracted for periodontal reasons, were endodontically treated and divided into 7 groups of 6 teeth each. In five of the groups, three different types of carbon fiber posts, quartz fiber posts, and titanium posts were used in combination with All Bond 2 dental adhesive. In two groups, two types of carbon fiber posts were also cemented with Panavia 21 dental adhesive. After 3 wk storage in saline, the teeth were longitudinally sectioned; one half was observed using confocal microscopy and the other by scanning electron microscopy. The specimens were evaluated for the presence of a resin dentin interdiffusion zone for the presence of voids at post–resin–dentin interfaces and for the determination of the fiber posts’ structure. Upon examination with the confocal microscope, the interfaces of teeth restored with All Bond 2 showed a higher percentage (p < 0.05) of resin dentin interdiffusion zone than those treated with Panavia. The fiber size and the post structure were similar in all the fiber posts observed. Some voids were present inside the fiber post structure.

Endodontically treated teeth are supposed to be weaker than vital ones. In particular, vertical root fractures often cause severe damages to nonvital teeth. In many cases, extraction is the only possible treatment. Several hypotheses have been formulated to explain this weakness.

Heifetz et al. (1) found a 9% lower moisture content of pulpless versus vital dog teeth and concluded that this might be the cause of the increased brittleness of endodontically treated teeth. Conversely Stanford et al. (2) found no significant differences in the modulus of elasticity of vital and nonvital teeth.

Many in vitro studies have shown that the loss of tooth structure weakens teeth much more than the endodontic treatment. Reeh et al. (3) observed that the reduction of the cuspal stiffness due to the root canal therapy was ~5%, whereas that due to the preparation of an occlusal cavity was 20% and that of a three surface preparation was 63%. Other possible causes of weakness might be the loss of pressoreceptors (4), an elevated pain threshold (5), poor gutta-percha condensation procedures, and placement of posts and pins.

Sorensen and Martinoff (6) conducted a retrospective study on 1273 endodontically treated teeth and discovered that 40% of their sample of self-threaded posts failed by angular and vertical root fracture, implying excessive stress within the residual root. Conversely, they found that passively cemented Para-posts had a 97% success rate.

Several hypotheses have been formulated to explain the weakening action of the posts cemented into the root canal: it was thought that the increase of the cement layer thickness was able to increase fracture rates, and therefore the use of tapered and cast posts was suggested, but Sorensen and Engelman (7) showed that the cement thickness did not increase the risk of root fracture.

The cementation technique must also be taken into consideration because the mechanical stress induced in the root structure by cementation procedures of the so-called “active posts” can cause root fractures both during the cementation and during functional loading. The use of an adhesive technique might reduce the stress created by post cementation.

The post core systems include components of different rigidity. Since the more rigid component (post) is able to resist forces without distortion, stress is transferred to the less rigid substrate (dentin) and causes its failure. The difference between the elastic modulus of dentin and post material is a source of stress for the root structures. Therefore, the use of composite, glass ionomers, and amalgam pins has been advocated to avoid the insertion of metal posts into the root canal. Trope and Tronstad in 1991 (8) found that endodontically treated premolars restored with acid etch resin technique were more resistant to root fractures than teeth restored with glass-ionomer cement. Linn and Messer (9) found that, for in vitro resistance to fracture of endodontically treated molars, the cuspal coverage was more important than the preservation of tooth structure. Unfortunately, if no post is cemented into the root canal, the link that can be obtained between the radicular and coronal parts of the restorative materials may not be strong enough to resist the chewing forces resulting in horizontal crown or root fractures.
It was suggested that an ideal post should have a modulus of elasticity close to that of root dentin and it was reported that carbon fiber posts fulfilled this requirement (10). When a load was applied with an angle of $\sim 35$ degrees to the long axis of the post the modulus of elasticity of carbon fiber posts was $\sim 21 \text{ GPa}$, whereas that of dentin is $\sim 18 \text{ Gpa}$ (10).

Carbon fiber posts consist of pyrolytic carbon fibers arranged longitudinally in an epoxy resin matrix with the carbon component constituting 64% of the structure (10).

Several works have recently been published to evaluate the properties of carbon fiber posts. Cohen et al. (11) found carbon fiber post-core systems less resistant to fracture load than Parapost (Waledent International, New York, NY). Sidoli et al. (12) found that human teeth restored in vitro with Composipost (RTD, St. Egreve, France) and composite core materials exhibited inferior strength properties in comparison with other post core systems; however, in the same work, the failure mode of the Composipost (RTD) post and core system was more favorable to the remaining tooth structure, when compared with gold alloy post and core systems.

Despite these partially unfavorable in vitro results, the 2-yr recall results of a recent study (13) showed that the clinical performance of carbon fiber posts were excellent.

