A Comparative Evaluation Of Fracture Resistance And Penetration Of Bonding Resin Into Three Different Fiber Reinforced Posts Using Confocal Microscope

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Citation

Abstract
Aim/Objective: To evaluate the fracture resistance of teeth restored with three different fiber reinforced composite posts and to compare the depth of penetration of the bonding resin into the fiber posts, using a confocal microscope.

Materials and Methods: Seventy freshly extracted human premolars were selected for the study. Out of these, sixty teeth were randomly divided into three groups of twenty teeth each for each of the three post systems under review namely, group I- EverStick post; group II-FRC Postec Plus post and group III-Mirafit Carbon fiber post. Each group of twenty teeth was further divided into two so that ten specimens were used to evaluate fracture resistance (Study 1) and ten specimens were used to observe the penetration of bonding resin (Study 2). The clinical crowns were removed; root canal treatment was done on each root and the fiber posts were luted according to manufacturers' instructions. The remaining ten teeth served as control (group IV) for Study 1, in which only root canal treatment was done and no posts were placed. The specimens were mounted in a customised metal jig and fracture resistance was tested in a Universal Testing Machine. To evaluate the depth of penetration of the bonding resin into the posts, the bonding resins namely, Stick resin, Excite DSC and silanating agent, Monobond S were labeled with Rhodamine B and the posts were luted according to manufacturers' instructions. Transverse sections were made at cervical, middle and apical levels of the root and depth of penetration of the bonding resin was calculated using a confocal LASER scanning microscope. Data were tabulated and statistically analyzed using one- way ANOVA and Tukey-HSD procedure.

Results: Significantly higher failure loads were recorded for root canal treated teeth without posts (group IV: 1668.4±9.8 N). The mean fracture resistance of group III (1204.4±4.0 N) was significantly higher than that of group I (950.1±4.7 N) and group II (751.9±2.6 N) (P <0.001). The mean depth of penetration of bonding resin in all three sections of the post was significantly higher in group I than in group II and group III (P< 0.001).Conclusion: Within the limitations of this in vitro study, it can be concluded that teeth restored with Mirafit carbon fiber posts recorded significantly higher fracture resistance values. Although EverStick posts showed maximum bonding resin penetration, which has clinical implications in achieving a good coronal seal, the fracture resistance values were lesser than those of carbon fiber posts.

INTRODUCTION
The restoration of endodontically treated teeth although practised for many years, remains a major concern in dentistry because of various reasons including decreased moisture content, coronal destruction from dental caries, fractures, previous restoration, and root canal treatment by itself, all of which increase the likelihood of fracture of the treated tooth during function. Although many studies have stated that decreased moisture content of root canal treated teeth could be one of the causes for increased brittleness in such teeth compared to vital teeth, studies by Stanford et al and Papa et al have shown that no such difference exists between vital and non-vital teeth. For many years, metal post-and-core systems were used and particularly the custom made cast post-and-cores were the restorations of choice. But, the disadvantage with cast post and core placement procedure is that it requires two visits and laboratory fabrication. Also, complications such as poor retention of the post, potential for post and root fractures and a risk of corrosion when different metals were used in the system have been reported. These reasons paved the way for the wide array of prefabricated post systems that are available in today's market.
to post-and-core systems. Prefabricated FRC posts are composed of glass fiber, quartz fiber or carbon fiber embedded in a polymer matrix. Carbon fiber reinforced resins are considered viable alternatives to metals when strength, stiffness, lightness, resistance to corrosion and fatigue are considered. Mirafit Carbon fiber post is a metal-free post made of carbon fibers embedded in an epoxy resin matrix. FRC Postec Plus is a prefabricated glass fiber post with a cross-linked polymer matrix. EverStick post is a flexible, resin-impregnated, uncured glass fiber post with an Interpenetrating Polymer Network (IPN) resin matrix, which can be cured to the anatomic shape of the root canal. It has been stated by the manufacturer that bonding of the FRC post with IPN resin matrix to composite resin and to adhesives/composite cements was improved by an interdiffusion bonding mechanism resulting in a ‘Monobloc’ type of restoration. It is not known whether this unique IPN resin matrix will result in better fracture resistance of EverStick posts and whether such a diffusion of bonding resin is possible in conventional cross-linked FRC post. Hence the aim of this in vitro study was to compare the fracture resistance of teeth restored with three different FRC posts and the penetration of bonding resin into the FRC posts using a confocal laser scanning microscope (CLSM).

