Fracture behaviors of maxillary central incisors with flared root canals restored with CAD/CAM integrated glass fiber post-and-core

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The objective was to evaluate the fracture resistance properties of maxillary incisors with flared canals restored with computer aided design and computer aided manufacture (CAD/CAM) integrated glass fiber post-and-core. Thirty prepared flared root canals were selected in vitro and restored with CAD/CAM integrated fiber post-and-core (Group A), prefabricated fiber posts (Group B), and cast gold alloy (Group C), respectively. After submitted to fatigue loading, each specimen was subjected to a static loading until fracture. Analysis of variance (ANOVA) tests were used to determine statistical differences. The mean fracture strengths of Groups A and C were significantly higher than those of Group B, whereas no differences were observed between Groups A and C. In addition, reparable fracture modes were mostly observed in Group A while irreparable and catastrophic fractures were mostly found in Groups B and C. These results demonstrate that, in comparison to traditional treatments, CAD/CAM integrated glass fiber post-and-core restoration significantly enhances the fracture resistance of flared root canals.

Keywords: CAD/CAM, Glass fiber, Post-and-core, Flared root canal, Fracture resistance

INTRODUCTION

Clinically, residual tooth crowns and roots with flared root canals frequently occur in anterior or bicuspid teeth due to external injury, severe caries, dislodgment of the post-and-core etc. Because such teeth have flared root canals with thin dentin walls, conventional treatments are often disadvantageous in terms of adhesiveness, sealability and risk of re-fracture5). It is thus of great importance to use post-and-core restoration techniques to repair the residual tooth crown and root in the treatment of oral rehabilitation. Different types of posts are inserted into root canals to support and strengthen the restoration, such as, titanium, gold-plated, chrome-nickel, gold-cast posts, and ceramic pre-fabricated posts and so on. The restoration by casting alloys and prefabricated glass fiber posts post-and-cores is usually used clinically as yet, which with usual failure modes like the post-and-core break and root fracture concerned with the quantity of residual tooth tissues, the intensity and elastic modulus of post-and-core materials. Esthetic considerations favor tooth-colored posts in the anterior maxillary region, where all-ceramic crowns are used. Light-conducting, fiber2,3), computer aided design and computer aided manufacture (CAD/CAM) blocks4-6), and all-ceramic posts are available for restorations in more esthetically demanding areas7,8).

In this study, a kind of multi-directional glass fiber-reinforced composite materials used for the preparation of integrated post-and-core products was proposed and performed by CAD/CAM technology9). It is considered as an ideal restoration way for weakened roots because of its individuation, elastic modulus similar to dentin and high suitability to root canal shape. This study aims to investigate the fracture resistance properties of maxillary incisors with flared canals restored with CAD/CAM integrated fiber post-and-core compared with traditional post-and-core restoration.

MATERIALS AND METHODS

Specimen selection and grouping
1. Selection standard
Thirty human maxillary central incisors were selected with root length about 13 mm, normal root development, no occult cleft, no caries and fillings, no internal or external absorption, and no endodontic treatment.

2. Grouping
The specimens were divided randomly into three groups, Group A (experimental group, n=10): CAD/CAM integrated glass fiber post-and-core system, Group B (n=10): prefabricated glass fiber posts, φ1.6 mm (Matchpost® RADIOPAQUE, RTD Dental, St E grève, France) and composite resin cores (Filtek™ Z350XT, Filtek, 3M ESPE, St. Paul, MN, USA), and Group C (n=10): prefabricated cast gold alloy post-and-core (ARGEDENT Y73, ARGEN, San Diego, CA, USA) system.

Preparation of flared root canals
Each maxillary central incisor was intercepted at 1 mm upper the cement-enamel junction after conventionally endodontic treatment. All canals were prepared to F3 by manual ProTaper instruments using the crown-down technique and filled routinely. After moistened at 37°C in a calorstat for 3 days, the gutta-percha was removed by Peeso reamer #2 (MANI, Utsunomiya, Japan) and the apical sealing area was remained 4 mm. Then the post space preparation of the flared root canal was performed gradually by Pre-Shaping reamer, MANI DIA-bur

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Fig. 1 Preparation requirement for flared root canal and post canal of maxillary central incisor.

(TR-11F) and Finishing reamer 1.6# (Matchpost®, RADIOPAQUE, RTD Dental) with remaining cervical dentin thickness 1 mm and spacious post canal. Then the dentin shoulders of flared root canals were prepared according to conceptual Fig. 1 with remained 1 mm high and 0.5 mm thick, and right angle shoulder 0.5 mm wide. All the performance was finished by the same prosthodontics doctor.

