Effect of post type and loading condition on the failure resistance and primary failure mode of flared canal teeth restored with fiber-reinforced or cast posts

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Key Words: cast post-and-core, failure mode, failure resistance, fiber-reinforced post, flared canal

Abstract

Objectives: This study investigated the influence of post type and loading condition on the failure resistance and primary failure mode of flared canal roots.

Materials and methods: Flared post holes were prepared in 40 sound human lower premolar roots. Twenty roots received glass fiber posts with resin core (fiber specimens) and 20 received cast post-and-core (cast specimens). After cementation with resin cement, in 10 fiber and 10 cast specimens, a quasi-static bending test was performed by an Instron-type testing machine. In the other specimens, before the bending test, a bucco-lingual load was applied for 900,000 cycles using a lever-type device. Failure resistance and primary failure mode in relation with post type and loading condition were statistically analyzed (significance level: 0.05).

Results: After cyclic loading, all specimens were intact; therefore, they underwent the bending test. Failure resistance showed a significant difference only for the post type (p = 0.002) (two-way ANOVA). In the presence of cyclic loading, the post type significantly influenced failure resistance (p = 0.010), whereas in its absence, it showed only a tendency to influence failure resistance (p = 0.054) (Tukey test). In the cycled specimens, significantly fewer root fractures and more frequent debonding without root fracture were found in the fiber than in the cast specimens (p = 0.02) (Fisher’s exact test).

Conclusions: Rather than cast post-and-cores, the use of glass fiber-reinforced posts and resin core for the restoration of flared canal teeth may prevent root fracture, but debonding may occur under high loads.
1. Introduction

Although many studies have pointed out the importance of preserving sound tooth structure apical to the dowel-core margin, so that the crown can brace the endodontically treated teeth and prevent fracture ("ferrule effect"). Clinicians are often faced with the need of restoring teeth with extensive caries, in which no ferrule can be maintained and the remaining dental structure is rather fragile. For this purpose, custom cast post-and-core buildups or prefabricated metallic posts with resin cores have been traditionally used, but a series of shortcomings has become evident in time. A serious complication that often leads to tooth extraction is root fracture. In vitro investigations of different post systems have found that teeth restored with cast or prefabricated metallic posts demonstrated most catastrophic failures by root fractures. Esthetic complications and allergic reaction to metal have also been related to metallic posts. Therefore, non-metallic posts have been added to the treatment options of endodontically treated teeth. Among these, glass fiber-reinforced posts are esthetic and, according to the manufacturer, their modulus of elasticity is 29.2 GPa, which is much closer to that of dentin (14.2 GPa) than dental alloys (90-100 GPa). Recently, the use of post materials with physical properties close to those of natural dentin has been recommended. These are expected to decrease the stress in the dental structure, and thus reduce the incidence of catastrophic root fracture. Although this supposition is supported by studies using only structurally sound roots, the clinical use of glass fiber-reinforced posts has been extrapolated to restore structurally compromised teeth whose post-hole preparation end up in flared canals. These are at higher risk for fractures than the sound roots, because of the thin walls remaining; however, whether the selection of post type can improve the failure resistance of roots with flared canals has yet to be determined.

Clinical failures in fixed prosthodontics are often caused by fatigue, as a result of long periods of function under occlusal forces (mastication, swallowing, etc.); fatigue failures of the tooth-restoration complex have been clinically reported in connection with endodontically treated teeth restored with posts and cores. However, when applications of new materials or techniques are tested in vitro, failure resistance of teeth restored with posts and cores are investigated by quasi-static rather than fatigue tests. Among the few studies that used fatigue loading to compare fracture strength of fiber and metallic posts, one evaluated their torsion resistance, while another study used high-stress cyclic loading in wet conditions. These studies bring valuable insight into the fatigue failure of structurally sound roots restored with different posts. However, clinically, rather than being exposed to torsion, teeth are compressed and bent by the axial and lateral components of the occlusal load, respectively. Thus, the effects of these components and especially that of the lateral...
component, which has a higher potential of damaging teeth, have to be also investigated. Moreover, although testing under high-stress loading is time-efficient, applying loads that are in the physiological range for a high number of cycles will more closely simulate the intraoral biomechanical environment that may finally lead to fatigue failure. Regarding the number of cycles, Wiskott et al.\(^{21}\) consider fatigue tests as conclusive for clinical restorations if they are conducted up to a range of \(10^4 - 10^7\) cycles.

