

Stress distribution of endodontically treated teeth with titanium alloy post and carbon fiber post with different alveolar bone height: A three-dimensional finite element analysis

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ABSTRACT

Objective: A three-dimensional (3D) finite element analysis (FEA) on the stress distribution of endodontically treated teeth with titanium alloy post and carbon fiber post with different alveolar bone height. **Materials and Methods:** The 3D model was fabricated using software to represent an endodontically treated mandibular second premolar with post and restored with a full ceramic crown restoration, which was then analyzed using FEA using FEA ANSYS Workbench V13.0 (ANSYS Inc., Canonsburg, Pennsylvania, U.S.A) software. **Results:** The FEA showed the maximum stresses of 137.43 Mpa in dentin with alveolar bone height of 4 mm when the titanium post was used, 138.48 Mpa when carbon fiber post was used as compared to 105.91 Mpa in the model with alveolar bone height of 2 mm from the cement enamel junction (CEJ) when the titanium post was used and 107.37 Mpa when the carbon fiber post was used. **Conclusions:** Stress was observed more in alveolar bone height level of 4 mm from CEJ than 2 mm from CEJ. Stresses in the dentin were almost similar when the carbon fiber post was compared to titanium post. However, stresses in the post and the cement were much higher when titanium post was used as compared to carbon fiber post.

Key words: Bone height, carbon fiber post, finite element analysis, titanium alloy post

INTRODUCTION

One of the most common challenges faced by the dentist is the restoration of endodontically treated teeth, more so because of its brittleness as compared to vital teeth.^[1-3] The success of endodontically treated teeth is related to the position of the tooth in the dental arch,^[4,5] occlusal contact,^[6,7] proximal contact,^[8] structural loss of tooth,^[9-13] and periodontal condition of endodontically treated teeth.^[14] The changes that accompany the root canal therapy and the thickness of the residual walls and cusps will determine the selection of the restorative materials and the procedures for endodontically treated teeth.^[15] The important factor of

treatment plan to be considered for a severely damaged tooth^[16] is evaluation of tooth for occlusion, esthetics,

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to access the remaining tooth structure after removal of all caries and old restorations, canal configuration, control of plaque, and eliminate periodontal infection. Loosening of teeth and fracture of teeth is one of the most common failures for post and core.^[17,18] The incidence of vertical root fracture in endodontically treated teeth with post and core was observed more in older patients,^[17] who usually have reduced alveolar bone height.^[19] This results because of improper stress distribution along the roots. Metal posts were commonly used for the past many years, however with increased demands of esthetics, the use of tooth color post and core was introduced in the market and are becoming popular.^[20,21] The purpose of the present *in vitro* study using finite element analysis (FEA) was to evaluate the stress distribution caused by the different alveolar bone height and the type of post used. FEA is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. It works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes and uses a complex system of points called nodes, which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. The mesh acts like a spider web and from each node there extends a mesh element to each of the adjacent nodes. Once the geometry, materials, and boundary conditions are set, the next step is to run the FEA software to obtain a physical displacement at each node. The strain data that is observed is then used to compute the stress data at each node. A graphical postprocessor is then used to process all of this data and display it superimposed over the geometry model of the part with color coded stress.

The finite element method is a highly approved method to simulate biophysical phenomena in computerized models of teeth and their periodontium. The finite element method is considered to be an extremely useful tool to simulate the mechanical effects of chewing forces acting on the periodontal ligament (PDL) and on the dental hard tissues.^[22] The null hypothesis is that bone height and the type of postmaterial show no difference in the stress distribution of endodontically treated teeth.

