Resistance to Cyclic Fatigue and Fracture of Structurally Compromised Root Restored with Different Post and Core Restorations

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The aim of this study was to evaluate the resistance to fracture of endodontically treated teeth with flared canals restored with different post and core restorations under static and cyclic fatigue loadings. Sixty human maxillary central incisors were used. Two main groups (non-ferrule and 1-mm ferrule) were divided into three types of restoration: custom cast post-and-core (MPC), resin composite post-and-core (RCP), and resin composite core in combination with prefabricated carbon fiber post (FRC). Half of each group was subjected to a static loading test, and the other to a cyclic fatigue test. FRC exhibited a significantly higher number of load cycles than the other groups, and MPC showed the highest failure load among the tested groups. However, all FRC and MPC specimens demonstrated unfavorable root fractures. The results of this study suggested that RCP prepared with 1-mm ferrule was the most desirable restoration for structurally compromised roots, as relatively strong resistance to cyclic fatigue and fracture was revealed – given that all RCP specimens demonstrated favorable root fracture.

Key words : Prosthodontics, Post and core, Fracture resistance

INTRODUCTION

There have been extensive studies on post-endodontic restorative therapy. Cast gold post and core has always been regarded as the golden standard in post and core restorations. Despite the long track record, rigidity in particular is still a major problem that plagues conventional, custom cast posts and cores. As resistance to great forces usually leads to distortion, the post-core/crown complex is then displaced and even possibly sustaining catastrophic root fracture on failure. Recent progress in fiber-reinforced post-and-core systems and the advent of adhesive technology have improved post and core restorations, offering an alternative to conventional techniques.

To evaluate the strength and durability of dental materials or restored pulpless teeth, monotonous static loading or cyclic fatigue loading have been used in many studies. It is presumed that a static load would simulate the impact trauma resulting from sports or accidental injury. As for the evaluation of long-term mechanical behavior of restorations, cyclic fatigue loading – which simulates accelerated mechanical deterioration – can be a partial alternative to time-consuming clinical trials.

The fracture resistance of restored endodontically treated teeth is highly dependent on the bulk of remaining tooth structure and the length of ferrule. Before embarking on therapy for this type of teeth, remaining thickness and height of tooth structure must be carefully taken into consideration. Although a large amount of research has been carried out concerning endodontically treated teeth with adequate radicular dentin structure, the question of how to establish optimal restorative therapy of severely damaged teeth – such as teeth with thin root wall and flared canal – is yet to be answered. A flared canal, whether due to extensive caries, over-aggressive preparation or frequent retreatments, is structurally compromised against fractures and poses a therapeutic management problem.

The present study is conducted to determine the effects of the following variables on the fracture resistance and failure mode of compromised, endodontically treated teeth with flared canals: dentin ferrule preparation (non-ferrule versus 1-mm ferrule), type of restoration (custom cast post-and-core, resin composite post-and-core, resin composite core in combination with prefabricated carbon fiber post), and mode of testing (static loading versus cyclic fatigue loading).

MATERIALS AND METHODS

Flared canal preparation
Sixty sound human maxillary central incisors of similar size extracted for periodontic reasons were selected and stored in distilled water at 4°C during the course of study. Endodontic treatment was performed with a stainless steel K-file (VDM GmbH, Munich, Germany) up to size 60 (International Standards Organization) at the apical constriction. A 5% NaOCl solution was repeatedly used for irrigation during canal instrumentation, and the root canals were subsequently obturated with gutta percha points (GUTTA PERCHA POINTS, GC Corp.,
Thirty teeth were assigned to each of the two different dentin ferrule preparations (non-ferrule and 1-mm ferrule). For the non-ferruled group, the crowns were removed with a diamond bur (SMOOTH CUT A18, GC Corp., Tokyo, Japan) at the cementoenamel junction (CEJ); for the 1-mm ferruled group, coronal portions were cut at 1-mm coronal to the CEJ. To prepare the flared canals, gutta percha points were removed by a No. 5 Peeso reamer (Moyco Union Broach, York, PA, USA) to a depth of 8 mm from the CEJ. Root canals were then enlarged using a bud-shaped diamond bur (SMOOTH CUT P17, GC Corp., Tokyo, Japan), preserving approximately a 1-mm width of the axial walls. After flared canal preparation, specimens from the two main groups of dentin ferrule preparation were randomly distributed into three equal groups of 10 each.

**Metal post and core (MPC)**

Direct post patterns were made with wax and cast with Ag-Pd alloy (Castwell M.C. 12% Gold, GC Corp., Tokyo, Japan). Surface of each post was air abraded with 50 μm aluminum oxide at 4.5 kgt/cm². A root canal post was seated into the prepared root canal with resin-based luting cement (Super-Bond C&B, Sun Medical, Shiga, Japan) according to manufacturer’s instructions. Finally, the core was prepared using a parallel milling device (APF-V, Amann GmbH, Germany) to a height of 6 mm (core + ferrule) with a convergence angle of 6 degrees and a circumferential shoulder width of 0.5 mm.

