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Original Article

An evaluation using micro-CT data of the stress formed in the crown and periodontal tissues from the use of PEEK post and PEEK crown: A 3D finite element analysis study

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Abstract

Aim: Metal-supported ceramics as crown material and glass fiber posts as dental post materials are in frequent current use. In recent years, it has been claimed that stress-based biomechanical problems in dentistry can be resolved with the benefit of the low elasticity modulus of polyetheretherketone (PEEK) material. The aim of this study was to use finite element analysis (FEA) to compare the stresses formed by forces applied after the use of PEEK material as dental post and crown material as an alternative to glass fiber posts and metal-supported ceramic crowns.
Methodology: The stress analysis method used in this study was FEA. First, micro-computed tomography (micro-CT) images were obtained of a maxillary central incisor tooth and the data of the post materials scanned with a 3-dimensional (3D) laser scanner were uploaded to a computer program. 3D models were obtained with designs made in the computer program of all the materials. The modelling of a maxillary central tooth was completed using 2 different post materials (glass fiber and PEEK) and 2 different crown materials (metal ceramic and PEEK) and 4 groups were formed for analysis. By applying force of 100 N at 135° from the absolute central point of the palatinal surface of the tooth, the stress values and distribution occurring in the 3D periodontal models were compared.
Results: The use of PEEK post reduced the stresses occurring on the periodontal ligament (PDL) and the cortical bone, and caused no significant change in the stresses on the crown. The use of PEEK crown reduced the stresses occurring on the crown and increased the stresses occurring on the PDL and cortical bone.
Conclusions: With further in vitro and clinical studies of PEEK material, it can be considered that within a short time PEEK post and PEEK crown could be in routine use in dentistry.

Keywords: Polyetheretherketone, PEEK post, glass fiber post, PEEK crown, finite element analysis, micro-CT

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Introduction

Teeth which have been treated endodontically are more fragile than natural teeth because of water loss (1). Teeth that have been treated endodontically, especially those with excessive crown destruction often present for post-core treatments to support the restorations to be made*. Crown treatments are applied to teeth that have undergone canal treatment to prevent the loss of the remaining dental tissues (2, 3).

Glass fiber posts as dental post material are currently widely-used materials in restorative dentistry because of the low elasticity modulus, close to that of dentin (4). In addition, glass fiber posts can bind to composite resins. This property also provides acceptable and homogenous stress distribution (5). Post materials with an elasticity modulus similar to that of dentin are known to reduce stress concentrations (6).

In recent years, the use of PEEK material has become more widespread in orthopedics, especially in trauma cases (7). PEEK is a material of the polyaryletherketone family with a high mechanical property, heat resistance, chemical stability and high biocompatibility (8). Over time, the use of PEEK material in dentistry has become more widespread and crown, implant and temporary abutment structures have benefitted from PEEK material (9). As PEEK can bind to composite resins, crown production both with cementation and veneer processes can be easily made (10).

Compared to metal-supported ceramics, the elasticity modulus of PEEK material is lower. However, that the biocompatibility is higher indicates that it can be an alternative to metal-supported ceramics (11). The relationship between metals and the oral cavity causes metal ion release and corrosion (12). In this respect, PEEK material is more advantageous than metal-supported ceramics (13).

In post-core crown treatments, forces occur on the crown first and with the aid of other elements are transferred to the sub-levels. In this context, mechanical properties of the prosthesis, post, core and other materials that are in close ranges to each other can reduce stress values (14).

FEA is an analysis method that is highly suitable for the measurement of stress values of complex structures such as the teeth. The applicability of stress analyses is difficult in vivo, but with FEA, mathematical analyses can be applied easily. Therefore, FEA has a wide area of use in dentistry (15).

The aim of this study was to use FEA to compare the stresses on the crown and periodontal tissues after the use of PEEK material as dental post and crown material in post-core crown systems as an alternative to glass fiber posts and metal-supported ceramic crowns, which are often used in routine treatments.

