MICROLEAKAGE AND FRACTURE PATTERNS OF TEETH RESTORED WITH DIFFERENT POSTS UNDER DYNAMIC LOADING

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Statement of problem. Many studies concerned with the microleakage of endodontically treated teeth restored with posts and cores and subjected to loading can be found in the literature. However, no studies have investigated microleakage under dynamic loading with simultaneous dye penetration, which is more relevant to clinical situations.

Purpose. The purpose of this study was to compare microleakage and to classify fracture patterns of endodontically treated teeth restored with various post systems under dynamic loading.

Material and methods. The crown portions of 40 human mandibular incisors were sectioned at the cementoenamel junction, and the teeth were endodontically treated. Teeth were divided into 4 groups (n=10): teeth restored with a cast post and core, prefabricated metal post (ParaPost), fiber-reinforced composite resin post (FRC Postec), and ceramic post (Cosmopost). After preparing the post space, each post was cemented with dual-polymerized resin cement (DuoLink). With the exception of the cast post-and-core group, the cores were formed directly using a light-polymerized composite resin (Light-Core). An intermittent load of 98 N at 1 Hz was applied for 50,000 cycles at an angle of 135 degrees to the long axis of the restored teeth, which were immersed in a 0.5% basic fuchsin solution. The ratio of the dyed surface area to the total area of the sectioned root surface was determined using an image analysis program. The data were analyzed by a 1-way ANOVA and Duncan's multiple range test (α=.05). The fracture patterns of the teeth were classified according to their fracture propagation lines.

Results. The cast post group showed a significantly higher level of microleakage compared to the other groups (P=.001). Regarding the failure mode, the FRC Postec and Cosmopost groups showed fracture patterns that would favor retreatment. The number of cycles of repeated loading was not significantly different among the groups (P=.161).

Conclusions. Both FRC Postec and Cosmopost groups showed less microleakage under dynamic loading and fracture patterns favoring a retreatment of fractured specimens. (J Prosthet Dent 2007;98:270-276)

 CLINICAL IMPLICATIONS
Study results suggest that the fiber-reinforced composite resin post may be the best clinical choice for endodontically treated teeth, based on microleakage test results, fracture patterns, dynamic load cycles endured, and the absence of fractured posts.

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Endodontically treated teeth are more susceptible to biomechanical failure than vital teeth. If endodontic treatment is inevitable, and there is insufficient dentin to support a crown restoration, a post is essential to retain the core. However, the placement of a post and core does not increase the fracture resistance of endodontically treated teeth. Several investigators reported that posts do not strengthen teeth but actually weaken them. Ideally, a post should minimize the stress on a tooth by distributing occlusal loads evenly and be easy to remove if the root canal should require retreatment. In addition, the elastic modulus of a post should be similar to dentin to avoid root fracture.

There are 2 types of posts in use, custom-made and prefabricated. Prefabricated posts are usually made of metals such as stainless steel, titanium, and malleable metal alloys, or nonmetals, such as ceramic and fiber posts. Cast and prefabricated metal posts have been commonly used for restoring endodontically treated teeth. However, with metal posts, roots are prone to fracture, due to the high elastic moduli of metals compared to dentin.

Fiber-reinforced composite (FRC) posts are made of composite in which fibers are embedded in a resin matrix to enhance mechanical properties. Glass, quartz, and carbon fiber can be used to fabricate FRC posts. Compared with metal posts, FRC posts have lower rates of root fracture since their elastic moduli are similar to dentin. In addition to the esthetic qualities of glass and quartz fiber posts, the adhesive strengths between composite resin cores and fiber posts are superior to those between composite resin and metal posts.

Previous studies of posts have typically considered mechanical properties, the adhesive strength between posts and resin cement, and the fracture resistance of teeth restored with various types of posts. However, microleakage is also an important factor, because it influences the initiation of secondary caries, as well as the survival rate of posts and restorations, and, ultimately, the failure of endodontic treatment. Microleakage is related to the rigidity of the post, the solubility of the cement, and the strength of the adhesive bond between posts and tooth structure.

