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Effects of the geometric shape and placing length of a fiber post on the stress distribution in a mandibular premolar tooth: A finite element analysis study

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Abstract

Aim: The aim of this study was to evaluate the effects of two geometrically different fiber post systems and two different placing lengths on the stress distribution of endodontically treated teeth.
Methodology: Four different mandibular premolar tooth models were created. These models were restored using oval or circular fiber posts with two different placing lengths. An oblique force of 300 N was applied to the top of the tooth, and von Mises stress evaluations were carried out on the dentin tissue, luting cement, and fiber posts.
Results: The maximum von Mises stresses were observed in the 10-mm long circular fiber post model, while the minimum stresses were seen in the 5-mm long oval fiber post model. In general, the oval fiber post models presented more homogeneous stresses than the circular fiber post models. Moreover, the 10-mm long fiber post models generated greater von Mises stresses than the 5-mm long fiber post models in the dentin tissue and luting cement.
Conclusions: According to the study findings, the use of oval fiber posts at both placing lengths is suggested for oval shaped root canals due to the lower stress concentrations.

Keywords: Circular fiber post, finite element analysis, oval fiber post, placing length, von Mises stress

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Introduction

Generally, additional restoration is required to compensate for the lack of coronal tissues in a tooth, and this is accomplished by using a post and core in the root canal of that tooth. Fiber posts are preferred because of their elastic modulus, which is compatible with that of dentin, and they provide good resin adhesion (1). As a result, a uniform stress distribution along the root structure can be obtained (1, 2). When considering that the percentage of oval-shaped canals in the dentition is high, especially in the apical region (3), in order to abstain from using circular fiber posts in oval canals, oval fiber posts have been introduced to provide better adaptation to the dentin walls (4). Thus, improved post adhesion and retention strength are achieved with the use of oval fiber posts in oval root canals (5, 6).

Some previous studies have revealed that an increased fiber post length can contribute to distributing the stress and preventing root fractures with more bonded areas (7, 8). However, some studies have shown that endodontically treated teeth are not strengthened by increasing the post length (9). Therefore, additional evidence is needed to determine the proper fiber post length.

A finite element analysis (FEA) involves a series of computational procedures to predict specific outcomes, including mechanical behavior, for a complex and specific geometric assembly. This is achieved by integrating the results obtained from smaller elements defined by a specific mesh. This analysis is extremely useful for indicating the mechanical aspects of biomaterials and human tissue that can be difficult to measure in vivo (10).

Because post designs (11) and post lengths (7) play important roles in stress distribution in the dentin and surrounding structures, this study aimed to compare the effects of 2 geometrically different fiber post systems and 2 different placing lengths on the stress distribution of endodontically treated teeth by means of an FEA.

Materials and Methods

A 3D-model of a mandibular lower premolar with an oval root canal was created in this study. The crown-restored tooth and surrounding tissues were modelled using the ANSYS software program (ver. 15; ANSYS Inc., Canonsburg, PA, USA). The average anatomical dimensions of the surrounding tissues and the geometry used for the tooth models were created for this study in accordance with the literature (12, 13). Four different restored teeth were modelled to represent two different geometrically shaped fiber posts with two different placing lengths into the root canals. The tooth models were created as follows:

Model 1 (M1): Circular fiber post placed 10 mm in the canal.

Model 2 (M2): Circular fiber post placed 5 mm in the canal.

Model 3 (M3): Oval fiber post placed 10 mm in the canal.

Model 4 (M4): Oval fiber post placed 5 mm in the canal.

The four models of the crown-restored teeth (including a 1 mm ferrule) were composed of a porcelain crown, dentin, composite core, crown-core adhesive layer, dentin-post adhesive layer, cortical bone, spongy bone, periodontal ligament (PDL), root canal gutta-percha filling, and oval or circular fiber posts. The properties of these materials are listed in Table 1 (1, 7). All of the materials were considered to be homogeneous, isotropic, and linearly elastic.

Table 1. Material properties used in the finite element models.

