

Received: 2015.09.30
Accepted: 2015.11.18
Published: 2015.11.29

Evaluation of Temperature and Stress Distribution on 2 Different Post Systems Using 3-Dimensional Finite Element Analysis

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Statistical Analysis C
Data Interpretation D
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Source of support: Departmental sources

Background: The mouth is exposed to thermal irritation from hot and cold food and drinks. Thermal changes in the oral cavity produce expansions and contractions in tooth structures and restorative materials. The aim of this study was to investigate the effect of temperature and stress distribution on 2 different post systems using the 3-dimensional (3D) finite element method.

Material/Methods: The 3D finite element model shows a labio-lingual cross-sectional view of the endodontically treated upper right central incisor and supporting periodontal ligament with bone structures. Stainless steel and glass fiber post systems with different physical and thermal properties were modelled in the tooth restored with composite core and ceramic crown. We placed 100 N static vertical occlusal loading onto the center of the incisal surface of the tooth.

Thermal loads of 0°C and 65°C were applied on the model for 5 s. Temperature and thermal stresses were determined on the labio-lingual section of the model at 6 different points.

Results: The distribution of stress, including thermal stress values, was calculated using 3D finite element analysis. The stainless steel post system produced more temperature and thermal stresses on the restorative materials, tooth structures, and posts than did the glass fiber reinforced composite posts.

Conclusions: Thermal changes generated stresses in the restorative materials, tooth, and supporting structures.

MeSH Keywords: **Finite Element Analysis • Post and Core Technique • Tooth, Nonvital**

Full-text PDF: <http://www.medscimonit.com/abstract/index/idArt/896132>



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Background

Endodontically-treated teeth are usually weakened and become more susceptible to fractures due to the loss of dental hard tissue structure by caries, cavity preparation, root canal shaping and instrumentation, and decrease in dentin moisture [1]. A widely used method for the treatment of structurally weakened teeth is the post-and-core system [1,2]. Prefabricated posts may be non-metallic (e.g., carbon fiber, zirconium, and resin composites reinforced with glass fiber) or metal (e.g., stainless steel and titanium). Metallic posts are luted to the root canal with zinc phosphate cement, and non-metallic posts are luted with adhesive bondings [3,4].

With advances in materials and technology, several new non-metal post materials, such as carbon fiber and glass fiber post systems have recently become available [5–8]. Although use of cast metal posts has been most common, the glass fiber reinforced post-core system is gaining in popularity in recent years [9].

Glass fiber post systems show much better esthetic results than metal posts. While metallic posts are prone to fatigue failure and corrosion, glass fiber post systems meet the requirements of mechanical strength and retention. Their elastic modulus, being similar to dentin, reduces stress on the post-dentin interface [10].

The oral environment is exposed to thermal stimuli with consumption of hot and cold food and drinks [11]. Palmer et al. identified maximum and minimum temperatures between 0°C and 67°C in hot and cold liquid using a digital thermometer probe [12]. They concluded that thermal conductivity and expansion values of metal, dentin, and non-metallic restorative materials are different [12].

Stress distribution analysis of prefabricated post applications have been studied by many researchers using different theoretical or experimental techniques [7,9,10]. With rapid improvements in computer technology, the finite element method (FEM) was shown to be a powerful method and numerical model for evaluating behavior of a post-dentin interface [13]. FEM was originally developed in the aircraft industry for stress analysis in 1956; this technique is used in engineering fields, as well as in dentistry, due to its flexibility [14]. FEM plays an important role in determining clinical and biomechanical states of thermal conditions in different areas of dentistry. Computer programs allow calculation of stress, strain, and deformations [15,16].

The aim of this study was to compare and evaluate the stress distributions on an endodontically treated tooth with stainless steel and glass fiber posts under thermal and mechanical loads.