Clinically, microleakage is caused by fatigue, a form of failure that occurs in structures subjected to dynamic stress. Fatigue is influenced by stress levels, design geometry, the condition and configuration of component surfaces, and the environment. Fatigue occurring as a result of repeated loading can induce microcracks and adhesive failure along the interface between the core and tooth structure. Dye penetration accelerates through microcracks and can be further influenced by dynamic loading. In previous studies regarding microleakage, specimens were placed in a dye solution after thermal or mechanical loads had been applied. However, under dynamic loading, microleakage could be directed influenced by the mechanical properties of the post and core specimens tested in a dye solution.

The level of microleakage was measured by various methods in previous studies. For example, dye penetration, followed by demineralization of the tooth specimen using 5% nitric acid, was measured under a microscope. Confocal microscopy was used with fluorophore markers to measure fluid penetration. Through the fluid transport test, the seal of test specimens was quantified by the movement of tiny air bubbles traveling within a micropipette. The quantitative analysis of dynamic microleakage using an image analyzer was used in the present study. The ratio of dye penetration to the total root area was measured. The objective of this study was to compare microleakage in endodontically treated teeth restored with different post and core material combinations by measuring the amount of dye penetration occurring during dynamic loading. Also, the fracture patterns of these endodontically treated teeth subjected to repetitive stress testing were classified.

MATERIAL AND METHODS

Forty human mandibular incisors extracted within a 2-week period were used for this study. Single-rooted teeth with single patent root canal of a similar size and shape without cracks, root resorption, and opened apices were selected to minimize anatomic variation. The teeth were stored in distilled water, and all external debris was removed using a curette. The clinical crowns of all the teeth were removed at the cementoenamel junction (CEJ) with a low speed saw (IsoMet; Buehler, Lake Bluff, Ill), leaving roots approximately 12 mm in length. The canals were prepared with rotary files (ProTaper Ni-Ti; Dentsply Maillefer, Ballaigues, Switzerland) and obturated with a gutta-percha cone (Dia-Pro; DiaDent, Cheongju, Korea) and sealer (AH-26; Dentsply DeTrey GmbH, Konstanz, Germany) using the continuous wave condensation technique, which is a modification of warm vertical compaction of gutta-percha.

The 40 teeth were divided into 4 groups for restoration with cast posts and cores, prefabricated stainless steel posts, ceramic posts, and fiber posts. Post information is presented in Figure 1 and Table I. Root canal gutta-percha was removed using reamers (Peeso; MANI Inc, Utsunomiya, Japan) to a point 2 mm from the root apices. Post spaces were prepared with low-speed drills supplied by each manufacturer. The post spaces for cast posts were prepared using drills supplied with the prefabricated parallel-sided metal post system (ParaPost; Coltene/Whaledent, Cuyahoga Falls, Ohio). Posts were placed in the roots to a depth of 8 mm, and extended 4 mm into the core components.

Each post space and sectioned tooth surface was etched for adhesive bonding with 37% phosphoric acid for 15 seconds and rinsed thoroughly with water spray. Two consec-
Table I. Post systems used in this study

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>Metal Post</th>
<th>Fiber Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia</td>
<td>Stainless Steel</td>
<td>Cast Post</td>
</tr>
<tr>
<td>Product name</td>
<td>Cosmopost</td>
<td>ParaPost</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
<td>Coltene/Whaledent, Inc, Cuyahoga Falls, Ohio</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Type</td>
<td>Tapered</td>
<td>Parallel</td>
</tr>
</tbody>
</table>

and wax cores. Then the patterns were invested in a gypsum-bonded investment (Cristobalite inlay investment; Whip Mix Corp, Louisville, Ky). After the burn-out phase, a 46% gold alloy (DM46; Woori Dongmyung Co, Kwangmyung, Korea) was cast into molds with a centrifugal casting machine.

To prevent apical microleakage, each root was coated with 2 layers of nail varnish (iaNTi; MD Cosmetics, Seoul, Korea) from the apex to a line 1 mm apically to the CEJ. The root surfaces were then covered with a 0.2-mm-thick heat-resistant polytetrafluoroethylene adhesive tape (Nittofon; Nitto Denko Corp, Fukaya, Japan) to simulate the periodontal ligament and to resist heat generated during the polymerization of the embedding resin. Subsequently, the specimen roots were embedded using autopolymerizing acrylic resin (Ortho-jet acrylic; Lang Dental Mfg, Co, Wheeling, Ill) in a polytetrafluoroethylene mold with an internal diameter of 25 mm and a height of 20 mm. Embedded specimens were stored in a plastic container filled with water. Prior to testing, they were placed in a 37°C drying oven (FO-600M; Jeio Tech, Kimpo, Korea) for 24 hours.