Recently, new quartz fiber posts and new carbon fiber posts covered with quartz fibers, with a design that is very similar to that of established carbon fiber ones, have been produced. The purpose of these new posts is to provide better aesthetic results by preventing the dark carbon fiber posts showing through the tooth, especially in those cases in which all ceramic crowns are used in anterior teeth.

The aims of the present study were to:
1. evaluate microscopically the fiber post structure
2. compare, by confocal and scanning electron microscopic (SEM) observations, the post–resin–dentin interfaces obtained using fiber posts and titanium posts with two different dentin bonding systems.

MATERIALS AND METHODS

Forty-two single-rooted lower premolars, extracted for periodontal reasons, were selected for this study. Roots with resorptive defects or cracks were excluded, and all external debris was removed with an ultrasonic scaler. After removing the crowns so that the working length was 20 mm, the roots were divided into 7 groups of 6 teeth each:

1. Carbon fiber posts (RTD) cemented by All Bond 2 dental adhesive (Bisco, Itasca, IL) and C&B composite cement (Bisco).
2. Carbon fiber posts (Spad, France) cemented by All Bond 2 (Bisco) and C&B composite resin (Bisco).
3. Experimental quartz fiber posts (RTD) cemented by All Bond 2 (Bisco) and C&B composite cement (Bisco).
4. Experimental posts made with carbon fiber covered with quartz fibers (RTD) cemented by All Bond 2 (Bisco) and C&B composite cement (Bisco).
5. Para posts XT titanium posts (Whaledent) cemented by All Bond 2 (Bisco) and C&B composite resin (Bisco).
6. Carbon fiber posts (RTD) cemented by Panavia 21 dental adhesive (Kuraray) cemented by Panavia 21 dental adhesive (Kuraray).
7. Carbon fiber posts (Tech 2000, Caronno Pertusella, Italy) cemented by Panavia 21 dental adhesive (Kuraray).

The root canals were prepared chemomechanically and the root canal filling procedure was performed with lateral condensation of gutta-percha and AH26 sealer (De Trey Konstanz, Germany), and 9 mm of the gutta-percha fillings were removed using large drills (Mailfeder, Baillagues, Switzerland).

The roots of group 1 were treated as follows: the root canal walls were enlarged with the low-speed burs provided by the manufacturer, the depth of the post space preparation was 9 mm, the root canal walls were etched with 37% phosphoric acid (Bisco) for 30 s, washed with water spray, and then gently air-dried. All Bond 2 Primer B was applied with Rhodamine B. In one tooth in each group, the Primer B was not labeled to act as a control.

All Bond 2 Primer A and B (Bisco) were mixed and applied into the canals.

All Bond 2 Pre-Bond Resin (Bisco) was applied into the canal. A layer of All Bond 2 Primer B was applied on #1 carbon fiber posts (RTD), then C&B cement (Bisco) base and catalyst were mixed according to manufacturer’s instructions. The cement was applied on the post surface and the post was inserted into the canal. The cement was allowed to set, and crown build-up was performed with Bis Core dual polymerizing composite resin (Bisco).

The height of the core was 4 mm and the width was conformed to the size of the coronal part of the root. The shape of the core was cylindrical.

The roots of groups 2, 3, 4, and 5 were prepared in the same way, with the only difference being the type of posts used. In group 3 experimental quartz fiber posts (RTD) and in group 4 experimental carbon fiber covered with quartz fiber posts (RTD) were used. In group 5 Parapost XT titanium posts (Whaledent) were cemented.

The roots of group 6 were treated as follows: the canal walls were conditioned with the Panavia 21 ED Primer (Kuraray), previously labeled with Rhodamine B, for 60 s. In one tooth the primer was not labeled. Panavia 21 composite cement was applied on the carbon fiber post (RTD) surface and a size 1 carbon fiber post was then placed into the root canal. A small amount of Bis Core dual polymerizing composite (Bisco) was placed around the canal access to allow the anaerobic setting reaction of the Panavia 21 composite cement. The crown build-up was performed as described for the previous groups. The roots of group 7 were prepared in the same way; the only difference was the type of carbon fiber post used (Tech 2000).

The diameter of all the posts used was $\sim 1.4$ mm. The posts of groups 1, 3, 4, and 6 showed different diameters in the coronal and apical part. The determining measurement was taken from the coronal portion.

After the crown build-up procedure the roots were stored in saline solution for 3 wk. The teeth were then sectioned parallel to the long axis of the tooth using a diamond saw (Isomet, Buhler, Lake Bluff, NY) at slow-speed under water. Three locating notches for standardized examination of the interfaces were made by a scalpel, 2, 5, and 8 mm apically to the dentin–core junction. Observations were performed by confocal microscopy and scanning electron microscope of the dentin–resin–post interface of the areas immediately apical and immediately coronal to the notches. Six areas were observed in each root half.