Material	Young's modulus (GPa)	Poisson's ratio
Dentin[a]	18.6	0.31
Resin core[a]	15.5	0.30
Gutta-percha[a]	0.00069	0.45
Porcelain[a]	69	0.28
Oval fibre post[a]	26	0.23
Circular fibre post[a]	26	0.23
Cortical bone[a]	13.7	0.30
Sponge bone[a]	1.37	0.30
Periodontal ligament[b]	0.0689	0.45

[a]From Er et al.
[b]From Asmussen et al.

The 3D meshes were created through 10-node tetrahedral elements with quadratic displacement shape functions and three degrees of freedom per node, with a mesh size mean value of about 0.5 mm, resulting from an optimization process based on the convergence analyses. The models were created using approximately 416,996 nodes and 271,984 tetrahedral solid elements (Fig. 1). The continuity of the displacement fields through the material interfaces was imposed.

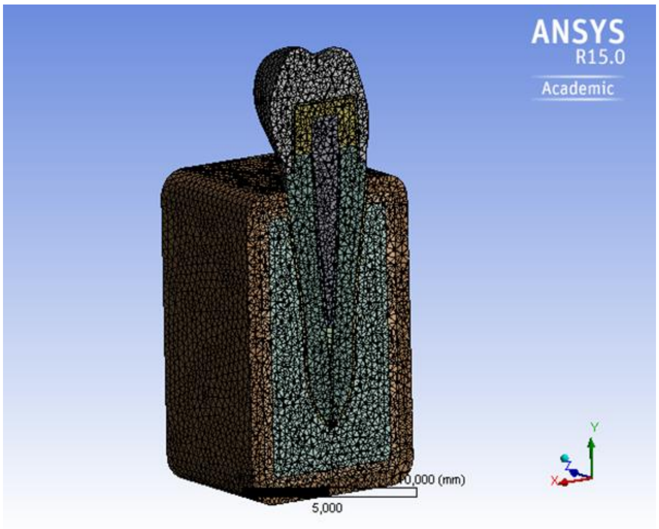

Figure 1. Meshed model containing elements and nodes.

This FEA study tested D.T. Light circular fiber posts (Bisco Inc., Schaumberg, IL, USA) with apical diameters of 1.1 mm and Ellipson oval fiber posts (RTD/Satelec, Merignac, France) with apical diameters of 1.1 mm. The thicknesses of the luting material between the post and root dentin and between the core and porcelain crown were equal to approximately 200–250 μm. An oblique force of 300 N was applied to the top of the tooth, angled at 45° with respect to the occlusal plane, and oriented toward the buccal side. The linear analyses were performed under defined loading conditions. The von Mises stress (equivalent stress) evaluations were carried out on the fiber posts, luting cement, and root dentin. In order to visualize the stress distributions in the FEA models more easily, the calculated numeric data were converted into color graphics.

Results

Stresses generated in the root dentin tissue

The stresses were concentrated in both the oval and circular fiber post models at nearly the middle third of the root dentin. The von Mises stresses in the root dentin increased with an increasing fiber post placing length in both the circular post and oval post models. M1 showed greater stress values than M3, and M2 showed greater stress values than M4. The maximum stresses were observed in M1, and the minimum were in M4. The circular fiber post models generated greater von Mises stresses than the oval fiber post models in the dentin tissue at the different placing lengths of posts (Fig. 2). The maximum von Mises stress values recorded within the dentin are summarized in Table 2.