Specimens were tested with dynamic loading to simulate mastication. Loads were applied at 135 degrees to the long axis of the teeth with a cyclic loading machine (WON CLMC-04-1; Won Engineering, Iksan, Korea). The loading point was placed on the lingual surface of the core 3 mm below the incisal surface (Fig. 2). The chamber of the cyclic loading machine was then filled with a 0.5%
solution of basic fuchsin. Since the average incisal force in the incisor region varies from 89 to 111 N, a load of 98 N at a frequency of 1 Hz for up to 50,000 cycles was used for this study. The machine was set to trigger an alarm and stop when the microsensor detected a shift of more than 0.5 mm from the original setting caused by specimen displacement or fracture.

The number of load cycles to fracture was recorded and fracture patterns were visually determined. Each fracture pattern was classified into 1 of 6 groups (Fig. 3). Group I specimens showed no fracture lines on root surfaces or cores. Group II included those with only adhesive failures along the interface between the root and core. In group III, fractures occurred only within the cores. In groups IV, V, and VI, the fractures propagated into the cervical third, the middle third, and the apical third of the roots, respectively. After classifying the type of fracture, specimens were sectioned labio-lingually through the middle of the roots using a low/high speed saw (RB 205 Metsaw; R&B Inc, Daejeon, Korea). Sectioned surfaces were photographed with a digital camera (FinePix S602ZOOM; Fujifilm Film Co, Tokyo, Japan) at a constant distance and magnification. The ratio of the dyed area to the entire sectioned root was determined for quantitative comparisons using an image analyzer (Image-Pro Plus 4.5; Media Cybernetics, Silver Spring, Md). Dynamic microleakage data (%) and the number of load cycles were analyzed by a 1-way ANOVA for statistical significance and by Duncan's multiple range test at an alpha level of .05.

RESULTS

The ANOVA indicated significant differences in microleakage within test groups (Table II). The amount of dynamic microleakage for each group was compared (Fig. 4). The percent of mean microleakage (SD) of the cast post and core group (36.95 (6.21) %) was significantly higher than that for other groups: ParaPost (23.3 (3.38) %), FRC Postec (23.29 (3.00) %).
### Table II. One-way ANOVA for microleakage

<table>
<thead>
<tr>
<th>Microleakage</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>1412.1</td>
<td>3</td>
<td>470.7</td>
<td>7.3</td>
<td>.001</td>
</tr>
<tr>
<td>Within groups</td>
<td>2328.4</td>
<td>36</td>
<td>64.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3740.5</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Amount of microleakage by dyed area to root section (Entries with same lowercase letters were not significantly different at \( P>.05 \)).

5. Mean load cycles resulting in fracture or final endurance of specimens. (Groups were not significantly different, \( P=.161 \)).

The type of fracture classification for each specimen is displayed in Figure 3. For the FRC Postec and Cosmopost groups, fracture lines were limited to the cervical third of the root, while fractures extending to the middle third were found in the cast post and ParaPost groups. In the cast post and Cosmopost groups, some of the posts were fractured into 2 segments within post spaces (2 in the cast post group and 3 in the Cosmopost group), and the fractured parts detached easily from the root canals after sectioning for image analysis.

According to the ANOVA (\( P=.161 \)), load cycles for the individual post system groups were not significantly different. The average number of load cycles to fracture or final endurance was compared (Fig. 5). Although the number of dynamic load cycles was not significantly different, the Cosmopost tended to fracture earlier than the other groups.