Materials and Methods

An upper central incisor tooth that was extracted for periodontal reasons was kept in saline then gutta-percha canal treatment was applied to be 1mm from the radiological apex. Preparation was applied using an F3 apical file with the ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) rotating instrument system. Between the instrumentations, the canal cavity was irrigated continuously with 5 ml 2.5% NaOCl. In the continuation of the main preparation, after irrigation again with 5ml 17% EDTA, the canal cavity was washed with distilled water and dried with paper cones. Using gutta-percha (Diadent Group International, Chongchong Buk Do, Korea) and resin-based paste (AH Plus, Dentsply DeTrey, Konstanz, Germany) the canals were filled with the lateral condensation technique. The tooth was covered with temporary filling material (Cavit TM-G; 3M ESPE AG, Seefeld, Germany) and was kept for 1 week at 37°C in an environment of 100% humidity. The post cavity was formed by removing the gutta-percha from the canal at 4mm from the apex with a Gates Glidden drill (No.3) (Mani Inc., Tochigi, Japan).

The tooth was scanned in a micro CT device (SkyScan 1174 v2; Bruker micro CT, Kontich, Belgium) using a 0.5 mm thick aluminum filter (Fig. 1). A total of 886 transverse sections were obtained with 13.6 μm slices along the tooth. To obtain 3D solid reconstruction, the data were transferred to Simpleware 4.1 software (Simpleware Ltd, Rennes Drive, Exeter, UK). In the final model formed, by removing a horizontal slice from the coronal section, the ferrule height was 2 mm above the enamel-cement border (16).

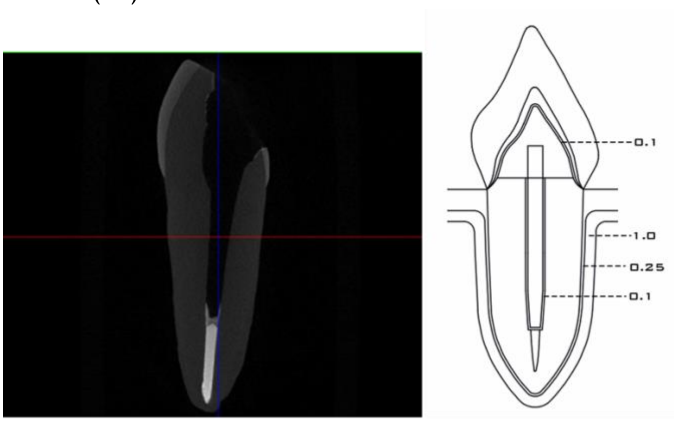

Figure 1. Micro-CT scan images and 2D imaginary model

The designs of all the materials in Table 1 were made on the computer (Fig. 2). The anatomic form of the dental crown was designed in accordance with the geometry in the Wheeler Tooth Anatomy textbook (17).

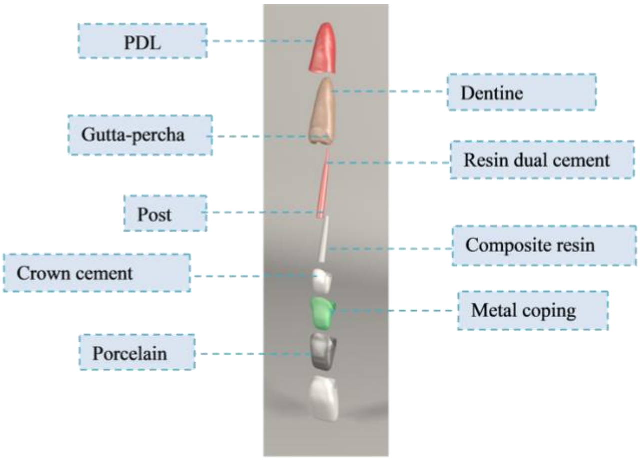

Figure 2. 3D images of all the models before combining

In the groups where metal-supported ceramics were used, zinc phosphate cement was used and in the PEEK crown groups, resin cement was selected.

With the aim of mimicking Type 3 bone, 3D dental and periodontal FE models were obtained by modelling trabecular bone and the cortical bone (1.0mm) surrounding it with the PDL (0.2mm) around the root (Fig. 3).

For scanning of the dental post, the Activity 880 (smart optics Sensortechnik GmbH, Sinterstrasse 8, D-44795 Bochum, Germany) 3D optic scanner was used. The Rhinoceros 4.0 software (3670 Woodland Park Ave N, Seattle, WA 98103 USA) was applied for the 3D modelling. The mesh design for the mesh procedures was made using VR Mesh Studio software (Virtual Grid Inc, Bellevue City, WA, USA). In all the models of this study, 228016 nodes and 1235775 elements were formed.