**Design and manufacture of CAD/CAM integrated glass fiber post-and-core**

The post canal digital data of the specimens of Group A were obtained with a BlueCam scanner (inEos Blue, Sirona Dental Systems, Bensheim, Germany) and the integrated glass fiber post-and-core was designed with CEREC4.0 after the data were imported into the software. The data were then transformed into STL format and the integrated post-and-core was manufactured with a milling machine (DeRTe DT-500, DeRTe (DLT) processing center Chinese office, Guangzhou, China) using a multi-directional fiber-reinforced composite material (OYA Ricom New Material Sci. & Tech., Beijing, China), a new type of epoxy matrix glass fiber resin block for cutting made by pultrusion molding, containing 62% volume fiber component and highly cross-linked polymer molecules. The CAD/CAM integrated post-and-core was finished, refined and treated with an ultrasonic washing unit (GT SONIC, Guangdong GT Ultrasonic, Guangzhou, China).

**Bonding of the post-and-core and manufacture of the crown**

The prefabricated glass fiber post ø1.6 mm and composite resin core in Group B and the cast gold alloy post-and-core in Group C were selected (Fig. 2). The surface of all the post-and-cores in Groups A and C were sprayed with an indicator to remove the blocking points, so as to ensure that the post-and-core was fully positioned in the root canal. The joint parts of CAD/CAM integrated glass fiber post-and-cores were cut down and ground. Then the samples were sandblasted with 100 mesh alumina under the pressure of 0.2 MPa for 3 s, 4 cm between the nozzle and the sample, and 45 degrees angle with the long axis of the post-and-core. Then the silane coupling agent (BIS-SILANE™, BISCO, Schaumburg, IL, USA) was applied on the clean bonding surface of the posts in Groups A and B, allowed to react for 30 s, and then air-dried for 5 s, while the post-and-core in Group C was treated by precious metal treatment agent (V-PRIMER, Sun Medical, Moriyama, Japan) before bonding. Each length of post inserted in the root canal from cement-enamel junction was 9 mm. All specimens were bonded according to specification requirements of the self-adhesive universal resin cement (RelyX™ Unicem 2, 3M, St. Paul, MN, USA), and the composite resin cores in Group B were shaped by resin (Filtek™ Z350XT, 3M ESPE). According to the size of CAD/CAM integrated glass fiber post-and-core shown in Fig. 1, the shape of core part with 6 mm high core, 1 mm high and 0.5 mm thick dentin shoulder, and 0.5 mm wide right angle shoulder was prepared in Groups B and C.

The cobalt-chromium alloy metal crowns (Co-Cr, Wirobond SG, BEGO Bremer Goldschlägerei Wilh. Herbst, Bremen, Germany) with the normal morphous of maxillary central incisor in every group were made by 3D printing (EOS M280, EOS, Hamburg, Germany). The small linear plane on the junction of the middle 1/3 and the biting surface 1/3 in the tongue side of the crown was reserved and the angle of inclination of the linear place to the tooth axis was 60 degrees. The crowns were then bonded to the post-and-cores with universal resin cement (RelyX™ U200, 3M Deutschland, Neuss, Germany).

**Fixation of the specimens**

All roots of the specimens with cement-enamel junction below 1 mm were coated with 0.2 mm thick wax layer and the coated parts were embedded in self-curing acrylic resin blocks. After the specimens were taken out after acrylic resin hardening, the wax layer on the root surface was removed and the roots are fixed in the acrylic resin blocks by silicone rubber to simulate periodontal ligament.
Fatigue loading and static loading
The specimens were fixed to the retainer and the location of the embedded position was at the junction of coronal and middle 1/3 parts of root and adjusted to ElectroForce Mechanical Test Instruments (ElectroForce 3330, BOSE, Eden Prairie, MN, USA), and the loading head is 45 degrees to the long axis of the tooth and contacts the side of the tooth palate, as shown in Fig. 3. The specimens were loaded at a crosshead speed of 1 mm/min till to destroy after 100 N force with 6 Hz, exposed to 300,000 cycles, and the fracture loads and fracture modes of each sample were recorded.

Statistical analysis
The data of fracture resistance strength in each group were analyzed with SPSS 19.0 statistical software, and one-way analysis of variance (ANOVA) and multiple comparison post hoc Tukey tests (α=0.05) was used to determine the significance of the failure loads among different groups. According to the broken areas of the root, the fracture was divided into the reparable or irreparable fracture. The difference of fracture modes between the groups was checked by Chi-square test, and a significance level was established at 5%.