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\( \% \), and Cosmopost (23.1 (2.36) \%) \( (P=.001) \).
DISCUSSION

Endodontic failures primarily result from the presence of bacteria within root canals caused by incomplete root canal preparation or reinfection through a poor coronal seal.\(^{20}\) In endodontically treated teeth, the lack of coronal tooth structure often necessitates the placement of a post and core to provide crown retention. In addition to retention, the post should also contribute to a hermetic coronal seal. Microleakage that occurs through a break in the coronal seal is an impeding factor in clinical success.\(^{17,21}\)

In a pilot study, a difference in the amount of microleakage was found between a group where dye penetration testing was performed during repeated loading and a group where a dye penetration test was performed after loading. Repeated loading resulted in the adhesive failure between the core and the tooth structure, through which dye penetrated into a larger area of root dentin. Consequently, measuring microleakage occurring during dynamic load testing could provide more clinically relevant information; hence, the rationale in this study for repeated load testing with specimens immersed in a dye solution.

The cast posts showed a significantly higher level of microleakage than those of the FRC Postec, ParaPost, and Cosmopost. The prefabricated posts with composite resin cores showed less microleakage than the cast post and core specimens under repeated loading. Greater microleakage in the cast post and core group may be attributed to lower adhesion between cast metal and root dentin. In the other groups, composite resin cores would be expected to adhere to the root dentin with a chemical bond. There were no significant differences in microleakage among the FRC Postec, ParaPost, and Cosmopost groups, the cores of which were made of composite resin, in spite of the fact that each post system had a different elastic modulus. Consequently, the adhesion between cores and root dentin seemed to have a more important role in limiting microleakage compared to the elastic moduli of the posts. This was consistent with previous studies, which concluded that microleakage was affected by the adhesion between post and dentin, or between core and dentin, rather than by the physical properties of the post itself.\(^{24,25}\)

Regarding the classification of fracture patterns (Fig. 3), fractures allowing retreatment were considered favorable, such as in groups I, II, III and less so in group IV. Retreatment would be impossible for fractures in groups V and VI.\(^{10,21}\) The results for Cosmopost and FRC Postec showed that fractures occurred within the first 4 fracture categories, groups I through IV, and approximately half of these fractured posts were found in groups I through III. This suggests that the ceramic and fiber posts were superior to metal posts in terms of favorable fracture expectations. For fiber posts, this could be related to having elastic moduli similar to dentin.\(^{26}\) The ceramic posts did not transmit occlusal stress to the root, but the post itself fractured as a result of its brittle characteristic. Three ceramic posts fractured into 2 pieces within the post spaces without concurrent root fractures. Although there were no significant differences among the groups in number of cycles to failure (Fig. 5), the Cosmopost tended to fracture earlier than the other groups. This is in agreement with a previous study showing that restorations using zirconia posts and composite resin cores have lower survival rates and a higher possibility of fracture compared to other types of posts, and composite resin cores.\(^{27}\)

The aim of this study was to compare microleakage in relation to the mechanical properties of each post under dynamic loading. The flexion of each post would have an important role in dye penetration through the microcracks created between the core and cervical dentin under dynamic loading. However, contrary to expectations, microleakage was influenced by the adhesion between cores and root dentin, more so than the elasticity of each post.

Instead of crown fabrication on cores, the cores were made to fit the size of clinical crowns in this study. If complete crown restorations were made for the post and core foundations, they would have influenced the results. Crowns would hinder assessing the direct effects of the mechanical properties of posts on microleakage under dynamic loading. Also, with the current study design, cracks propagating from the loading point can be clearly seen without crowns. However, stress distribution to the post and core foundations through the crown would be different from that of the enlarged core components. From this perspective, the test specimen design is not a clinically relevant model, and this is a limitation of the study. Further studies, inclusive of crowns, are anticipated to compare the behavior of stress distribution and microleakage. The lack of a proper control group is a further limitation in the design of this study. However, no studies have measured microleakage in endodontically treated teeth restored with posts while subjected to dynamic loading, an important experimental design consideration for microleakage studies.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. The microleakage in the ParaPost, FRC Postec, and Cosmopost groups was significantly lower than microleakage measured in the cast post and core group (\(P<.001\)).
2. Both the Cosmopost and FRC Postec groups showed fracture patterns that would favor retreatment.
3. The Cosmopost group recorded the lowest number of load cycles
to failure, even though there were no significant differences among the groups. For 3 specimens, posts fractured within the post spaces.

REFERENCES


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1. Carbon Fiber
2. SiC Fiber
3. Zirc. Fiber
4. Type IV Gold (Shiny Fiber)
5. SS Posts
6. Ti Alloy
7. Dentin bars