One half of each root was observed using confocal microscopy and one half using scanning electron microscopy.

A confocal microscope of the tandem scanning type (TSM; Noran Instruments, Madison, WI) was used to observe the cut surfaces of the teeth, focusing below the surfaces damaged by sectioning. Samples were kept at 100% humidity before the ob-
Fig 1. Labeled specimen of the carbon fiber-All Bond 2 group. The RDIZ is observed as an area of infiltration of the labeled primer into the dentinal tubules. F = fiber post, C = Composite cement, R = RDIZ. ×20 oil immersion/0.8 numerical aperture. Field width = 500 μm.

Fig 2. Unlabeled specimen of the carbon fiber-All Bond 2 group. The RDIZ is observed as a reduction of the reflection of the dentinal tubules due to the presence of the bonding agent. F = fiber post, C = Composite cement, R = RDIZ. ×20 oil immersion/0.8 numerical aperture. Field width = 500 μm.

The following aspects were evaluated both by confocal and scanning electron microscope:
1. The diameter and the orientation of the fibers and the aspect of the resin matrix of the different fiber posts.
2. The formation of a RDIZ of the dentin bonding agents.
3. The presence or absence of gaps:
   a. Inside the adhesive layer
   b. Between the adhesive and resin cement layer
   c. Inside the resin cement layer
   d. Between the adhesive and the composite core
   e. Inside the composite core
   f. Between the adhesive and post
   g. Into the post structure.

A χ² test and a Kruskal-Wallis analysis at the 0.05 level of significance were used to evaluate statistically the results obtained in the various groups regarding the presence of a RDIZ, as observed by confocal microscopy.

RESULTS

The teeth labeled with Rhodamine B showed no significant difference from those left unlabeled (Figs. 1 and 2). In the labeled group, the areas infiltrated by the primers were more easily detectable, but no difference was found regarding the dentin penetration patterns of the primers, or the presence of voids observed in the various interfaces. It was concluded that the use of Rhodamine B did not interfere with the penetration properties of the adhesives in the interfaces observed.

The results obtained regarding the presence of hybrid layer in the various groups (Figs. 1 and 2) under the confocal microscope are shown in Table 1.

The ratio between the length of the RDIZs and the length of the observed interfaces was significantly higher in the groups treated with All Bond 2 than in the groups treated with Panavia 21 (p < 0.05). No statistically significant difference was found between the
groups of posts treated with the same adhesive. The resin tags of the roots treated with All Bond 2 (Fig. 3) were much longer than those of specimens treated with Panavia 21 (Fig. 4). The SEM observations confirmed that the areas of resin–dentin interdiffusion were more frequently present in All Bond 2 groups than those in Panavia 21.

Gaps were observed into the RDIZ of all specimens. Voids were present in the composite cement layers of all groups (Fig. 5). In the most apical part of many sections of all groups, only dental adhesive was observed, whereas the composite cement was absent. The composite cement layer showed some fractures in the titanium posts’ group. The cement layer was substantially similar in All Bond 2 and Panavia 21 specimens. Large filler particles were present in all the cement layers observed. The adhesive–composite cement interface was substantially free of voids. No voids were found into the composite cores.

All the fiber posts observed showed some voids in their structure.

Spherical structures, probably formed as part of the epoxy resin matrix, were present in some of the fiber posts observed (Fig. 6).

No difference was observed between the dimensions of the fibers of the various groups. All of them showed a diameter of \( \sim 8 \) to \( 9 \mu m \).

**DISCUSSION**

All the fiber posts observed showed some voids when observed under the confocal microscope. These observations were less frequent in SEM observations. In fact, only the confocal microscope allowed subsurface observations of the internal post structure.

The voids observed might be the result of a defect in the epoxy resin injection procedure that might have failed to fill the spaces completely between the fibers.

The clinical relevance of the voids into the fiber post structure is, at present, unknown. The longevity of carbon fiber post (Composiposts, RTD) restorations was tested in 2-yr recall clinical trials (13, 14), and no case of post-failure was reported. The microscopic appearance of the cement layer of All Bond 2 and Panavia 21 specimens was very similar. In both cements big quartz particles are used as fillers (15).

In all the samples observed a high number of voids were seen within the composite cement layer. This might be due to the fact that both the composite cements used were introduced into the canals covering the post itself with cement, as recommended by the manufacturers. If the composite cements are introduced with different, possibly more effective, techniques (e.g., with a paste inject filler), the most apical part of the cements might set before post insertion, because of their anaerobic setting reaction. An imperfect link between the inorganic particles and the resin matrix could be another possible cause of void formation.