RESULTS
The CAD/CAM integrated fiber post-and-core has been successfully designed and fabricated. The post-and-core can be positioned smoothly after a minor adjustment, and it is very fit to the inner wall of the flared root canal. No restoration failure was found after 300,000 cycling loadings; no loosening was found in the crown of the specimens; and there was no fracture line on the root surface either. The mean fracture strength was (927.6±275.6) N in Group A, (616.5±154.9) N in Group B and (967.9±157.5) N in Group C, respectively. There were no significant differences between Groups A and Group C (p>0.05), but they were significantly higher than those in Group B (p<0.05, Table 1).

Table 1  Fracture resistance strength in three groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Number (n)</th>
<th>Fracture strength N/(x±s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>927.6±275.6</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>616.5±154.9*</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>967.9±157.5</td>
</tr>
</tbody>
</table>

*Compared with Group A and C, p<0.05

Table 2  Fracture modes in three groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Reparable fracture</th>
<th>Irreparable fracture</th>
<th>Total (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a, b, c</td>
<td>d, e</td>
<td>f</td>
</tr>
<tr>
<td>A*</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

*Compared with Group B and C, p<0.05; No difference between Group B and C, p>0.05
distribution of fracture parts of static loading result is shown in Fig. 4. The modes of a, b, and c were regarded as reparable fractures and the modes of d, e, and f as irreparable ones. The results showed that there were six cases of reparable fracture and four cases of irreparable fracture in Group A, whereas there were seven and nine cases of irreversible fracture in Group B and Group C respectively (Table 2).

**DISCUSSION**

In this study, maxillary incisors with flared canals were restored with three different kinds of post-and-core systems, and the fracture resistance strength and fracture modes were detected after simulated mastication loading. The results showed that CAD/CAM integrated glass fiber post-and-core with similar elastic modulus to the dentin and highly fit to the root canal inner wall had higher fracture resistance and more favorably reparable fracture modes for the restoration of flared root canals. Further work is required to ascertain whether such differences will translate into improved clinical outcomes.

The strength of the root after the post-and-core restoration is closely related to the post-and-core systems, ferrule presence, adhesive strength, residual tooth tissue, and occlusion etc. Previous studies showed that, the post-and-core restoration with similar elastic modulus to dentin can make the distribution of chewing stress more uniform and protect the remaining dental tissue. If the rigidity of the prefabricated glass fiber post is not enough, the post is prone to deformation after repeated loading and the high stress fracture zone is easily formed at the root neck. Meanwhile, the bending of the fiber post will cause minor movement in the core, affecting the crown margin sealing, resulting in marginal fissures or secondary caries. Especially for the flared root canal, which the remaining tooth structure is less, and dentin collar height is insufficient or no, the prefabricated fiber post and root canal has poor adaptability, requiring a lot of luting cement to fill the clearance between the post and root canal wall. A large number of cement reduces the overall strength of post-and-core, and the lower load leads to fracture at root neck. It showed that restoration with fiber-reinforced post and sleeve combination was effective in reducing debonding and, hence, improving the fracture strength of pulpless premolars with flared root canals.

The post and core with high elastic modulus may increase fracture risk in roots with flared canals by increasing the stresses within root dentin. Therefore, an individually shaped post-core system constructed with a material that has an elastic modulus close to dentin should be used in weak roots. The fracture resistance strength of the metal cast post-and-core is obviously larger than that of the single prefabricated fiber post-and-core, which is similar to the results of Varvara et al. The elastic modulus (100–200 GPa) of metal cast post is very higher than that of elastic modulus (18 GPa) of dentin. When the root bending deformation occurs under occlusal stress, the post cannot deform synchronously and wedge stress appears at the tip of the post, and the force zone changes from surface contact to point contact. The huge elastic modulus difference between the metal post and dentin will make the root reach the peak value of stress instantaneously when the post is subjected to an excessive impact load, resulting in irreversible root fracture.

Previous study results also showed that the greater the diameter of the post, the higher the fracture resistance strength after teeth restoration. Custom-made zirconia one-piece posts and cores restoration is more beneficial to disperse the bite force than the prefabricated zirconia post and the cast gold alloy post and core. The one-piece of post and core is good to protect the teeth and keep the restoration intact. The fiber posts reduced the stress distribution at the middle and apical part of the posts compared with the stainless steel, zirconia and titanium posts, which could affect the stability of restoration of tooth. After precision design and processing, CAD/CAM integrated glass fiber post-and-cores underwent sandblasting for roughening treatment for fiber post-and-core surface which could improve the bonding strength between the post-and-core and dentin. The raw material of CAD/CAM integrated glass fiber post-and-core used in this study is a new type of epoxy matrix glass fiber resin block for CAD/CAM cutting with a high content of glass fiber arranged in a variety of directions. The fiber is wrapped around the resin matrix and it will not spread during the cutting and sandblasting process. It cannot be broken when sandblasted with 100 mesh alumina under such a low pressure (0.2 MPa), such a short time (3 s) and so far distance (4 cm between the nozzle and the sample). The elastic modulus of the material is about 35 GPa, and the bending strength is 1,100 MPa. The integrated glass fiber post-and-core was custom-designed and manufactured according to the root canal morphology, which with similar elastic modulus to dentin, greater diameter, highly fit to the root canal, and improved self-strength of post-and-core. Therefore, it could reduce the bonding interface, transfer stress distribution more even, avoid stress concentration zone, so that the overall fracture strength was further improved.