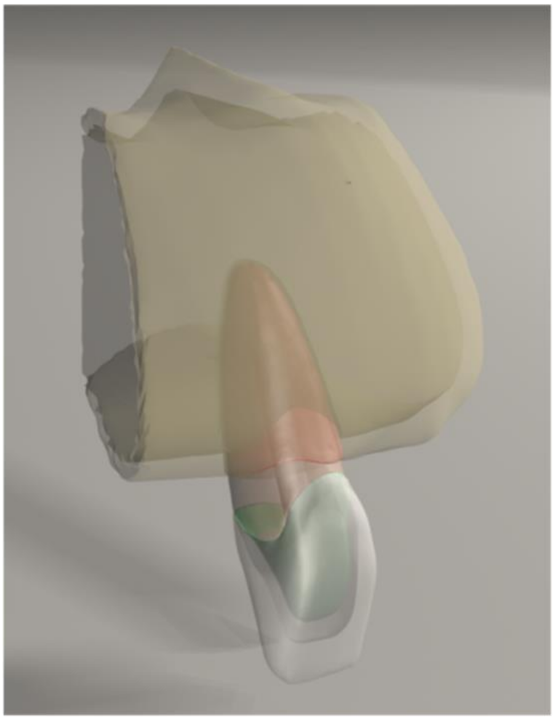

Figure 3. 3D images of all the models after combining

The values representing the physical properties of the materials in all the 3D models (Table 1) were entered and 4 groups were formed (Table 2).

Table 1. The physical properties of all the models used in the analysis

	Elastic modulus (GPa)	Poisson's ratio	Reference
Dentin	18.6	0.31	(18)
Cortical bone	13.7	0,30	(18)
Trabecular bone	1,37	0,30	(18)
Ceramic	69	0,30	(19)
PDL	0,0689	0,45	(18)
Gutta-percha	6,9 × 10−4	0,45	(20)
Resin Dual cement	7	0,30	Supplier's data (Variolink II) fromby Ivoclar Vivadent Srl (CasalecchiodiReno, Italy).
Zinc phosphate cement	22	0,35	(21)
Composite Resin Core	12	0.33	(22)
Glass Fiber Post	x-37	Xy-0,27	(21)
	y-9,5	Xz-0,34	
	z-9,5	Yz-0,27	

PEEK	3,5	0,36	Values provided by manufacturer. "JUVORA DentalDisc; JUVORA Ltd"
Metal coping (Ni-Cr)	200	0,33	(19)

Table 2. The groups formed for analysis

Groups	Post	Crown
GM	Glass Fiber	Metal ceramic crown
GP	Glass Fiber	PEEK
PM	PEEK	Metal ceramic crown
PP	PEEK	PEEK

For the application of the stress analysis, all the data were input in stl format to the Algor Fempro (ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA) analysis program. Stress analysis was performed by applying force of 100N at 135º from the absolute center of the palatinal surface in each of the 4 models (Fig 4).

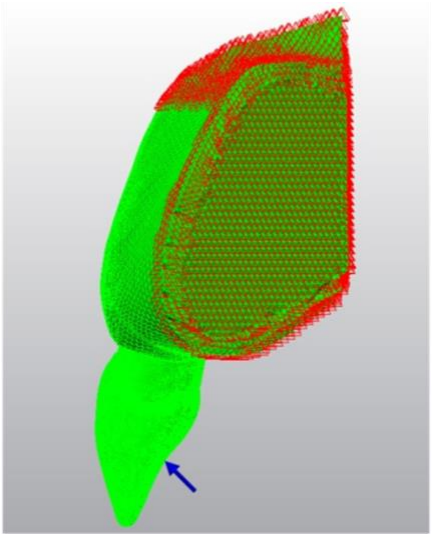

Figure 4. The application of oblique force of 100N at 135˚ from the absolute center of the palatinal surface.

Following the analysis, the size and distribution of the von Mises stress values formed in the crown and periodontal models were compared (Fig 5-7).

The materials used in the study were accepted as homogenous, linear elastic and isotropic. The combinations of the materials in all the models were assumed to be perfect.

Results

Table 3. The von Mises stress values of all groups (MPa) are shown in Table 3.