The link between posts and composite cement was found substantially free of voids in all the fiber post groups. The producer states that the resin matrix of Tech 2000 carbon fiber posts contains a resin obtained by the polymerization of diphenylpropane and metiloxirane, a resin monomer that should be compatible with 10 methacryloxy decylhydrogenphosphate that is contained in Panavia 21 dental adhesive, thus producing a chemical link between the adhesive and the post itself. A chemical link, according to the manufacturer, should be possible even between Composiposts (RTD) and a Bis GMA-based resin like All Bond 2, even if the
nature of the resin monomer contained in Composiposts matrix has not been specified. Composiposts and Tech 2000 posts were cemented with both All Bond 2 and Panavia 21, but the SEM and the confocal microscope examination of the four groups of posts involved did not show any difference between the carbon fiber posts–dental adhesive interfaces of the four experimental groups involved in the comparison.

The development of confocal microscopy (16) greatly reduces artifacts due to specimen preparation when tooth restoration interfaces are observed. Incorporation of fluorescent labels into the adhesive materials improves the discrimination of adhesive components within interfaces. In the present investigation, the confocal microscope provided low-medium magnification images without the artificial changes that might have been induced in the specimens by the various steps involved in SEM specimens preparation: fixation, dehydration, drying, heavy metal sputter-coating, and high vacuum (Fig. 7). The SEM observations provided higher magnification images of the same roots (Fig. 8).

No previous studies have evaluated the ratio between the resin–dentin interfaces observed and those in which a RDIZ is present. Dietsehl et al. (17) recently performed a semiquantitative SEM study of prefabricated posts and resin–dentin interfaces after load and pointed out that it was “likely” that the acid-resistant layer observed at low magnification was a hybrid layer.

The confocal microscopic observation showed that the RDIZ obtained with All Bond 2 was present all over the root surface, and these results were substantially confirmed by the SEM observations. The presence of a RDIZ was less frequently observed in the specimens treated with Panavia, and the penetration of the adhesive resin into the dentinal tubules was less deep in this group. This is probably related to the use of a self-etching primer in this material, compared with phosphoric acid for All Bond 2.

In an in vivo study (18) the absence of hybrid layer formation resulted in bad sealing performances of class V composite resin fillings. In another dye leakage, in vitro, test (19), performed on carbon fiber post–composite core restorations under the confocal microscope the seal obtained with Panavia 21 was found to be significantly worse than that obtained with All Bond 2. It can be concluded that an adhesive procedure, able to produce a hybrid layer, is essential to ensure good sealing for carbon fiber post restorations.

The presence of a good seal at the resin–dentin interface of composite cores used for crown build-ups of endodontically treated teeth is a fundamental step for prevention of bacterial penetration, recurrent caries, decementation, and root fracture.

The results of some recent studies on carbon fiber posts might have been influenced by incorrect adhesive procedures. In Cohen et al.’s work (11) the core materials used for fracture strength test were amalgam-Ti core composite without any adhesive procedure used to link it to the root or to the post, and glass-ionomer cements. There is no chance to obtain adhesion of amalgam to carbon fiber posts, and nor can adhesion be obtained with a composite resin if a dental adhesive is not used.

In Purton and Love’s (20) study of post retention, no dental adhesive was used for the cementation of the carbon fiber posts before injecting the adhesive cement into the etched roots. Even in this case the adhesive cementation procedures were not properly performed. The same procedure was followed by Sidoli et al. (12) in their in vitro compressive strength test.

Therefore, we conclude that the use of a resin-based 3-step adhesive system can be strongly recommended to obtain a good link between composite cement, composite cores, and the root canal walls.
You Might Be Interested

Meta-analysis has not yet flourished to any great extent in the dental literature. However, it is of enormous interest—and a source of great controversy—in medicine. The problem addressed is that, because of expense, time constraints, etc., much clinical research is based on small sample sizes. Meta-analysis attempts to systematically search out all relevant studies on any subject, assess their intrinsic validity, and then quantitatively combine the acceptable results to arrive at an estimate of treatment results, validated by the resultant larger sample size (Br Med J 315:617).

On the surface, reasonable; but, like all things that seem too good to be true, . . . . The main criticism is that the method's necessary assumption is that differences in the results of studies are primarily due to chance; thus, use of large sample sizes achieved by combination will yield valid results. Unfortunately, this assumption also requires almost complete homogeneity of each combined study's condition. If this is not the case, observed differences may be due to other factors—differences in treatments, population, etc., and not chance—in which case combination is a flawed method.

In a few instances, actual very large-scale studies have later been done on treatment outcomes that had previously been calculated by meta-analysis. Conclusions were at variance. Another potential flaw in meta-analysis is that, in general, only studies having positive results are published. But, because the technique requires inclusion of all related studies, and unpublished negative results are irretrievable by ordinary search means, the meta-analysis is often based on an already-biased (toward positive results) sample.

Resolution of the issue of the validity of meta-analysis is probably crucial to the hope for improved health care.

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