**Resin composite post and core (RCP)**

An experimental dentin bonding system was used in this study. Surface of the post channel was conditioned with 0.5 mol/L ethylene diamine tetraacetic acid (EDTA Dojin, Wako Pure Chemical Industries, Osaka, Japan) which was neutralized with sodium hydroxide dissolved in water to pH 7.4 for 60 seconds, followed by rinsing and thorough air-drying. An aqueous solution of 35vol% glyceryl monomethacrylate solution (Blemmer GLM, NOF, Tokyo, Japan) was then applied for 60 seconds and dried for 10 seconds with oil-free compressed air. After applying a self-cured dentin bonding agent (Clearfil New Bond, Kuraray Medical Inc., Kurashiki, Japan) and after thorough air-drying, a self-cured resin composite (Clearfil FII, Kuraray Medical Inc., Kurashiki, Japan) was dispensed using a Mark III C-R syringe (Centrix, Shelton, CT, USA) with a syringe tip (Centrix, Shelton, CT, USA) and then polymerized. After core build-up was performed, a full coverage crown preparation in the same manner as MPC group was done after storage in 37°C water for 24 hours.

**Prefabricated carbon fiber post with resin composite core (PFR)**

A self-cured resin composite (Clearfil FII, Kuraray Medical Inc., Kurashiki, Japan) and a prefabricated carbon fiber post (C-POST, Bisco, Itasca, USA) with a 2.1-mm diameter were used. Surface of the post was air abraded with 50 μm aluminum oxide at 4.5 kgt/cm². After root canal surface treatment following the same manner as RCP group, resin composite was placed into the root canal and the post immediately inserted into the canal. After core build-up was completed, crown preparation was done in the same manner as RCP group.

After tooth specimens preparation, crowns were waxed to full coverage directly on the prepared teeth. Each specimen received a 10-mm height custom cast crown (Castwell M.C. 12% Gold, GC Corp., Tokyo, Japan) cemented with glass-ionomer cement (Fuji I, GC Corp., Tokyo, Japan) (Fig. 1). To simulate the function of periodontium, roots were covered with a 0.3-mm-thick elastic layer of vinyl polysiloxane (Examix fine, GC Corp., Tokyo, Japan) and embedded in a self-curing acrylic resin (Technovit 4004, Heraeus-Kulzer, Wehrheim, Germany) in a 1-inch-diameter PVC tube (EX embedding ring, Refine Tec, Kanagawa, Japan) at a 135° inclination. Following the concept on biological width, 2 mm of root structure extended beyond the acrylic resin block (Fig. 2).

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**Fig. 1** Diagram of specimen.

**Fig. 2** Test specimen in positioning jig.
Thermocycling
After storage in 37°C water for 24 hours, all samples were cycled thermally 10,000 times by being immersed in two baths filled with distilled water at temperatures of 10°C and 45°C for 20 seconds each (K178, Tokyo Giken, Yokohama, Japan). Transfer time between baths was less than 5 seconds.

Static loading test
Specimens were mounted in a custom-made stainless steel jig and loaded in an Instron universal testing machine (Instron 1125, Instron Co., Canton, USA). A continuously increasing compressive load was applied via a stainless steel rod to the crown (2 mm below the incisal edge on the palatal side) in an angulation of 135° to the longitudinal tooth axis at a cross-head rate of 0.5 mm/min until initial tooth cracking occurred. For all specimens, the load (N) in which initial tooth cracking occurred was determined, and the type of failure was also recorded and classified after a careful examination of each fractured sample with a microscope at ×20 magnification.

Cyclic fatigue test
Specimens were mounted in a special jig and loaded in a fatigue testing device (K655, Tokyo Giken, Yokohama, Japan) using compressed air and pneumatic cylinders to generate the forces. An intermittent force of maximum 54 N was applied and transferred over the extendible titanium rods to each specimen in the same direction and position as the static loading test at a frequency of 1.25 Hz in 37°C distilled water until initial root crack occurred. During the cyclic fatigue test, macroscopic observation of the specimens was made after every 10,000 load cycles to detect any tooth cracking or displacement of the post and/or core. If no failures occurred, then the test was ceased after 1,000 repetitions. Failure modes of each tested specimen were recorded and classified in the same manner as static loading test.

Statistical analysis
Statistical analysis was performed using JMP software (SAS Institute Japan Ltd., Tokyo, Japan). Means and standard deviations were calculated, and statistical differences were determined using two-way analysis of variance (ANOVA) and Tukey HSD test. The dependent variables were namely the type of restoration (MPC, RCP, and FRC) and ferrule length (0 mm or 1 mm). All tests were conducted at 5% level of significance.