The bond strength affects the fracture resistance strength of the root. The bonding integrity to the cervical area would play a critical role in the survival of the restored tooth. When the post and core are bonded, the binder combines the teeth and the post-and-core together to form a whole, called the post-cement-dentin complex. The resin cement binder may be considered as a component of the post-and-core crown system; it can not only transfer the stress to the root canal and periodontal support tissue, but also enhance the adaptability between post and root canal wall into a closed solid complex, and then effectively transfer the load to the surrounding of the tooth. In this experiment, CAD/CAM integrated glass fiber post-and-core showed high adaptation to the inner walls of canal. The luting cement thickness was even and thin, which could form
a chemical bond between the cement and the post-and-core resin composite. The bond strength got higher, which further improved the resistance strength of the whole restoration. In the CAD/CAM integrated post-and-core group, there were two specimens with fractures in dentin shoulder collar and six cases in coronal 1/3 part of the root. Because the strength of the root can increase after the post-and-core was bonded, the tooth neck becomes a relatively weak position after the restoration, and then the fracture mostly occurs in the tooth neck when the stress gets greater, whereas those fractures mainly broken in root areas in the prefabricated fiber post group and cast alloy post-and-core group are considered to be irreparable. The RelyX™ Unicem 2 cement is allowed for the permanent cementation of fiber posts with high adhesive bond strength. In this study, the same Unicem 2 cement was selected for post bonding in each group in order to eliminate the effects of different bonding materials on the experimental results. But this contributed to thick resin cement layers surrounding the prefabricated glass fiber posts in Group B. The difference of the elastic modulus between resin cement and composite resin for core might have caused uneven stress distributions, probably leading to lower mean fracture strength and larger number of the mode “d” fractures.

Moreover, the dentin shoulder collar was important for fracture resistance and restoration failure. Ferrule specimens showed greater resistance than non-ferruled ones, regardless of the cement used. There was no statistical difference between the group of specimens cemented with resin cement and without ferrule and the ferruled groups. A 2.00-mm cervical ferrule is important for fracture resistance of restored teeth, and resin cement has a better performance. In this study, the dentin shoulder collar of the flared root canal was defined as 1 mm high, 0.5 mm thick, and 0.5 mm wide in order to simulate flared root canal morphology. The results of fracture resistance and fracture modes indicated that anterior teeth with flared root canals resorted using CAD/CAM integrated fiber post-and-core could help to the protection of residual tooth tissue, and reduce the occurrence of irreparable root fractures.

Static loading test and fatigue test are the common methods for evaluating the fracture resistance of post-and-core restorations. In view of failures of clinical restorations were mostly caused by long-term use resulting in fatigue, the methods of static loading before fatigue cycles were adopted, it is in accordance with the methods of Ambica et al. The maxillary central incisor was used in this study. The cyclic loading was 100 N and the loading number was 300,000 cycles to simulate mastication of one year. When the post was implanted into the tooth, it became the main body of the conductive load of the restorations and weakened the influence of the crown material on the stress distribution. The different type of full-coverage crowns was not a significant factor affecting fracture resistance after restoration of endodontically treated teeth, whereas the presence of a post was. The posts could contribute to the reinforcement and strengthening of pulpless teeth. Placement of fiber posts improved the fracture from nonrestorable to restorable patterns and it is necessary to improve fracture resistance even under full-coverage crowns. Therefore, the uniform 3D printing metal crown was used in this experiment, which could simplify the influence of irrelevant factors on the experimental results.

CONCLUSIONS

Albeit its limitations, this current in vitro study has led to the following two conclusions. First, the fracture part of post-and-core with low elastic modulus is closer to the root neck which is favorable for re-restoration, while the post-and-core with high elastic modulus can transfer the occlusion stress directly and the broken parts mostly occur in the middle and the tip of the roots. Second, compared with conventional methods, CAD/CAM integrated glass fiber post-and-core restoration for flared root canals can increase the overall fracture resistance of the root and reduce the occurrence of irreparable root fractures.

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REFERENCES