When the stress values occurring in the crown were examined, the highest von Mises stress values for all the groups were determined in the center of the palatinal surface where the force was applied. The lowest von Mises stress values were seen in Group GP (1235,62 MPa) and Group PP (1235,61 MPa) where composite veneer with PEEK substructure was applied. With a change in post material, no significant change was observed in stress on the crown (Fig. 5).

Table 3. The von Mises stress values of all groups (MPa)

	Crown	PDL	Cortical Bone	Cancellous Bone
Group GM	1239,14	4,3242	30,3319	2,5465
Group GP	1235,62	4,3383	30,4055	2,547
Group PM	1239,12	4,3091	30,168	2,5548
Group PP	1235,61	4,3211	30,219	2,5557

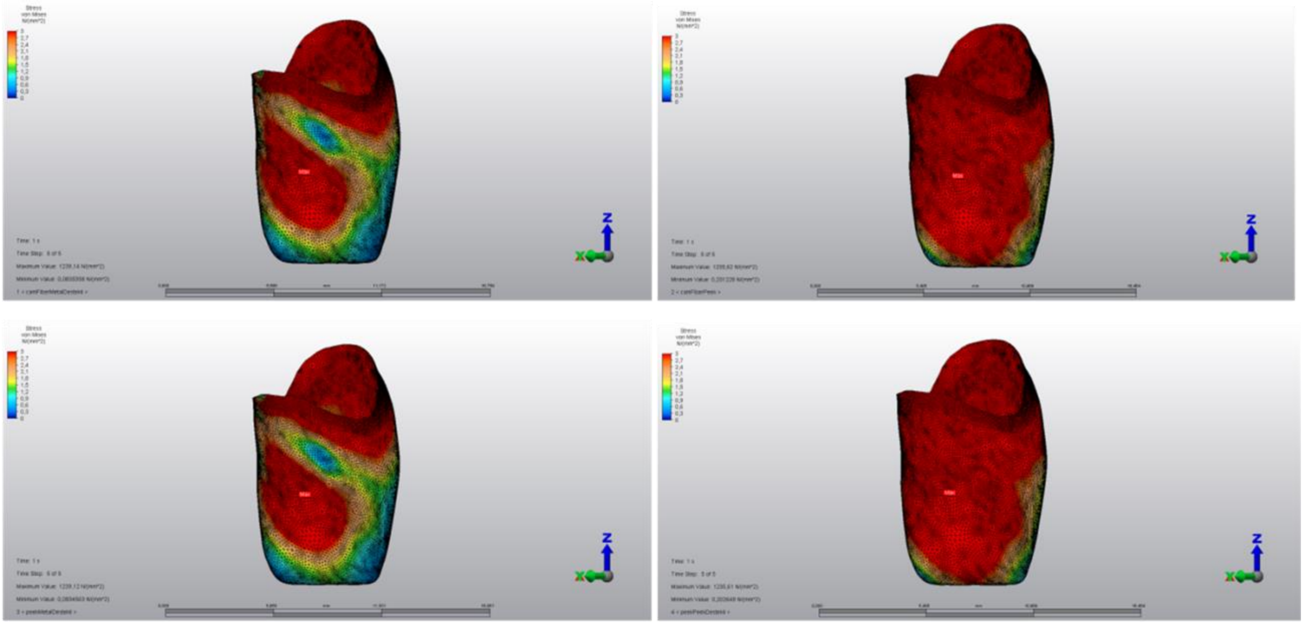

Figure 5. The von Mises stress values and distributions formed in the crown

When the stresses occurring on the PDL were examined, the highest von Mises stress values were in the coronal section of the model in all the groups. A change in post material caused a greater change in stress on the PDL than a change in crown material.

Lower stress values were observed in Group PM (4,3091 MPa) and Group PP (4,3211 MPa), where PEEK posts were used, compared to Group GM (4,3242 MPa) and Group GP (4,3383 MPa), where glass fiber posts were used. The use of PEEK material as crown material led to greater stresses than the use of metal-supported ceramics (Fig. 6).