MATERIALS AND METHODS

The study was conducted using a three-dimensional (3D) finite element model and were analyzed using FEA. The 3D model was fabricated using commercially

available software ANSYS Workbench V13.0 (ANSYS Inc., Canonsburg, Pennsylvania, U.S.A) to represent an endodontically treated mandibular second premolar restored with a full ceramic crown restoration. ANSYS is a dedicated computer-aided finite element modeling and FEA tool. ANSYS is known as the standard in the field of computer-aided engineering. The graphical user interface of ANSYS enables the user to work with 3D models and also generate results from them. The model was made with a simulated PDL with the alveolar bone. Although PDL thickness differs according to age, position, and individual variations, the thickness of the PDL was modeled as a 0.25 mm thin layer around the root. The measurements used in the tooth model were taken as described by Wheeler's^[3] and model was simulated with the help of an Intel core i7 processor, with 8GB RAM, 64 bit operating system. All the materials used in this study were assumed to be homogenous and isotropic. The modulus of elasticity and Poisson's ratio for the elements involved in the study are shown in Table 1. The models included a porcelain crown, dentin, composite core, alveolar bone, gutta percha filling, and posts (carbon fiber post and titanium alloy post). The geometry of the model was made as shown in Table 2. Discretization was done by generating mesh containing 9,82,759 nodes

Table 1: Material properties

Material	Modulus of elasticity	Poisson's ratio
Enamel ^[3]	84.1	0.33
Dentin ^[3]	18.6	0.31
Pulp ^[3]	0.00207	0.45
PDL ^[3]	0.0689	0.45
Cancelous ^[3]	1.37	0.3
Gutta percha ^[3]	0.292	0.45
Porcelain ^[3]	86.2	0.19
Carbon fiber ^[12]	21	0.33
Titanium alloy ^[3]	120	0.3
Panavia ^[3]	18.3	0.3

Table 2: Material geometry

	Dimension
Porcelain crown	2 mm
Alveolar bone height	2 mm from the CEJ and 4 mm from the CEJ
Gutta-percha filling	5 mm
Cement thickness	At coronal: 0.75 mm At middle: 0.4 mm At 5 mm from the apex: 0.1 mm
Postdiameter	At coronal: 1.3 mm At middle: 1.15 mm At 5 mm from the apex 1 mm
Ferrule height	2 mm
Periodontal ligament	0.25 mm
CEJ: Cement enamel junction	

and 6,56,093 elements for the model of 2 mm alveolar bone height from cement enamel junction (CEJ) and 9,48,119 nodes and 6,35,849 elements for the model of 4 mm alveolar bone height from CEJ. The base of the alveolar bone was kept static, and a load of 300 N at an angle of 60° to the vertical was applied to the triangular ridge of the buccal cusp in a buccolingual plane. The relationship of alveolar bone height at 2 mm, 4 mm, and the type of the post used was calculated using von Mises stresses.

RESULTS

The FEA showed the stress distribution in all the structures as shown in Figures 1 and 2. As shown in Table 3, the maximum stresses in dentin were observed in the carbon fiber post in alveolar bone height of 4 mm from the CEJ, and the minimum stresses in dentin were observed with a titanium alloy post with alveolar bone height of 2 mm from the CEJ.

DISCUSSION

The FEA has been used for stress analysis by various investigators.^[23,24] Previously, other methods have been used to analyze stress concentration in the tooth structures like the photoelastic studies.^[25] The advantage of FEA is that the experimental condition can be kept identical in all the models, which is not possible in the experimental human study. In the present study, the FEA showed changes in the stress distribution between the two models at 2 mm and 4 mm alveolar bone height from CEJ. In this study, a load of 300 N was applied although a higher load may be observed in the clinical conditions. The maximum load in the present study was observed in the dentine, and the minimum load was seen in the cement.

The major finding, in this study, is that the bone height was a significant factor in the stress distribution. The stress in the dentin, post, and the cement was