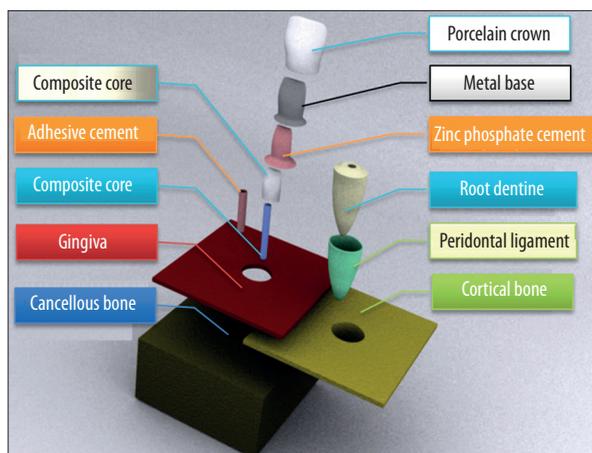


Figure 1. 3D finite element model and illustration of materials.

Material and Methods

An endodontically treated maxillary central incisor was modeled to include the periodontal ligament and alveolar bone (Figure 1). Thermal properties of materials, elastic modulus values, and Poisson's ratios are given in Table 1 in accordance with the literature. Temperature and thermal stresses were determined on the labio-lingual section of the model at 6 different points (Figure 2).

The model placed static vertical occlusal force of 100 N onto the middle of the occlusal surface of the tooth. Rhinoceros 4.0 software (Seattle, USA) was used for modeling and Algor Fempro software (ALGOR, Inc. Pittsburgh, USA) was used for stress analysis. Stress distribution and values were calculated taking into consideration 3D Von Mises criteria. The thermal loads were applied to have an initial value of 0°C (Figure 3, 4), and 65°C for the hot liquids (Figures 5, 6). Thermal stress levels were measured after 5 s. These temperature ranges and times were selected based on previous studies [11,12].

Results

Stress was observed in the middle third of the root. In contrast, minimum values were observed both in the apical portion of the post and in the root apex. Assessments were made according to the color changes in Figures 3–6, in which warm colors denote higher stresses.

Temperature and thermal stresses of the model on 6 different points are shown in Table 2. Numerical calculations were made according to the Von Mises criteria. For better observation, stress values were converted to the color chart. All stress levels were measured in megapascals.

Table 1. The mechanical and thermal properties of the materials.

Material/component	Elastic modulus (MPa)	Poisson raito	Thermal expansion (10 ⁻⁶ /°C)	Specific heat (103 J/kg)	Thermal conductivity [J/(mm·s·°C)]
Cortical bone (11, 17, 24)	13.700	0.30	10	0.44	0.5868
Cancellous bone (11, 17, 24)	1.370	0.30	10	0.44	0.5868
Dentin (11, 18, 19, 24)	18.600	0.31	11.4	0.588	0.15
Ligament (11, 20, 24)	68.9	0.45	4.1	0.36	0.5
Gingiva (11, 13, 24)	3	0.45	4.1	0.36	0.5
Gutta-percha (11, 17, 24)	0.69	0.45	54.9	0.22	0.48
Adhesive cement (21, 24)	18.600	0.28	30	0.197	0.976
Composite core (*) (24)	18.600	0.26	39.4	0.2	1.0878
Nickel–Chromium (11, 22, 24)	200.000	0.33	14.3	0.11	66.944
Porcelain crown (11, 19, 23, 24)	68.900	0.28	13.1	0.25	0.754
Zinc phosphate cement (11, 21, 24)	22.000	0.35	35	0.12	1.294
Stainless steel post (11, 13, 24)	200.000	0.33	14.3	0.11	66.944
Glass fiber post (11, 21, 24)	49.000	0.28	8.5	0.26	1.3

* Information from company.

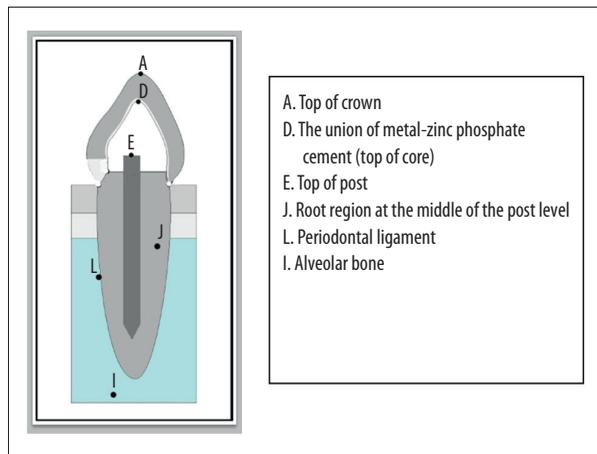


Figure 2. Six measurement points on labio-lingual view and their localizations.