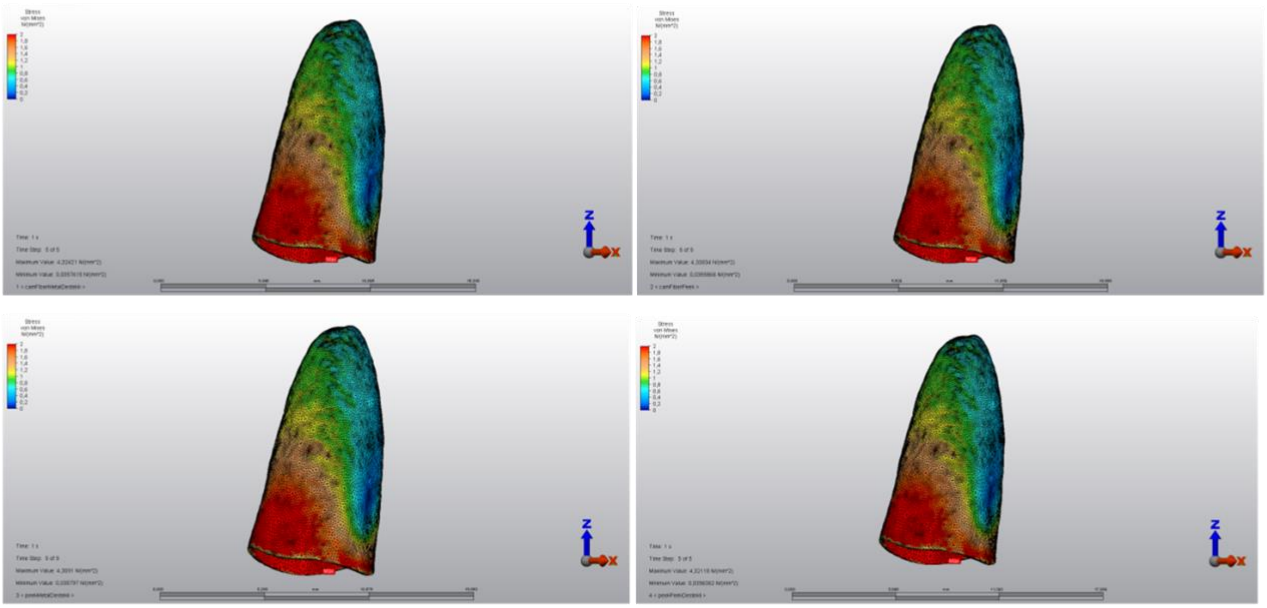

Figure 6. The von Mises stress values and distributions formed in the PDL

When the stresses occurring in the cortical bone were examined, a change in post material caused greater stresses than a change in crown material. Lower stress values were observed in Group PM (30,168 MPa) and Group PP (30,219 MPa), where PEEK posts were used, compared to Group GM (30,3319 MPa) and Group GP (30,4055 MPa), where glass fiber posts were used. The use of PEEK material as crown material led to greater stresses than the use of metal-supported ceramics (Fig. 7).

