Stress behavior of cemented fiber-reinforced composite and titanium posts in the upper central incisor according to the post length: Two-dimensional finite element analysis

Ji-Hyun Jang a, Su-Jung Park b, Kyung-San Min b, Bin-Na Lee c, Hoon-Sang Chang c, Won-Mann Oh c, Hyunpil Lim d, Young-Tae Cho e, Jeong-Tae Koh f,h, Ho-Hyun Son g, Yun-Chan Hwang c,h*, In-Nam Hwang c*

a Department of Conservative Dentistry, College of Dentistry, Yonsei University, Seoul, Korea
b Department of Conservative Dentistry, School of Dentistry, Wonkwang University, Iksan, Korea
c Department of Conservative Dentistry, School of Dentistry, Dental Science Research Institute, Chonnam National University, Gwangju, Korea
d Department of Prosthodontics, School of Dentistry, Dental Science Research Institute, Chonnam National University, Gwangju, Korea
e Department of Manufacturing and Design Engineering, Jeonju University, Jeonju, Korea
f Department of Pharmacology and Dental Therapeutics, Gwangju, Korea
g Department of Conservative Dentistry, School of Dentistry, Dental Research Institute, Seoul National University, Seoul, Korea
h Research Center for Biomineralization Disorders, Gwangju, Korea

Final revision received 29 November 2011; accepted 27 April 2012
Available online 21 November 2012

KEYWORDS
fiber-reinforced composite post; finite element analysis; stress distribution; titanium post

Abstract  Background/purpose: This study examined the stress distribution in endodontically treated maxillary central incisors restored with various lengths of either titanium or fiber-reinforced composite (FRC) post-and-core systems, using two-dimensional finite element analysis models.

Materials and methods: Eight models of the maxillary central incisor were formed, surrounded by cortical bone, cancellous bone, and the periodontal ligament. Two different post-and-core systems, titanium and FRC posts (D.T Light Post), were modeled. In each restorative system, four models were designed by changing the post lengths cemented to the root at 10 mm,
Introduction

A tooth can lose a large amount of structure due to a variety of causes, including trauma and dental caries, and requires restoration and fabrication of an artificial crown after endodontic treatment. However, in most cases, retention is commonly enhanced when using a core with a post inside the root canal, because pertinent retention and resistance cannot be maintained only with the residual tooth structure. A post is a device placed into the space formed in the root canal to maintain the core. Clinicians once believed that restoration of a lost tooth structure by a post reinforced a tooth that had undergone endodontic treatment. However, that view has been refuted.1–3 In contrast to Davy et al,4 who reported that the stress in dentin decreases when restored by a post, Travert et al5 and Kantor and Pines6 reported a higher incidence of fracture when a post was applied to a tooth that had undergone endodontic treatment. Sorensen et al7 suggested that the ideal post should have a modulus of elasticity very similar to that of dentin, and proposed the fiber-reinforced composite (FRC) post as one that would meet this requirement.

Enhancing retention is an important factor because the purpose of a post is to retain the tooth crown by connecting the remaining core to the root structure.8–11 A conventional post, the elements of contour, surface quality, thickness, and length are important factors affecting retention.12–17 The length of the post is one of the most important concerns for core retention. The more apically the post is placed in the root canal, the more retentive it becomes, unless the apical seal of the obturated root is damaged.11,13,14,18 The stress concentration in the layer between the post and dentin is affected by the type of material, rather than any other factor; thus the material has become recognized as being advantageous for stress dispersion with a decreasing increase in the modulus of elasticity with dentin.7,19

This study examined the stress distribution in endodontically treated maxillary central incisors restored with various lengths of either titanium or FRC post-and-core systems, using two-dimensional finite element analysis (2D FEA) models. The overall aim of the study was to determine if the length of commonly used titanium posts, which have a large difference in the modulus of elasticity from that of dentin, is also applicable to FRC posts, which have a similar modulus of elasticity to that of dentin.