MATERIALS AND METHODS
Seventy freshly extracted human mandibular premolars each with a relatively straight root, a similar root size, a single canal, free of caries and fractures were selected for the study. All external debris was removed with an ultrasonic scaler and the teeth were stored in normal saline until use. Based on the type of root canal post used, sixty teeth were randomly divided into three groups of twenty teeth each, of which ten specimens were taken up for evaluation of fracture resistance (Study 1) and the remaining ten specimens were used to observe the penetration of bonding resin into the FRC posts under a Confocal Laser Scanning Microscope (CLSM) (Study 2). The remaining ten teeth served as control (group IV) for Study 1, in which only root canal treatment was done and no posts were placed. The three post systems used in this study are listed in Table 1.

STUDY 1: EVALUATION OF FRACTURE RESISTANCE OF TEETH RESTORED WITH FRC POSTS.
The teeth were decoronated maintaining a tooth length of 15mm from the root apex, using a diamond disc (Hi – DI Diamond Precision Tools Ltd., London, U.K) in a slow speed hand piece under copious water supply. The root occlusal surfaces were then polished with 600-grit, fine grade silicon carbide paper (Moyco Precision Abrasives Inc., Montgomeryville, PA). The root canals of all specimens were instrumented sequentially up to a size 30 (6%) ProFile rotary nickel-titanium instrument (Dentsply Tulsa Dental, Tulsa, USA), in a crown-down manner. Along with this instrumentation, 10 ml of 3% sodium hypochlorite solution (Prime Dental Products Pvt. Ltd., India) was delivered as an irrigant into the canals using a 27-gauge needle between use of each succeeding file. After instrumentation of the root canals was completed, all the specimens were irrigated with 10 ml of 17% ethylenediamine tetraacetic acid (EDTA) (RC Help, Prime Dental Products Pvt. Ltd., India) followed by 10 ml of 3% sodium hypochlorite solution to remove the smear layer. A final rinse of 10 ml of saline was used for irrigation. The root canals were obturated with gutta percha (Dentsply Maillefer; Ballaigues, Switzerland) using AH Plus (Dentsply DeTrey, GmbH, Germany) as a sealer. All the specimens were then stored in saline at room temperature for one week before post space preparation. In all the specimens, gutta percha was removed from the root canals to a constant depth of 10mm from the root occlusal portion, using Gates Glidden drills sizes 2 (0.7mm diameter) and 3 (0.9mm diameter) (MANI Inc, Tochigi, Japan) maintaining an apical root canal filling of at least 5mm.

GROUP I - EVERSTICK POSTS
The post space was prepared with size 4 (1.3mm in diameter) peeso reamer (MANI Inc, Tochigi, Japan). The
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Post spaces were then cleaned with 17% EDTA for 30 seconds followed by 3% sodium hypochlorite solution for 30 seconds. The post spaces were then rinsed with 10 ml of saline and dried using air and paper points. Each EverStick post was pre-cut to the desired length, trial fitted into the root canal, shaped and initially light cured for 20 seconds. An Astralis 3 light curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) was used throughout the study. The posts were then removed from their respective canal with locking forceps and again thoroughly light cured on all sides for 40 seconds. The posts were coated with a layer of Stick Resin (Stick Tech Ltd, Turku, Finland) which was light cured immediately before cementation for 10 seconds. The post spaces of the teeth were etched with 37% phosphoric acid (Total Etch etching gel, Ivoclar Vivadent, Schaan, Liechtenstein) for 15 seconds, rinsed with water spray and gently air dried. The excess moisture was blotted dry with paper points. Excite DSC (Ivoclar Vivadent, Schaan, Liechtenstein) was used as the bonding agent. Variolink II resin luting cement (Ivoclar Vivadent, Schaan, Liechtenstein) was mixed according to manufacturers’ instructions and carried into the post spaces using a paste carrier (MANI Inc, Tochigi, Japan). Each post was gently seated into the root canal and light cured for 40 seconds. The excess post was cut flush with the root occlusal surface with a diamond bur under copious water supply.