Analyses of Von Mises values for the stainless steel post showed that the maximum stress concentration was on the highest peak surface of the post and coronal third, between 550.364 and 653.678 Mpa. For the glass fiber post model, it showed that the maximum stress concentration was on the highest peak surface of the post and coronal third, between 389.957 and 521.704 Mpa. Analyses of thermal stress values for the stainless steel post showed that the maximum stress concentration was on the highest peak surface of the post and coronal third, between 12.504 and 46.137 Mpa. Analyses of thermal

stress values for the glass fiber post showed that the maximum stress concentration was on the highest peak surface of the post and coronal third, between 6.035 and 6.427 Mpa.

Discussion

Many studies have evaluated variables related to the use of posts using mechanical tests. Destructive tests, such as fracture mechanics testing, are important in the biomechanical analysis of teeth and restorative materials, but they have very limited ability to calculate complex stress and strain between the tooth and restoration surfaces [25–28]. Non-destructive testings, such as strain gauge [29] and FEM test [30–32], are more appropriate tools for calculation of the distribution of stress in this area [33–37].

In investigations of complex biomechanical structures, finite element analysis (FEA) works by dividing a problem domain into small elements and executing an element-level computation to generate a piecewise solution, which cannot be revealed by direct experimental techniques. Rapid progress and development in computer technology have increased the accuracy of FEM analysis. Finite element analysis has become a powerful method in measuring internal stress when investigating complex systems that are difficult to standardize during *in vitro* and *in vivo* studies [38,39].

Table 2. Temperature and thermal stresses of the model on 6 different points.

Material	A	D	E	J	L	I
Stainless steel 0°C	550.364	12.504	5.011	3.356	2.645	0.317
Stainless steel 65°C	653.578	46.137	12.703	3.361	2.855	0.823
Glass fiber 0°C	389.957	6.0358	3.171	3.210	2.483	0.409
Glass fiber 65°C	521.704	6.42740	3.533	3.220	2.660	0.737

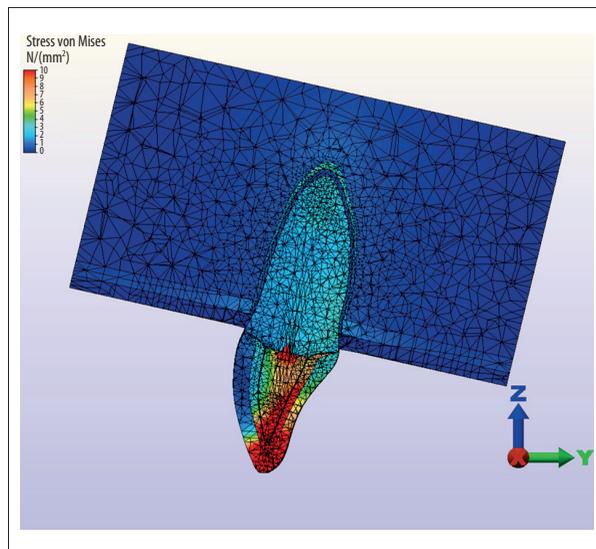


Figure 3. Stainless steel post model (0°C).

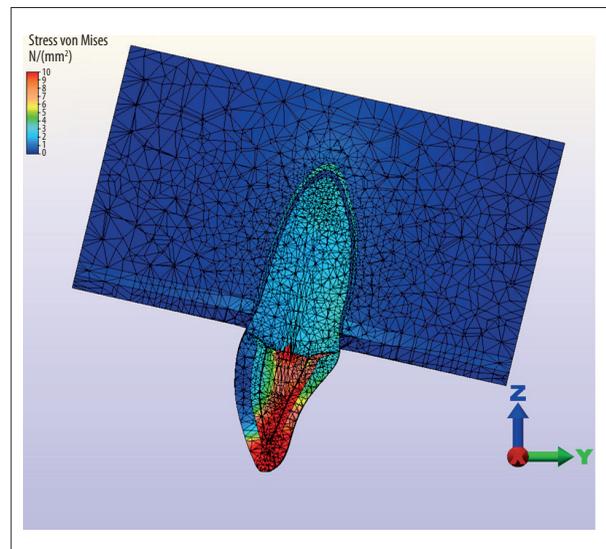


Figure 5. Stainless steel post model (65°C).