Materials and methods

Eight 2D FEA models of maxillary central incisors were created surrounded by cortical bone, cancellous bone, and the periodontal ligament, based on actual measurements of the extracted maxillary central incisor. Two different post-and-core systems, titanium and FRC posts (D.T Light Post; Bisco, Schaumburg, IL, USA) and IPS-Empress-2 (Ivoclar Vivadent, Schaan, Liechtenstein) all-ceramic crowns were used. The overall length of the tooth was 23 mm, and the diameter and overall length of the post were set to 1.4 mm and 13 mm, respectively. The length of the post exposed in the upper part of the root was set to 3 mm. Four models of each post group were then designed by increasing the gutta-percha length to 4 mm, 5 mm, 6 mm, and 7 mm after changing the post lengths that had been cemented into the root to 10 mm, 9 mm, 8 mm, and 7 mm, respectively. The average thickness of the IPS-Empress-2 internal core and external layering porcelain were set to 0.8 mm and 1.2 mm, respectively (Fig. 1).

FEA software, ABAQUS Solver (Simulia Inc., Providence, RI, USA) a commercial FEA tool was used to generate the model, create the mesh of the individual elements, and perform the analysis of the resulting models. The model of the incisor in cross-section was constructed using measurements and geometries similar to other studies20–22 with isotropic material properties. All materials and interior structures, such as post/core, alveolar bone, and the periodontal ligament used in this study were taken from previous reports20–22 and were assumed to be homogeneous, linearly elastic, and isotropic (Table 1). Fig. 2 shows the mesh generation, boundary conditions, and loading direction in the design model for the 2D FEA in this study.

A 100-N load was applied to the center of the lingual plane of the crown at a 45° angle to the long axis of the tooth. The analysis was performed assuming that the post and core, and the post and dentin were in perfect adhesion. The stress distribution levels were calculated according to Von Mises criteria.20

Results

Compressive stress distributions are shown in Fig. 3. The maximum compressive stress in the post under a load was higher in the titanium post at all cemented lengths than in the FRC post; whereas in dentin, a higher stress was
observed with the FRC post. The maximum compressive stress with the FRC post decreased with a decreasing length, but there was no significant change in the titanium post.

With all lengths of titanium posts, a higher compressive stress was distributed in the post compared to that in the surrounding dentin. In contrast, with FRC posts, a higher compressive stress was distributed on the facial side of the root, where a compressive force was applied, compared to the titanium post. In addition, with the titanium post, a high compressive stress was observed in the area where the protrusion of the root adhered to the core (Fig. 3A).

Regarding the stress distribution in the crown of the titanium post when loaded, a higher compressive stress was concentrated in the area from where the load was applied to the post than in the surrounding area, and a stress concentration toward the lower part of the core was also observed. In contrast, the FRC post showed similar stress distributions to that in the surrounding area (Fig. 3B).

Discussion

FEA is a research method widely used in basic dentistry studies. During analysis of load distributions, FEAs examine stresses and deflections. FE modeling has several advantages over direct research methods performed in the lab. It can modify the diversity of each object and can substitute physical properties of tissues, when biological tissue is