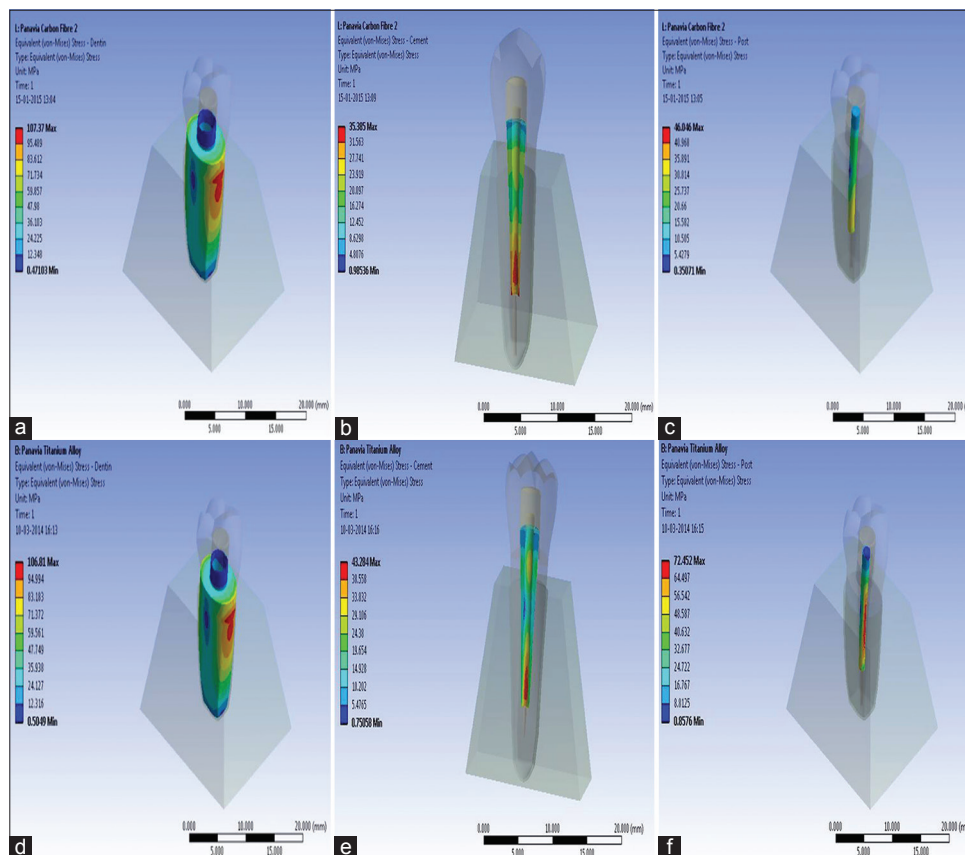


Figure 1: (a) Stress distribution in dentin with carbon fiber post and alveolar bone height of 2 mm from cement enamel junction. (b) Stress distribution in cement with carbon fiber post and alveolar bone height of 2 mm from cement enamel junction. (c) Stress distribution in post with carbon fiber post and alveolar bone height of 2 mm from cement enamel junction. (d) Stress distribution in dentin with titanium post and alveolar bone height of 2 mm from cement enamel junction. (e) Stress distribution in cement with titanium post and alveolar bone height of 2 mm from cement enamel junction. (f) Stress distribution in post with titanium post and alveolar bone height of 4 mm from cement enamel junction