GROUP II - FRC POSTEC PLUS POSTS

The post spaces were prepared using the size 3 (1.0mm in diameter) drill provided by the manufacturer. Before the bonding procedure, the FRC Postec Plus posts were cleaned with phosphoric acid gel. In this process they were slightly etched. Then the posts were silanised for 60 seconds with Monobond S (Ivoclar Vivadent, Schaan, Liechtenstein). The post spaces were etched, rinsed and bonded as in group I. Each post was adhesively bonded to the root canal as in group I.

GROUP III - MIRAFIT CARBON FIBER POSTS

The post spaces were prepared with a size 2 (1.2mm in diameter) reamer provided by the manufacturer. Prior to cementation, a thin layer of the bonding resin, Excite DSC was applied onto the surface of the posts. The post spaces were etched, rinsed and bonded as in groups I and II and the posts luted as in groups I and II. The specimens of all three groups were stored in a humidor for 24 hours, and then in water at 37C for one week before mechanical testing.

GROUP IV – CONTROL

Control group comprised of ten specimens which were only root canal treated but received no posts.

PREPARATION FOR MECHANICAL TESTING

A metal specimen holder of size 50mmx50mmx10mm, with tapered holes drilled in it to a depth of 5mm was custom made and the roots were embedded vertically in the specimen holder using Araldite resin (Huntsman Advanced Materials LLC, Delaware, USA), leaving 10mm of each root exposed. The root canal access was shaped using a round carbide bur with a head diameter of 4.0mm (Brasseler, USA) to accept the loading fixture (Figure 1).

Figure 2

Figure 1- Specimens mounted in a metal jig for mechanical testing.

A loading fixture with a spherical tip of 4mm diameter was aligned vertically with the centre of the root canal of each specimen and the load delivered in a universal testing machine (LR 100K, Lloyd Instruments, USA) at a cross head speed of 1mm per minute, until the roots fractured 16,17 (Figure 2).
STUDY 2: EVALUATION OF PENETRATION OF BONDING RESIN INTO THE FRC POSTS USING CONFOCAL LASER SCANNING MICROSCOPE

The specimens were prepared in a manner similar to that described for mechanical testing, except that, to enable better visualization of the bonding resin-post interface, fluorescent labelling of the light curing adhesive resins namely, Excite DSC, Stick Resin and the primer agent Monobond S was done by adding a few grains of the dye Rhodamine B (Hichem lab, batch no: 0496/496/240372, Bombay, India), which emits fluorescence when excited with 514nm green light. The posts were luted as described in Study 1. The root specimens were stored for 24 hours in a humidor, and then in water at 37°C for one week. The roots were sectioned at three positions namely 2mm, 5mm and 8mm from the coronal root surface, perpendicular to the long axis of the roots with a low speed diamond disc under copious water supply. The sectioned surfaces were polished with a 600-grit silicon carbide paper. The post/adhesive interface was examined using a Confocal Laser Scanning Microscope (CLSM).

This study utilized the Zeiss LSM 510 META system, Jena, Germany, attached to an Inverted Zeiss microscope, which receives illumination from an Argon ion Laser (Lasos). The 543 nm excitation line was used and the fluorescence emissions were collected beyond 560 nm. The optical sections were taken at 1.0µm intervals starting from 30µm with 60X oil immersion objective with 1.4NA (Numerical Aperture). Images were analyzed using LSM 510 software 3-D reconstruction. Individual optical sections were combined to give a three dimensional reconstruction for the calculation of the extent of penetration, i.e. the measurement of the deepest penetration depth of the bonding resins along the diameter of the post. The data of Study 1 and Study 2 were tabulated and statistically analyzed using one-way ANOVA and Tukey-HSD procedure. In the present study, P < 0.05 was considered as the level of significance.

RESULTS

The fracture resistance values for each post system are given in Table 2.

Figure 4

Table 2 - Mean, Standard deviation and Test of significance of fracture resistance of different groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean±S.D (in Newtons)</th>
<th>Significance</th>
<th>Multiple comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>950.1±4.7</td>
<td>0.000***</td>
<td>IV vs. II***</td>
</tr>
<tr>
<td>II</td>
<td>751.9±2.6</td>
<td></td>
<td>IV vs. III***</td>
</tr>
<tr>
<td>III</td>
<td>1204.4±4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>1668.4±9.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

***P<0.001

Group IV (1668.4±9.8 N) showed a significantly higher mean fracture resistance compared to groups I, II and III. The mean fracture resistance of group III (1204.4±4.0 N) was significantly higher than that of group I (950.1±4.7 N) and group II (751.9±2.6 N) (P <0.001). Further, the mean fracture resistance of group I was significantly higher than that of group II (P < 0.001).