RESULTS
Mean fracture loads after static loading test are presented in Table 1. Two-way ANOVA revealed that ferrule length (p<0.005) and type of restoration (p<0.001) significantly affected fracture load, whereas the interaction between these two factors was not significant (p=0.665). Further analysis with post-hoc Tukey HSD test revealed that MPC had a significantly higher fracture load than FRC and RCP (p<0.05), although no significant differences could be found between FRC and RCP (p>0.05).

Fig. 3 shows the number of load cycles prior to initial tooth cracking for each group. Results from the cyclic fatigue test revealed a skewed distribution; thus, all values were transformed to logarithms. ANOVA showed that ferrule length (p<0.001) and type of restoration (p<0.001) significantly affected the number of load cycles that resulted in tooth cracking, whereas the interaction between these two factors was not statistically significant (p=0.493). The order of fatigue resistance for the restorations was FRC > MPC > RCP (p<0.05), regardless of ferrule length.

After mechanical load testing, three different patterns (A, B, and C) of failure mode were observed on the tested samples (Fig. 4). Pattern A, which was most frequently observed, had vertical root fracture from the margin to the apical 1/3 of the root. Pattern B had a mid-root fracture from the cervical 1/3 to the apical 1/3 of the root. Pattern C failed on the inside of the resin composite core without root fracture.

Table 1 Means and standard deviations of fracture loads

<table>
<thead>
<tr>
<th>Type of restoration</th>
<th>Ferrule length (mm)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC</td>
<td>0</td>
<td>598.2</td>
<td>54.6</td>
</tr>
<tr>
<td>MPC</td>
<td>1</td>
<td>639.0</td>
<td>146.2</td>
</tr>
<tr>
<td>RCP</td>
<td>0</td>
<td>256.0</td>
<td>50.4</td>
</tr>
<tr>
<td>RCP</td>
<td>1</td>
<td>385.4</td>
<td>102.7</td>
</tr>
<tr>
<td>FRC</td>
<td>0</td>
<td>291.3</td>
<td>60.9</td>
</tr>
<tr>
<td>FRC</td>
<td>1</td>
<td>411.9</td>
<td>96.0</td>
</tr>
</tbody>
</table>

n=5. Unit: N

Fig. 3 Number of load cycles to failure.
With regard to failure modes caused by cyclic fatigue loading, all RCP specimens showed root fractures of Pattern C whereas all MPC and FRC specimens revealed root fractures of Pattern A, be it ferruled or non-ferruled specimens (Table 2). In static loading test, all RCP specimens showed root fractures of Pattern C, regardless of ferrule length. However, FRC specimens showed Pattern A (100%) in non-ferruled group, and Pattern A (60%) and Pattern B (40%) in ferruled group. MPC specimens revealed Pattern B (100%) in ferruled group, and Pattern B (40%) and Pattern A (60%) in non-ferruled group (Table 3). In this study, no vertical root fractures occurred in RCP group although all post/core complexes failed; however, no post failures were observed in MPC and FRC groups.

**DISCUSSION**

With regard to restoration of a severely damaged tooth, such as an endodontically treated tooth with a thin root wall and flared canal, clinicians are perennially faced with a dilemma of whether to extract it or not. Due to loss of a large amount of radicular tooth structure, a flared canal is structurally weak and poses a higher risk of biomechanical failure as compared to a tooth with ample radicular dentin structure. The shape of the flared canal investigated in this study is often encountered in daily clinical practice. It requires internal tooth reinforcement and reconstruction by post and core restoration in order to continue use as a support for a crown or fixed partial denture.

Static loading test is a commonly used method to predict the fracture resistance of post and core-restored, endodontically treated teeth. Although such a monotonously increasing load simulates impact stress resulting from sports injury or parafunctional activities such as bruxism, a restoration does not clinically fail within a short time period following placement in the mouth. In keeping with loading conditions in vivo, half of the specimens showed root fractures of Pattern C.

Table 2 Percentage of failure of tested specimens in relation to ferrule length under cyclic fatigue loading

<table>
<thead>
<tr>
<th>Ferrule length (mm)</th>
<th>MPC</th>
<th>RCP</th>
<th>FRC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mode of failure*</td>
<td>Mode of failure*</td>
<td>Mode of failure*</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Unit: %

*A: Vertical root fracture from the margin to the apical 1/3 of the root; B: Mid-root fracture from the cervical 1/3 to the apical 1/3 of the root; C: Failed on the inside of the core without root fracture.