Furthermore, in both static and fatigue studies on failure of post-restored teeth, the outcome parameter has been in many instances fracture strength/resistance.\(^{18,19}\) However, beside root/post fractures, clinical failures of teeth restored with posts and cores have also included loss of retention and marginal gaps.\(^{22, 23}\) Thus, the present study was designed to record the first sign of failure (primary failure\(^{17}\)): fracture of the tooth-restoration complex, debonding (loss of post retention or presence of marginal gaps), etc. Its purpose was to investigate the influence of post type and loading condition (presence or absence of a 2-kgf (19.62 N) lateral load that was applied in \(9 \times 10^5\) cycles), on the failure resistance and primary failure mode of roots with flared canals restored with posts and cores. Two hypotheses were tested: 1) Post type influences failure resistance and primary failure mode of flared roots restored with a fiber-reinforced post and composite core or cast post-and-core and 2) the loading condition influences the failure resistance and primary failure mode of flared roots restored with the abovementioned posts and cores.

2. Materials and methods

2.1 Teeth preparation

Freshly extracted mandibular premolars were disinfected with 6% sodium hypochlorite solution (Purelox, OYALOX Co., Ltd., Tokyo, Japan) and inspected under a stereomicroscope to check for caries, crack and stain. Forty intact teeth of similar dimensions were selected and stored in isotonic saline solution. The mean dimensions (SD) of the teeth as measured at the most apical level of the cementoenamel junction were: 4.95 (0.43) mm mesiodistally, 7.25 (0.64) mm buccolingually, and 13.96 (1.32) mm in root length.

Each tooth was decoronated with a diamond point at the most apical level of the cementoenamel junction and the root section was flattened by a carborundum disk to obtain a surface perpendicular to the longitudinal tooth axis.

All teeth were endodontically instrumented up to a size 50 K-type file (MANI Inc., Ustunomiya, Tochigi, Japan) with water irrigation between file sizes. After the canals were dried, they were obturated using the lateral condensation technique, with gutta-percha master points #50 (GC Co. Tokyo, Japan), auxiliary cones (GC Co.) and a calcium hydroxide root canal sealer (Sealapex, Kerr Manufacturing Co., Romulus, MI, USA). A small quantity of zinc phosphate cement (Shofu Inc, Kyoto, Japan) was filled on top of the gutta-percha and the specimens were stored in the saline for at least 7 days before canal preparation.

The canals were prepared to receive posts (Fig 1) to a depth of 8 mm with #1 through #3 Peeso reamers (MANI Inc., Ustunomiya, Tochigi, Japan) and #1 through #2 tapered reamers (RTP Reamer, Dentech, Tokyo, Japan). On the lingual aspect, a keyway type antirotational groove was also prepared with a diamond bur. Thereafter, the canal was flared in the cervical area by a conical carborundum point, to simulate the preparation required in gross carious destruction (Fig 1). In all the specimens, the mesiodistal width of the remaining tooth structure in the cervical area was 1 mm on each side.

2.2 Post and core fabrication and cementation

All the posts were fabricated by the indirect method. The impressions were taken with putty and injection types of vinyl polysiloxane impression material.
in the central hole of a resin block with an orthodontic resin applied in layers (Dentsply International Inc., York, PA, USA) up to 2 mm below the root surface level. To ensure the bond to both root and resin, a cyano adhesive (Dental cyano, Koatsu Gas Kogyou Co., Ltd., Chiba, Japan) was used on the inner side of the Scotch tape during taping and on its outside with each of the orthodontic resin layers. During this procedure, the preserved sprue of the cast core or the top of the fiber post was fixed in the arm of a surveyor, to align the post to the vertical axis. Prior to the cyclic loading, the artificial mobility of the restored teeth was evaluated by measuring the buccolingual deflection of the loading point with an electric micrometer (Minicom, Tokyo Seimitsu Co., LTD., Tokyo, Japan) in the same setting as for the mechanical tests. Under 2 kgf (19.62N) load, the mean (± SD) was 35.7 (± 21.6) μm.

2.3 Fatigue loading

Half of the cast and half of the fiber specimens were firmly mounted in a brass holder of a custom-made lever-type fatigue testing machine\(^\text{24}\). Serrate-type cyclic loading between 0 and 2 kgf (19.62N) was applied to the buccal face of the core, 4 mm from the cemento-enamel junction (Fig. 2). The load was applied at a rate of 80 cycles/min (1.33 cycles/s) for 900,000 cycles in a wet environment at room temperature. During each cycle the specimens were loaded for 0.3 s. The machine was equipped with 2 types of shutoff sensors to automatically discontinue loading in case of specimen failure.