The depths of penetration of the bonding resin at cervical, middle and apical sections for each post system are given in Table 3 and the corresponding images are shown in Figure 3.
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Table 3- Mean, Standard Deviation and Test of Significance of the depths of penetration of the bonding resin at cervical, middle and apical sections for each post system.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cervical (µm)</th>
<th>S.D</th>
<th>Middle (µm)</th>
<th>S.D</th>
<th>Apical (µm)</th>
<th>S.D</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>61.6</td>
<td>1.4</td>
<td>70.5</td>
<td>1.4</td>
<td>82.9</td>
<td>1.7</td>
<td>0.000***</td>
</tr>
<tr>
<td>II</td>
<td>209</td>
<td>1.1</td>
<td>212</td>
<td>1.6</td>
<td>204</td>
<td>1.0</td>
<td>0.13(NS)</td>
</tr>
<tr>
<td>III</td>
<td>55.5</td>
<td>1.6</td>
<td>47.8</td>
<td>2.0</td>
<td>43.2</td>
<td>1.8</td>
<td>0.000***</td>
</tr>
</tbody>
</table>

***P < 0.001
NS - not significant

Figure 5
Table 3- Mean, Standard Deviation and Test of Significance of the depths of penetration of the bonding resin at cervical, middle and apical sections for each post system.

Figure 6
Figure 3- Confocal microscopic images of the cross-section of EverStick posts showing greater bonding resin penetration at cervical (A), middle (B) and apical (C) sections; FRC Postec Plus posts showing the least bonding resin penetration at cervical (D), middle (E) and apical (F) sections; Mirafit Carbon fiber posts showing greater penetration in the cervical (G) section compared to middle (H) and apical (I) sections.

GF- glass fiber, B- bonding resin penetration into the post, M- margin of post, R- resin matrix of post, CF- carbon fiber, Bar = 20 µm.

The mean depth of penetration of the bonding resin in group I was significantly higher in the apical section (82.9±1.7µm) than in the cervical (61.6±1.4µm) and middle sections (70.5±1.4µm) (P < 0.001). In all the three sections of the post, the depth of penetration of the bonding resin was significantly higher in group I than in group II and group III (P< 0.001).

DISCUSSION
In this in vitro study, the sample size was determined following reference to expert statistical advice and a power calculation was carried out with 80% and at 95% level of significance.

The control group (group IV) exhibited highest fracture resistance values (1668.4±9.8 N) because of more amount of remaining tooth structure. It has been suggested that remaining dentin thickness is a critical factor in resisting fracture19. FRC posts have become increasingly popular for the restoration of endodontically treated teeth and compared to metal posts, FRC posts revealed a restorable failure mode20, 21, 22. In the present study, teeth restored with Mirafit Carbon fibre posts showed the highest resistance to fracture (1204.4±4.0 N). The results are in direct correlation with the previous in vitro studies23, 24, 25 done using carbon fibre posts. The higher fracture resistance values are attributed to the interwoven arrangement of the long carbon fibres (8 microns in diameter constituting 64% of weight of the post) in the epoxy resin matrix which gives superior mechanical properties like high transverse strength and modulus of elasticity to the FRC post26. The carbon fibre post with woven fibre arrangement showed better mechanical properties than the one with short (<5mm) fibres distributed randomly26. This interwoven arrangement of carbon fibres in the post and the modulus of elasticity of the post, which is less than or equal to that of dentin, may redistribute stress into the tooth in such a way as to increase the likelihood of failure of post / tooth union instead of tooth fractures27, 28.

EverStick posts recorded the second best fracture resistance values (950.1 ± 4.7 N), which is higher than many other glass fiber posts tested in various in vitro studies14, 29, 30. This could be attributed to the IPN structure of the post that results in an interdiffusion bonding phenomenon, enabling the stick resin to penetrate the post, as well as establish a strong bond to the dentin via the resin cement13.

FRC Postec Plus posts recorded the lowest mean fracture resistance value (751.9 ± 2.6 N), but still within the range recorded by other glass fiber posts14, 29, 30. This high cross-link density of the matrix in a prefabricated FRC post makes it...
difficult to bond the post to composite resin luting cements\textsuperscript{12}. Accordingly, only adhesive failures were seen in this group.