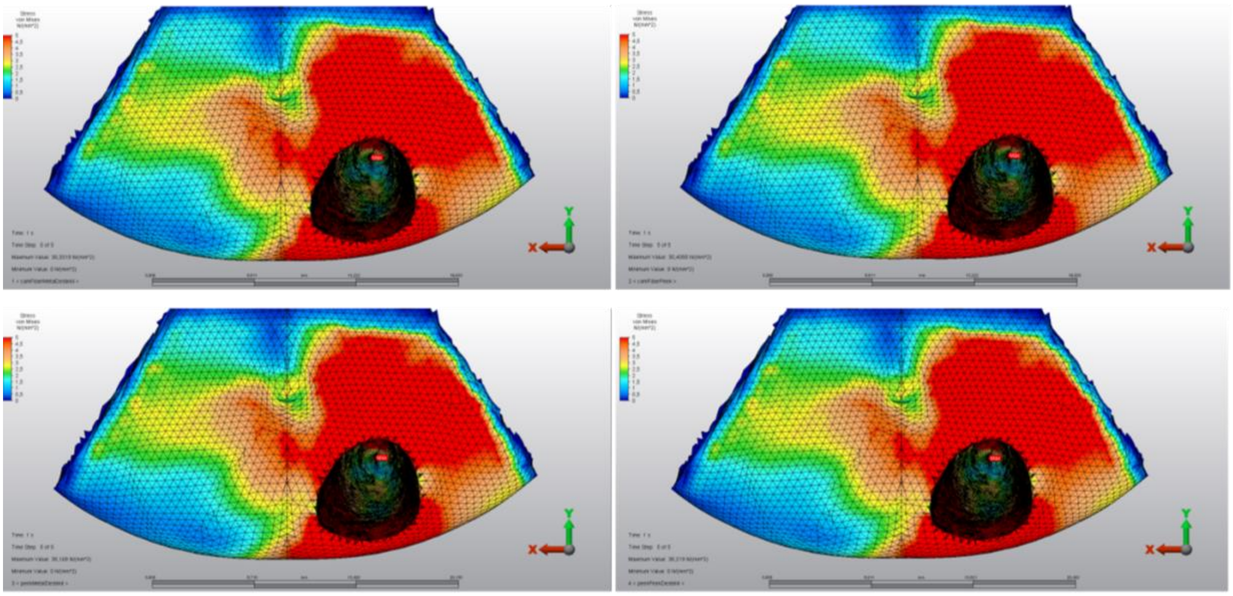

Figure 7. The von Mises stress values and distributions formed in the cortical bone

Discussion

The elastic modulus and mechanical properties of the materials used have a significant impact on the transmission and distribution of force (15).

As the elastic modulus of PEEK material is very low, stresses formed on the bone are reduced to a minimum by absorption of the forces and it has been suggested that this could promote the bone remodelling process (8).

In this study of force transmission, a comparison was made of the stresses formed on the crown and the periodontal tissues with the use of PEEK material, which has a low elastic modulus and of metal-supported ceramics and glass fiber posts, which are used in routine treatment.

Micro-CT images were used in this study as they provide the closest simulation of reality in a tooth model (8). In all of the available stress analysis methods, finite element analysis (FEA) was selected for use in the study as mathematical analyses can be easily made of objects with a complicated structure (23).

In post-core treatments, force occurs first on the crown and is then transmitted to the periodontal tissues. Therefore, to what degree the force is transmitted to the lower levels by the crown material is an important subject. In the current study, when the stresses in the crown model, as the model where the force is first seen, were examined, it was observed that less stress was formed on the crown in the groups where PEEK substructure composite veneer was used compared to the groups where metal-supported ceramics were used. A change in post material was not observed to make any significant change in stress on the crown.

The PDL is connective tissue joined to the alveolar bone which functions as a cushion for the tooth in the alveolar bone. Thus the alveolar bone and the tooth root are protected against damage. The PDL may easily become deformed. It allows a certain level of movement of the tooth against force and it supports the tooth, holding it in place during function. Increased stress on the PDL impairs this mechanism and if it continues, can cause increased stress on the alveolar bone (15).

In the current study, when the stresses occurring on the PDL were examined, the highest von Mises stress values for all the groups were concentrated in the most coronal section of the models. The use of PEEK posts with low elastic modulus as an alternative to glass fiber posts was observed to reduce the stress values on the PDL. A change of crown material had less effect on the stresses on the PDL and, albeit by a small amount, PEEK substructure composite veneer crowns caused an increase in stresses on the PDL.

When the stresses occurring in the cortical bone were examined the data obtained were in parallel with the results for the PDL. PEEK material used as posts were observed to provide a reduction in stress values in the cortical bone model. A change in crown material had less effect on the stresses in the cortical bone. PEEK substructure composite veneer crowns caused an increase in stresses on the cortical bone.

PEEK is a material which is being increasingly used in dentistry. However, there are insufficient studies on the use of PEEK material as post material. With the development of material properties, PEEK could acquire a place in post-core treatments in the dental sector and can be considered an alternative material to the dental posts that are routinely used.

Conclusions

Taking into account the limitations of this present study, the following conclusions can be drawn:

1. The use of different materials in post-core crown treatments can change the stress values.
2. In the PDL and cortical bone models, a change of post material had a greater effect than a change of crown material and the use of PEEK posts provided a reduction in stress values. However, the use of PEEK crowns increased the stresses occurring on the PDL and cortical bone.
3. In the crown model, a change of crown material had a greater effect than a change of post material and the use of PEEK substructure composite veneer crowns caused an increase in the stress values on the crown. The use of PEEK post did not lead to any significant change in the crown.

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