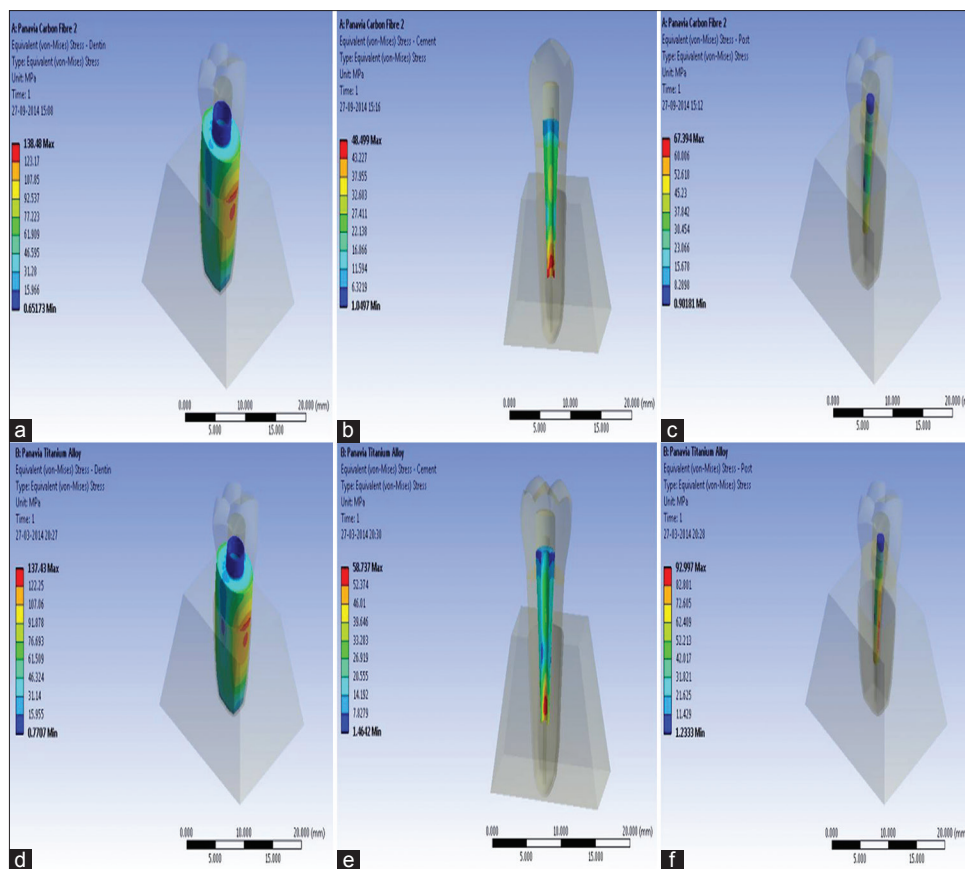


Figure 2: (a) Stress distribution in dentin with carbon fiber post and alveolar bone height of 4 mm from cement enamel junction. (b) Stress distribution in cement with carbon fiber post and alveolar bone height of 4 mm from cement enamel junction. (c) Stress distribution in post with carbon fiber post and alveolar bone height of 4 mm from cement enamel junction. (d) Stress distribution in dentin with titanium post and alveolar bone height of 4 mm from cement enamel junction. (e) Stress distribution in cement with titanium post and alveolar bone height of 4 mm from cement enamel junction. (f) Stress distribution in post with titanium post and alveolar bone height of 4 mm from cement enamel junction

Table 3: Stresses in Mpa				
Bone height	Type of post	Stresses (in Mpa)		
		Dentin	Post	Cement
2 mm	Titanium post	105.91	146.21	49.97
	Carbon fiber post	107.37	46.046	35.385
4 mm	Titanium post	137.43	185.71	67.29
	Carbon fiber post	138.48	67.394	48.499

much higher in the model with the alveolar bone height of 4 mm from CEJ compared to model of better bone support of 2 mm alveolar bone height from the CEJ. This shows that the height of the bone plays an important factor in tooth stability. Moreover, it was observed that higher alveolar bone height supports stronger forces until root fracture.^[26] In the present study carbon, fiber postmodel showed higher stress value in dentin at both levels of bone height as compared to titanium post. A material with a higher modulus of elasticity altered the natural biomechanical behavior of the tooth.^[27] Moreover, studies by Chuang *et al.*^[28] and Strub^[29] *et al.* have also shown that post with Young’s modulus similar

to the dentin is an effective method of reducing the root fracture risk.

The internal canal architecture of the tooth may be modified because of severe carious involvement and during root canal instrumentation resulting in greater canal diameter. Therefore, it is important that the selection of the cementing medium for the post be carefully evaluated. It has been observed that the modulus of elasticity of the cement layer is more important to the stress concentration of root filled teeth than the thickness of the cement layer.^[30] Moreover, cements with elastic modulus similar to dentin could reinforce weakened root and reduced stress in dentin.^[31] The use of unidirectional glass fibers customized post, modeling the internal anatomy of the root canal can be considered effective, less invasive, and suitable for restore endodontically treated teeth.^[32] In this study Panavia F, (Kuraray America, Inc.) was chosen for postcementation, which has a modulus of elasticity of 18.3, which was almost similar to the dentin [Table 1].

CONCLUSIONS

In the present study, stress was observed more in endodontically treated tooth with a post where the alveolar bone height was 4 mm from CEJ as compared to 2 mm from CEJ. Stresses in the dentin were almost similar when the carbon fiber post was compared to titanium post. However, stresses in the post and the cement were much higher when titanium post was used as compared to carbon fiber post. Within the limitations of the study, it can be concluded that the bone height and the type of the post plays an important role in stress distribution of endodontically treated teeth.

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Conflicts of interest

There are no conflicts of interest.

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