| Table 1 Mechanical properties of the dental structure and restorative materials. |
|-----------------------------------------------|-----------------|-----------------|---------------|
| Material                                      | Young’s modulus (E; MPa) | Poisson’s ratio (ν) | Reference  |
| Crown                                         |                 |                 |               |
| IPS-Empress-2 layering ingot                  | 100,000         | 0.25            | 15            |
| IPS-Empress-2 layering ceramic                | 65,000          | 0.19            | 15            |
| Core Composite                                | 12,000          | 0.30            | 18            |
| Dentin                                        | 18,600          | 0.31            | 18            |
| Post                                          |                 |                 |               |
| Titanium                                      | 112,000         | 0.33            | 18            |
| FRC (D.T Lght Post, Bisco)                    | 15,000          | 0.29            | Manufacturer’s information |
| Periodontal ligament                          | 68.9            | 0.45            | 20            |
| Cortical bone                                 | 13,700          | 0.30            | 20            |
| Gutta percha                                  | 0.69            | 0.45            | 20            |
| Cancellous bone                               | 1370            | 0.30            | 20            |
required. Maximum standardization is also available. FEA is performed with 2D and 3D models; a 2D FEA was chosen in this study because it can obtain mathematical results more easily than the 3D method; 2D FEA modeling easily represents stress differences without using unnecessarily complex geometries. This study assumed isotropic properties for materials and dentinal structures. Furthermore, with the maxillary central incisor used in this study, the 2D FEA analysis represented similar locations of peak dentinal stresses with the 3D FEA, despite simplification of the 2D model. Nonetheless, 2D models limit the analysis, as the stress distribution along the Z direction cannot be evaluated. The isotonic loading method, which may differ in vivo, is one of the limitations of the present study. A 3D model may demonstrate varying amounts of stress in all planes in clinical situations.

In the current study, a 100-N load was applied to the center of the lingual plane of the crown at a 45° angle to the long axis of the tooth. This experimental 100-N load was suggested to represent a normal chewing force as a third of

Figure 3  Distribution of compressive stresses when loaded (MPa). (A) Distribution in the root dentin and post according to the post length. (B) Distribution in the crown portion.
the maximum biting force.\(^{20}\) The oblique force to the long axis of the tooth simulated the protractive force that is the most frequently applied force to the maxillary incisor.\(^{20,21}\)

To simulate a clinical situation, IPS-Empress-2 and composite resin cores were used. The preparations were designed to produce a ferrule effect for reducing direct forces to the post-and-core system\(^{21}\) and the all-ceramic crown was supported by the ferrule.

Currently, clinically available posts are fabricated from a range of materials, such as gold alloy, titanium, Co-Cr, ceramics, and FRC. In this study, titanium and FRC with different elastic moduli of restorative materials were chosen to compare the stress distributions of various post lengths. Under loading, the ferrule specimen with the titanium post showed a higher stress concentration in the post than did teeth restored with the FRC post, which is consistent with results from previous studies.\(^{20,21}\) The results demonstrated that the FRC post resisted oblique occlusal stresses better than the titanium post, due to a better modulus of elasticity. In the complete bonding model used in the present study, stress to the FRC posts was distributed more evenly in the dentin, rather than in the core area and near the root. In contrast, with the titanium post, the stress was concentrated at the post and was not dispersed to the dentin. This behavior seems to be related to the better fracture resistance of teeth restored with FRC posts which had a similar rigidity to dentin compared to metal posts.

The present results suggest that the FRC post can resist stress concentration, even when placed only at half the depth of the root, leading to a decrease in the risk of fracture of the tooth. If the depth of placement was shortened, both the FRC and titanium posts showed stress concentration at the posts. In contrast, the maximum stress generated in the FRC post placed 7 mm deep, which corresponded to half the length of the root, was less than that of the stress generated in the titanium post placed 10 mm deep. Other studies suggested that excessive preparation to obtain a longer post length of the root, was less than that of the stress generated in the FRC post placed 7 mm deep, which corresponded to half the length of the root.\(^{32}\) Adhesive fixation of FRC posts and ferrule incorporation might decrease the effect of post length on the fracture resistance of dowel-restored teeth. Clinically, placement of an FRC post at half the depth of a root is contentious. Nevertheless, new guidelines for FRC posts, which differ from those for metal posts, can be established if correlations between the length of the FRC post and retention, fracture resistance, and fracture characteristics can be evaluated.

In conclusion, the possibility of fracture of FRC posts is relatively low compared to titanium posts, even for short posts. Adhesive cement, FRC posts, and a full coronal restoration with a ferrule may reduce the effect of post length on tooth fracture resistance.

**Acknowledgments**

This study was supported by the National Research Foundation of Korea (NRF) grant (no. 2011-0030759) funded by the Korean government (MEST).

**References**