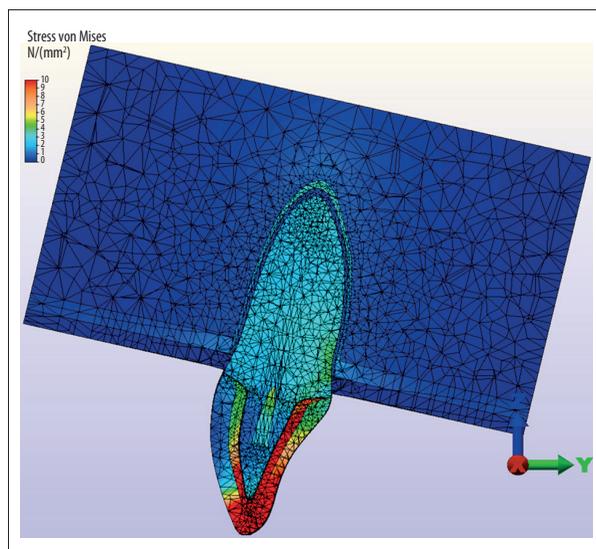


Figure 4. Glass fiber post model (0°C).

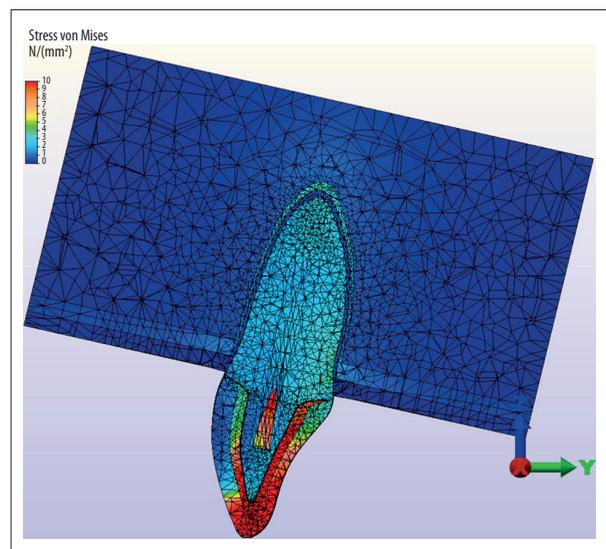


Figure 6. Glass fiber post model (65°C).

Correctly done, FEM analysis can describe how the stress distribution between dental tissue and dental materials occurs. The dental restoration of endodontically treated teeth has an important place in dentistry practice. Lately, post and core

restorations have become viable options for endodontically treated teeth and this treatment can make teeth more brittle and susceptible to fracture [40].

High compressive or tensile stress concentrated around posts may lead to root fractures and may result a new cracks or worsen an existing crack along with tooth surface [41,42].

Our study, which compared stainless steel and glass fiber posts under thermal and mechanical loads, determined the effectiveness of post different material types.

The modulus of elasticity of metal is much higher than that of dentine. This results in a system that can lead to a catastrophic, unrestorable fracture [43]. The high elasticity modulus and high fracture resistance of cast metallic dowels make the teeth highly susceptible to catastrophic fractures under intense occlusal forces [21]. Young's modulus of glass fiber posts is close to that of dentine and exhibits higher fatigue and tensile strength [22]. Teeth restored with fiber posts showed higher resistance than metallic posts under static loading.

Hot and cold liquids cause thermal stress over time. This phenomenon is a serious condition that should be investigated. Drinking hot liquids causes more thermal stress on stainless

steel posts, and glass fiber posts exhibit less thermal stress behavior. Stainless steel post has more thermal stress than glass fiber post systems.

According to the results of the present study, post material, post design, and post mechanical properties are very important in stress distribution. The numerical results indicated that the mechanical behavior in the root dentin was affected by post material and temperature.

Conclusions

We conclude that thermal and physical properties of the posts affected stress distribution in post and core applications. Our study showed that when thermal heat is applied, stainless steel posts create more stress than glass fiber posts.

Conflict of interest

The authors declare no conflict of interest.

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