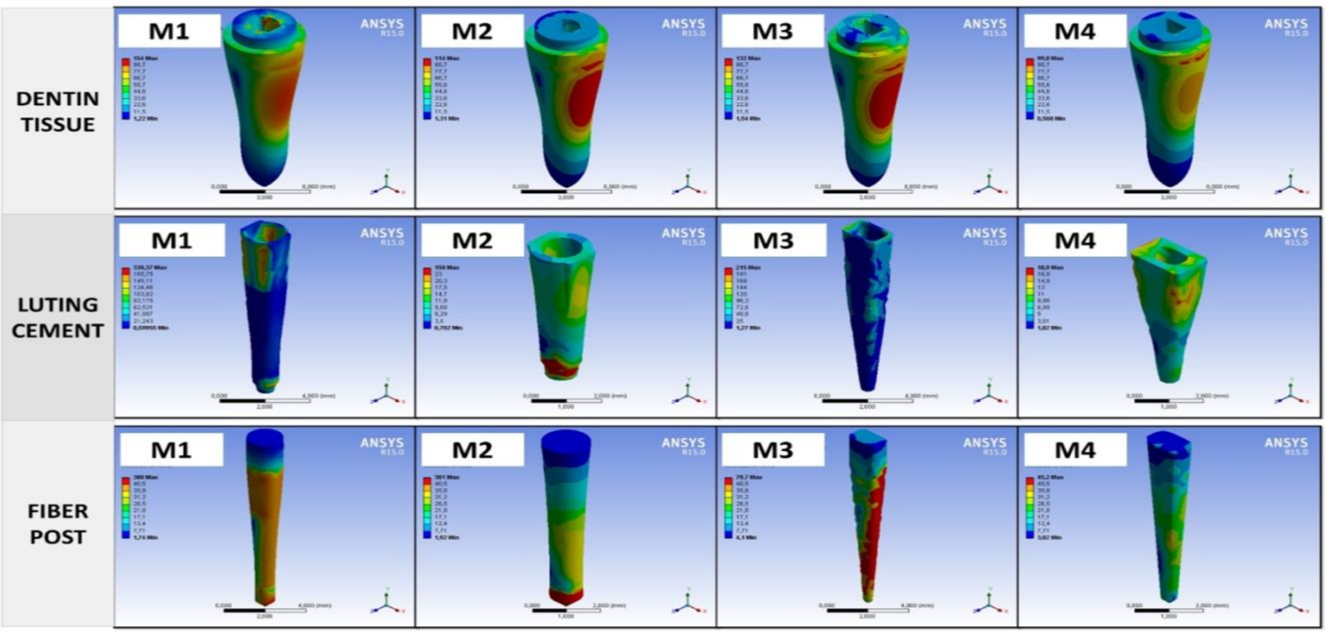

Figure 2. Stress distributions in the dentin tissue, luting cement, and fiber posts. The red color shows the maximum stress, while the blue color shows the minimum stress. Each model should be evaluated based on its own color scale.

Stresses generated in the luting cement

In both the circular and oval fiber post models, greater stresses were generated in the luting cement when the placing length was increased. M1 showed greater stress values than M3, and M2 showed greater stress values than M4. The maximum von Mises stresses were observed in M1, and the minimum were in M4. The stresses were especially concentrated in the apical region of the luting cement in the circular fiber post models; however, in the oval fiber post models, the stresses were more homogeneous along the luting cement (Fig. 2). The maximum von Mises stress values recorded within the dentin are summarized in Table 2.

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Table 2. Maximum von Mises stress values of the finite element analysis models (MPa).

	Maximum Stress Values (MPa)		
	Dentin Tissue	Luting Cement	Fiber Post
M1 (10-mm Circular Fiber Post)	154	339.37	388
M2 (5-mm Circular Fiber Post)	114	150	381
M3 (10-mm Oval Fiber Post)	132	215	79.7
M4 (5-mm Oval Fiber Post)	99.8	18.9	45.2

Discussion

Oval fiber posts were produced to better match the canal's cross sectional shape while avoiding excessive dentin removal during a circular post space preparation (14). The manufacturer has reported that this system leads to less fractures (15). In contrast, a novel study reported less fracture resistance in oval fiber post groups than in circular fiber post groups (16). Krastl et al. evaluated the fracture resistance of oval and circular post-restored teeth with composite crowns, and did not find a significant difference (14). In a previous FEA study, oval and circular post restorations were compared by Er et al. who found that the circular fiber posts generated more stress on the residual root dentin than the oval fiber posts (1). Pest et al. showed in a finite modeling study of lower premolar teeth that the highest von Misses stresses were concentrated in the coronal part of the root (8). In addition, some studies have revealed that longer fiber posts distribute the stress and prevent root fractures with more bonded areas (7, 8, 17). Conversely, some studies have shown that endodontically treated teeth are not strengthened by increasing the post length (9, 18). It can be seen that there is contradictory data about the effects of the placing lengths and geometric shapes of fiber posts in the literature. Therefore, this study was designed to investigate the effects of different post shapes and placing lengths on the stress distribution of crown-restored premolars with oval canals.