Table 3 Percentage of fracture of tested specimens in relation to ferrule length under static loading

<table>
<thead>
<tr>
<th>Ferrule length (mm)</th>
<th>MPC</th>
<th>RCP</th>
<th>FRC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mode of failure*</td>
<td>Mode of failure*</td>
<td>Mode of failure*</td>
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<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
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<tr>
<td>0</td>
<td>60</td>
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<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Unit: %

*A: Vertical root fracture from the margin to the apical 1/3 of the root; B: Mid-root fracture from the cervical 1/3 to the apical 1/3 of the root; C: Failed on the inside of the core without root fracture.
were subjected to a fatigue load of 54 N (which is within the range of mean chewing forces\(^2\)) at a frequency of 1.25 Hz\(^3\) in this study. It has been shown that restorations that were exposed to 1,200,000 chewing cycles in a fatigue testing device corresponded to those that were in the oral environment for approximately five years\(^4\).

In this study, human teeth were used for specimens preparation. Bovine teeth are comparable to human teeth in their modulus of elasticity, tensile strength, and bonding characteristics. As such, they are used as a substitute for human teeth in many studies\(^5,9,15^19-38\). However, their discrepancy in size relative to human teeth is unacceptable for this study.

In the past, a cast post-and-core was widely accepted for every pulpless tooth without regard to the quantity of remaining supportive tooth structure\(^11\). However, custom cast post-and-core is time-consuming and expensive. It requires two appointments, as well as elimination of all undercuts and irregularities during preparation. Furthermore, mechanical properties of cast metal, in particular the modulus of elasticity, are far higher than those of radicular dentin. This incompatibility creates stress at the tooth/cement and post/cement interfaces, occasionally causing post separation and failure\(^39\).

Due to continuous progress of adhesive material and technology, resin composite and fiber-reinforced posts have become more popular than conventional cast posts and cores. It has been advocated that the modulus of elasticity of a post should be similar to that of root dentin to distribute applied forces evenly along the length of the post\(^10\). Duret et al.\(^5\) had reported that the modulus of elasticity of prefabricated carbon fiber posts is similar to that of dentin — thus it may effectively transmit stress between the post and the remaining root structure, reducing stress concentration. In this study, it was observed that FRC specimens had significantly longer fatigue life than MPC specimens. This difference in fatigue life could be partially attributed to the difference in rigidity, suggesting that unlike static loading, resistance to cyclic fatigue loading may strongly be affected by the modulus of elasticity of post and core restorations.

Vertical root fracture was observed in all FRC and MPC specimens regardless of ferrule length. Clinically, teeth that show this kind of fracture will require extraction. In contrast to cyclic loading test results, MPC recorded the highest fracture load among the three types of restoration. This was because a higher modulus of elasticity resulted in less bending of post and core restoration under load. Besides MPC, RCP recorded a relatively high fracture load almost equal to FRC. This result was also compatible with those of other studies\(^4,12\). For MPC and FRC, when a ferrule was absent, loads were resisted only by a post, hence the vertical root fracture in all the specimens. However, when a 1-mm ferrule was present, the majority showed mid-root fractures as the post might have evenly transferred the stress to dentin.

Though teeth with flared canals could be structurally weaker, no root fractures were detected in all RCP specimens. This showed that RCP restoration served to protect the remaining tooth structure. RCP with 1-mm ferrule exhibited relatively strong resistance to cyclic fatigue and fracture. Hence, RCP is highly recommended for the construction of post and core restorations on flared canals, as the insufficient mechanical strength and moderate elastic modulus of RCP made it to be favorably compatible with a tooth that has been structurally compromised by a flared canal.

Several authors have claimed that the placement of a crown when testing post-and-core complexes obscured the effects of different foundation restorations\(^41-16\). However, it has been shown that a crown creates a ferrule effect and a different load distribution pattern when placed over a core — if the margins encircle a sound dentin collar. Within the limitations of the present study, the effect of 1-mm ferrule cannot be confirmed. Although a ferrule is known to positively enhance both fracture and failure resistance, differences in root length may influence the test results. To investigate the influence of root length or ferrule effect, a further study is required in the future. Nonetheless, the results of this study suggested that a ferrule extension of at least 1 mm by periodontal crown lengthening or orthodontic extrusion is required to ensure treatment success and longevity, although it may occasionally be difficult to provide an appropriate ferrule for a severely damaged tooth.

CONCLUSIONS

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

1. Resin composite post-and-core (RCP) prepared with 1-mm ferrule had relatively strong resistance to cyclic fatigue and fracture loading. As it also demonstrated favorable root fracture, RCP is the most desirable restoration for structurally compromised roots.
2. Resin composite core in combination with a carbon fiber post (FRC) had an advantage in restoring pulpless tooth with flared canal due to its long fatigue life, and custom cast post-and-core (MPC) showed the highest fracture strength. However, all FRC and MPC specimens demonstrated unfavorable root fractures.
3. The results of this study suggested that dentin ferrule preparation was required to ensure treatment success and longevity.
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