![Loading jig](image)

**Fig 2.** Fiber specimen mounted in the brass holder of a lever-type fatigue testing machine. The wet environment during the cyclic loading was created by wet gauze, which emerged from a recipient filled with water and encircled the cervical portion of the root.
2.4 Bending test

In the specimens, in which no failure occurred after the cyclic loading, and in those that did not undergo cyclic loading, a single-cantilever bending test was performed. The specimens were secured in an Instron-type testing machine (AG-1000E, Shimadzu, Kyoto, Japan) and an increasing load (crosshead speed of 1 mm/min) with the same direction and location as in the mechanical cycling was applied until failure was recorded. For each specimen, the magnitude of the force causing failure was recorded in kgf.

The primary failure mode was defined from both the force-deflection curve and specimen appearance at the in-situ visual inspection. While it was recorded, the force-deflection curve was continuously watched; when a small, gradual drop-down in the force curve occurred, the sample was visually inspected for gaps between core and root. When any gap became visible, the machine was stopped to avoid further destruction. Then, the roots were cut out of the embedment resin and the specimens were inspected by a stereomicroscope to check for any other damage of the tooth or restoration. The presence of a gap between core and root without any fracture of the dental structure was defined as “debonding”. Conversely, when no gradual drop occurred in the force-deflection curve and no gap was visible, the force was increased almost linearly until a considerable, sharp drop-down could be depicted. At that point, the testing machine was immediately stopped and the specimens were inspected, as described above. In these specimens, root fracture was always detected and the primary failure mode was defined as “root fracture”.

2.5 Statistical analysis

The failure resistance (load-to-failure) data were analyzed statistically by two-way ANOVA (2 x 2) and an all pairwise multiple comparison procedure (Tukey Test) (p < 0.05), after the normal and homogeneous distribution of the data was confirmed.

Specimen mode of failure was classified as either debonding (without root fracture) or root fracture. The frequencies of root fracture occurrence in each group were counted and compared by Fisher’s exact probability tests, to determine the probability of an association between post type and occurrence of root fracture in each loading condition, as well as that between loading condition and occurrence of root fracture in each post type. The statistical analyses were performed using a commercial computer program (SigmaStat 2.03, SPSS, Chicago, IL, USA).

3. Results

In the cycled specimens, no failure was recorded at the end of the test; therefore, all the specimens were then subjected to the quasi-static bending test in the Instron-type testing machine.

3.1 Failure resistance

Since the failure resistance data showed normal and homogeneous distribution, they were analyzed by two-way ANOVA (2 x 2) (Table 1), which showed a statistically significant difference for the factor post type (p < 0.05). However, no statistically significant difference was detected for the factor load condition, or for the interaction between the 2 factors (p > 0.05). The mean failure resistance and standard errors of the means for each group are illustrated graphically in Fig 3. The Tukey test showed that, in the presence of cyclic loading, the post type resulted in a statistically significant difference (p < 0.05) (Table 2), with higher resistance of the cast specimens. In the absence of cyclic loading, post type showed a tendency to influence failure resistance, but without reaching significant difference (p = 0.054). Loading condition

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Table 1 Results of the two-way ANOVA (2 x 2) of the failure resistance values (kgf)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>SS (kgf)</th>
<th>MS (kgf)</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post type</td>
<td>1</td>
<td>1056.578</td>
<td>1056.578</td>
<td>11.186</td>
<td>0.002</td>
</tr>
<tr>
<td>Load condition</td>
<td>1</td>
<td>5.837</td>
<td>5.837</td>
<td>0.0618</td>
<td>0.805</td>
</tr>
<tr>
<td>Post type x Load condition</td>
<td>1</td>
<td>25.536</td>
<td>25.536</td>
<td>0.270</td>
<td>0.606</td>
</tr>
<tr>
<td>Residual</td>
<td>36</td>
<td>3400.518</td>
<td>94.459</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>4488.470</td>
<td>115.089</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DF = degree of freedom, SS = sum of squares, MS = mean squares, F = variance ratio, P = probability
Table 3 shows the results of the Fisher's exact probability tests, in which the probability of an association between post type and occurrence of root fracture was analyzed for the cycled and non-cycled specimens, respectively. In the cycled specimens, significantly fewer root fractures were found in the fiber specimens than in the cast specimens (p < 0.05). However, no significant difference was found in the non-cycled specimens (p > 0.05).