Of the available post sizes, among the post systems used in this study, the closest approximating dimensions were chosen. Similar studies using closely approximating post dimensions had been carried out and reported in the literature\textsuperscript{13,32,33,34}. Several variables are involved when comparing the resistance to loading of different post systems. Rather than just differences in post diameter, variables such as the post material also could have influenced the result of this study.

Fluorescence imaging is probably the most important readout mode in biological confocal microscopy\textsuperscript{13}. In this study, a fluorescent probe traditionally used for biological microscopy, such as Rhodamine B, was used to label the bonding resins, in order to trace their penetration into the fiber posts. A transverse sectioning of the root was selected, to enable uniform specimen preparation and to overcome the difficulties of uneven sectioning of the post commonly encountered in longitudinal sectioning. The three points (2mm, 5mm and 8mm from the coronal root surface) chosen for sectioning, coincide with the cervical, middle and apical thirds of the 10mm span post space\textsuperscript{18}.

EverStick posts showed the maximum penetration of bonding resin in all the three sections of the post compared to the other groups. This is attributed to the unique nature of the IPN matrix of the EverStick post\textsuperscript{13}. A layer of polymethylmethacrylate (PMMA) is present on the outer surface of these posts. Adhesive resins which have solubility parameters close to that of PMMA can diffuse into the EverStick post. Stick resin is one such adhesive resin that contains 2,2-Bis-[4-(2-hydroxy-3-methacryloyloxy-proxy)phenyl]-propane (bis-GMA), Triethylene glycoldimethacrylate (TEGDMA), camphoroquinone and 2-(dimethylamo)ethyl methacrylate. The bis-GMA and TEGDMA present in Stick resin have solubility parameters close to that of PMMA, thus enabling the diffusion of the resin into the PMMA enriched outer surface of the EverStick posts\textsuperscript{13,35,36}, which becomes interlocked into the IPN polymer matrix after polymerization.

Mirafit Carbon fiber posts showed greater penetration of the bonding resin, next to EverStick posts. The adhesion of resinous material to an already polymerized substrate can be obtained by the interdiffusion of monomers of the new resin into the polymer structure of the substrate or by free radical polymerization of the bonding resin to the unconverted double bonds of the remaining functional groups of the substrate. The former phenomenon could be the most probable reason for the penetration of bonding resin seen in Mirafit Carbon posts, since the likelihood of free radical polymerization of the bonding resin to the substrate is minor with FRC posts whose polymer matrix is typically based on epoxy\textsuperscript{13}, as seen in Mirafit posts. The better penetration of the bonding resin, Excite DSC into the Mirafit carbon posts could be attributed to the mixture of dimethacrylates and HEMA monomers in the bonding resin and the presence of bis-GMA monomers in the matrix of the post.

FRC Postec Plus posts showed the least depth of penetration among the three groups. This was because of the high cross-link density of the dimethacrylate polymer matrix of the FRC Postec Plus post which makes it difficult for the adhesive system or the composite resin luting cement to penetrate the post or bond to the post. Also the high degree of conversion of the polymer matrix does not allow free radical polymerization of the adhesive monomers to the post\textsuperscript{13,32}.

The presence of IPN polymer structure in EverStick posts has resulted in a significantly higher fracture resistance value compared to the FRC Postec Plus posts which lack such a unique structure. Bonding between the post and the bonding resin/composite luting cement plays an important role among the many parameters which influence the clinical success of an FRC root canal post / tooth / crown system. Thus, in spite of showing a lesser depth of bonding resin penetration compared to EverStick posts, Mirafit carbon fibre posts have exhibited higher fracture resistance values owing to the superior mechanical properties of the carbon fibre. Future studies are needed in which the bonding between the dentin and cement as well as design based parameters of the post / tooth / crown system will be investigated.

**CONCLUSIONS**

Teeth restored with Mirafit carbon fiber posts recorded the highest fracture resistance values than those restored with EverStick posts and FRC Postec Plus posts. Although the fracture resistance values were not as high as those of Mirafit carbon fiber posts, EverStick posts with IPN structure bonded better to composite resin luting cement, which has clinical implications in achieving a good coronal seal, through improved bonding between the post, luting
cement and composite core.

References


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