The stresses in the root dentin tissue were found to be greater in the 10-mm fiber post models than in the 5-mm fiber post models. Moreover, the use of a circular fiber post in the mandibular premolar tooth that was modelled with an oval canal caused more stress than the use of an oval fiber post at the different placing lengths. Oval fiber post systems and short fiber posts do not require much preparation due to the natural shape of the canal. Thus, more protected dentin tissue might occur with the lower stress concentrations. In all of the FEA models in this study, the stresses generated on the buccal sides of the roots were greater than those on the lingual sides. This could be related to the oblique force that was applied to the occlusal plane and oriented toward the buccal side. In one FEA study, Hsu et al. applied a 300-N force at an angle of 45 degrees to the palatal surfaces of the upper central teeth that were restored with fiber posts, and stated that the maximum stresses were concentrated between the root dentin and adjacent cortical bone (19). In the 5-mm fiber post models in this study, the maximum stresses were concentrated more cervically than in the 10-mm fiber post models. This could be related to the moment effect of the short fiber posts (5-mm length).

Adhesive failures associated with fiber posts are common and usually occur along the luting resin cement that fills the post-dentin interface (20). Previous stress evaluations of luting cement have indicated that 10-mm long fiber post models generate greater von Mises stresses than 5-mm fiber post models in different geometrically shaped posts. This could be related to the increased thicknesses of the luting cement in the short fiber post models. The greater stress concentrations in the long fiber post models (10-mm length) could be generated from the thinner structure of the luting cement. In the 5-mm fiber post models, the fiber post diameters were incompatible with the root canal diameters, especially in the coronal third. Thus, the luting resin cement thickness was greater than that in the 10-mm fiber post models. In the literature, some authors reported that a thinner luting cement thickness caused greater bond strength values (21, 22), while other authors did not observe these findings (23, 24). In contrast, some authors advocated that a thicker luting cement was better for the retention of fiber posts (20, 25). Overall, the studies on this issue are controversial; however, if these results are taken into account in terms of the FEA, a thinner material structure could generate more concentrated stresses within the material. In the present study, the stresses were especially concentrated in the apical part of the luting resin in the circular fiber post models, but more homogeneous in the oval fiber post models. This may be due to the better fit of the oval post in the post space (5, 6) and the more stable stress distribution. In circular fiber post models, the sharp end of the fiber post might cause stress accumulation in the apical part of the luting cement.

Quartz oval fiber posts and circular fiber posts with the same Poisson's ratio and Young's modulus were used in the tooth model (1). Thus, the effects of the post design and placing length on the von Mises stresses could be seen clearly. The von Mises stresses that were generated in the circular fiber posts were greater than those in the oval fiber post models at the different post placing lengths. The stresses in the circular fiber posts were generally concentrated at the tip of the post, and they were quite high. This might have been due to the tip design of the circular fiber post, which has a sharp point. In general, there were homogeneous stress distributions in the oval fiber posts, which could be the result of the anatomical compatibility with the oval root canal morphology.

In general, the short fiber posts seemed to be safer than the long fiber posts. However, FEA models can produce limited information about the systems that were evaluated in this study. In clinical conditions, the success of a fiber post depends on several factors. One of the main restrictive factors is the shrinkage stress induced by the polymerization of the luting cement, known as the C-factor, which has to be ignored in FEA studies. The C-factor can cause failure as a result of debonding, gaps, and voids (26-28). Thus, no direct suggestion can be made based on the results of this study. The data obtained in this study was only informative, and it might be in conflict with natural conditions.

Maceri et al. stated that oblique loads are more hazardous than vertical loads for endodontically treated teeth (29). Therefore, an oblique load was used in this study to mimic the parafunctional load related to bruxism, and to limit the chewing conditions in the case of very tough foods. In addition, all of the materials were considered to be linear, isotropic, and homogeneous, even though most dental materials and tooth tissues are anisotropic and nonhomogeneous. Moreover, the loading scenarios investigated lacked the complexity that occurs during functional loading in a patient. This resulted in the nonlinearity of the load application and its effects (30), and therefore, constitutes one limitation of this study.

Conclusions

Within the limitations of this study;

1. It could be concluded that the placing length and geometric shape affected the stresses that formed in the circular and oval fiber post models.
2. The use of oval fiber posts may be safer than circular fiber posts, and 5-mm placed fiber posts may be safer than 10-mm fiber posts.

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