Table 4 shows the Fisher's exact probability tests, in which the probability of an association between loading condition and occurrence of root fracture was analyzed for the fiber and cast specimens, respectively. In the fiber specimens, although a tendency of less root fractures was found in the presence than in the absence of cyclic loading, this difference did not reach significance (p = 0.179). In the cast specimens, no significant difference was found in association with loading condition (p > 0.05).

4. Discussion

To have clinical relevance, an in vitro test should simulate intraoral conditions as accurately as possible. In this respect in the present study, the independent
variables that may remarkably influence the outcome were set as close as possible to those of the intraoral environment. Since dryness makes teeth more brittle, each specimen was kept wet during both storage and the approximately 9-day long fatigue test.

To simulate the biomechanical behavior of tooth during function, applied load and tooth constraints are important. Graf & Grassl\(^25\) have reported that lateral force peaks between 0.5 and 2 kgf were observed in the buccal direction of the molar teeth; during the fatigue test of this study, the tooth was slightly challenged by setting the load to the upper value (2 kgf). During each cycle, the specimens were loaded for 0.3 s, which approximately corresponds to the duration of tooth contact in one chewing cycle.\(^{26-28}\) The cyclic loading was carried out at 80 strokes/min, which is within the range of the average human chewing frequency (70 to 80 cycles/min).\(^{26,27}\) The duration of cyclic loading (900,000 strokes) may be equivalent to 3 years of clinical function, because it has been estimated that application of fatigue-type stress during mastication may amount to approximately 300,000 flexures per year.\(^{12,26}\)

Regarding tooth constraints, a too rigid constraint of the root during the mechanical testing will lead to a more stressful biomechanical environment than the intraoral fixation of the tooth in the alveolar socket, whereas a too loose constraint will have an opposite effect. To ensure artificial tooth mobility similar to the physiological behavior, one layer of Scotch tape was wrapped and bonded around each root, before fixation in orthodontic resin. This resulted in a mean buccolingual deflection (SD) of 35.7 (21.6 μm), which is within the physiological range (17 - 39 μm) reported for the same load direction and a similar location in the dental arch.\(^{29}\)

The statistic analysis of the failure resistance data by ANOVA (Table 1) showed that post type influenced the failure resistance of flared roots restored with a fiber-reinforced post and composite core or cast post-and-core. Moreover, the Tukey test (Tables 1 and 2) showed a significant difference for the post type in association with cyclic loading, with lower failure resistance in the fiber than the cast specimens (Fig. 3). Although the factor loading condition was not found to significantly influence the failure resistance (Table 2), it showed a tendency of affecting the failure mode in the fiber specimens (Table 4). Putting all these facts together the following explanation could be given.

Fatigue loading in wet environment, in association with the use of composite resin added cervically around the fiber-reinforced post to fit the flared canal, increased the likelihood of debonding in the fiber specimens. This supposition is supported by the fact that significantly more failures by debonding without root fracture were found in the fiber than the cast specimens in the presence, but not in the absence of cyclic loading (Table 3). Another argument in favor of this explanation is that, in the fiber specimens, a tendency of more debonding without root fracture was found in the presence than in the absence of cyclic loading; however, this was not the case for the cast specimens (Table 4), in which instead of composite resin, a dental alloy that is more resistant to cyclic

### Table 3
Comparison of the primary mode of failure (occurrence/ non-occurrence of root fracture) between the cycled fiber and cast specimens, as well as between the non-cycled fiber and cast specimens (Fisher’s exact probability tests)

<table>
<thead>
<tr>
<th>Load condition</th>
<th>Post type</th>
<th>Root fracture</th>
<th>No fracture but debonding</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycled</td>
<td>Fiber</td>
<td>3</td>
<td>7</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>Cast</td>
<td>9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Non-Cycled</td>
<td>Fiber</td>
<td>7</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cast</td>
<td>8</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4
Comparison of the mode of failure (occurrence/non-occurrence of root fracture) between the cycled and non-cycled fiber specimens, as well as between cycled and non-cycled cast specimens (Fisher’s exact probability tests)

<table>
<thead>
<tr>
<th>Post type</th>
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<th>Root fracture</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Fiber</td>
<td>Cycled</td>
<td>3</td>
<td>7</td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>Non-Cycled</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Cast</td>
<td>Cycled</td>
<td>9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Non-Cycled</td>
<td>8</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
loading and humidity ensured the post fit into the flared canal. In the fiber specimens, the adhesive resin cement, matrix resin of post, and composite resin might have been deteriorated by the fatigue test in the wet environment and this may have allowed for a greater deflection and thus a larger deformation of the more flexible fiber-reinforced post. This put a higher burden on the weakest tooth-adhesive cement-composite resin interfaces, which therefore failed at lower loads than the weakest link of the tooth-restoration complex in the cast specimens. In contrast, the more frequently encountered root fracture and resistance to higher loads in the cycled cast specimens can be explained by the higher stiffness of these posts, as compared with the glass-fiber reinforced posts and the cervically added composite resin. Higher loads were needed to deflect them, and thus a higher burden was concentrated in the cervical region of the surrounding tooth structure. This ended up in more root fractures. Once a fracture occurred, a higher burden was transferred to the tooth-cement interface and slight debonding (gaps) followed immediately in half of the cycled cast specimens. On the other hand in the absence of cyclic loading, the difference in stiffness of the 2 posts could explain the tendency of higher failure resistance in the cast than the fiber specimens; however, in the absence of the fatigue test in wet environment, the tendency did not reach significance (Fig 3).

In the present study, root fractures and debonding (gaps at the core-dentin interface) were recorded as modes of failure. The latter were most probably caused by the debonding at the post-dentin interface. Clinically, the following mechanical failures have been reported in teeth restored with posts and cores: root or restoration fracture, restoration loss of retention, marginal gaps, etc. Among these, root fractures and debonding of the post and core (post loosening) have been reportedly the most common post and core complications clinically encountered. Thus, it may be extrapolated that in a mechanical test, rather than recording only the specimen fracture, the investigation of the initial sign of failure may lead to an outcome of clinical relevance.

This study is also in agreement with in vitro studies on fiber posts, in which significantly higher failure loads, but more tooth fractures, were reported for cast post-and-core specimens in comparison with carbon-fiber post specimens or glass fiber-reinforced posts when tested without crown coverage. In another study that investigated failure resistance and primary failure mode of post-and-core submitted to quasi-static compressive load, a tendency of increased failure resistance, but no significant difference, was reported for teeth restored with cast post-and-cores in comparison with those restored with carbon-fiber posts. Although the difference in the direction of force application does not allow for direct comparison, the findings of the abovementioned study are in agreement with the results of the cast and fiber specimens not subjected to cyclic loading in the present study.

From the point of view of re-treatment options, in vitro studies on the failure resistance/mode of post-and-core restored teeth often classify modes of failure into “favorable/unfavorable” or “retrievable/irretrievable”, while clinical studies similarly define “reversible/irreversible” complications. Similarly, the failure modes recorded in the present study could be classified as either “favorable” (“reversible”) or “unfavorable” (“irreversible”). Debonding without fracture fell in the first category, since re-cementation of the restoration could be a possible re-treatment option, while root fracture was classified into the latter, because the fracture line continued well below the simulated bone level, and thus would most probably imply tooth extraction. From this point of view, the use of glass-fiber reinforced posts, which led to significantly less root fractures after cyclic loading, may prevent root fracture to a greater extent than cast post-and-cores, but debonding, a reversible complication, may occur under high buccolingual load. However, an 18-year retrospective survival study that included full crowns with posts warns that the occurrence of a previously reversible complication is a predicting factor for an irreversible complication. Therefore, any complication should be carefully analyzed and its cause should be removed, to avoid a more serious complication that can end up with tooth extraction.

Finally, some limitations of this study needs to be acknowledged. A study that compared failure resistance/modes of various post systems at different stages of tooth restoration showed different results for teeth restored with post-and-cores only and those additionally covered by crowns. This implies the
necessity of further testing of post-and-cores under crown coverage to increase clinical relevance of the results. Moreover in the present study, cyclic loading tended to influence failure mode in the fiber specimens only, and it did not significantly affect failure resistance. Prolonged cyclic loading needs to be performed to elucidate the effect of loading condition on the failure resistance/mode of restored teeth.

5. Conclusions

Within the limitations of this in vitro study, the following conclusions were made:

1) Rather than cast post-and-cores, the use of glass-fiber reinforced posts and core build-up material for the restoration of flared canal teeth may prevent root fracture, as found in a fatigue test followed by a quasi-static bending test. However, debonding, a reversible complication, may more frequently occur in these fiber-post teeth under high buccolingual loads.

2) After 900,000 load cycles, flared canal teeth restored with cast post-and-core resisted to significantly higher loads than those restored with fiber posts, but when they failed, significantly more unfavorable failures (root fractures) were recorded.

3) The application of 900,000 cycles of load tended to influence primary failure mode in the fiber specimens only, and it did not significantly affect failure resistance. Prolonged cyclic loading needs to be performed to elucidate the effect of loading condition on the failure resistance/mode of restored teeth.

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References


