Mechanical and thermal stress evaluation of PEEK prefabricated post with different head design in endodontically treated tooth: 3D-finite element analysis

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An endodontic post is required to retain and support the core restoration in case of insufficient remaining coronal dentin after root canal therapy. This study analyzed the biomechanical and thermal behavior of PEEK prefabricated post after choosing the head design that produces the least amount of stress on the core and remaining tooth structure. These results were compared with the most common commercially available prefabricated post, which is titanium and glass fiber post. Thus a CBCT scanning of a maxillary central incisor with its supporting structure was used to construct a 3D solid model of an endodontically treated teeth for finite element analysis (FEA). The restored tooth with the spherical head design of PEEK prefabricated post yielded a more benign stress distribution and repairable failure mode on the crown, luting cement, core, and dentin under both mechanical and thermal loads, followed by glass fiber post and titanium post respectively.

Keywords: Finite element analysis, Endodontic post, PEEK, Mechanical and thermal stress distribution

INTRODUCTION

A successful restoration of endodontically treated teeth has a major impact on the survival of the tooth. The remaining coronal tooth structure, along with the position of the tooth in the arch, and the esthetic requirement will determine the type of restoration indicated; whether restored directly or reinforced by post with core and crown¹⁻³. Cast posts have been utilized for many decades owing to the fact that they follow the shape of the root cavity in the most adequate way. More recently, prefabricated posts have become more popular since they can provide satisfactory results with limited preparatory work while saving time and reducing cost^{4,5}.

Nowadays with increased demands toward a heightened awareness of aesthetics, tooth-colored metal-free post-core systems have become the preferred choice in restoring pulpless teeth⁶. According to previous studies, a post like fiber post with a relatively low elastic modulus enables more uniform distribution of the occlusal load on root dentin and cement interfaces⁶, and transmit the position of maximum stress above the level of the bone at the neck of the tooth^{7,8}. However, fiber posts have lower elastic moduli than those of metal alloy posts, but still higher than the root canal dentin⁹, especially the elastic modulus of dentin decrease after root canal treatment¹⁰. Therefore; the use of post material with elastic modulus less than dentin like PEEK (Polyetheretherketone) distributes the stress in dentin more uniformly and produce repairable type of failure at the neck of the tooth when fracture occurred under excessive load.

PEEK is a tooth-colored synthetic thermoplastic polymer, which exhibits appropriate mechanical and shock-absorbing properties^{11,12}, with the ability of bonding to both the dentin and resin cement^{13,14}, make it suitable material to be used as a post especially the retention of the post is achieved with adhesive luting cement instead of the thread as later introduces great stresses within the dentin².

In recent years, after successful applications of PEEK as a primary substitute for metallic components in the field of orthopedics and trauma, it has been introduced to dentistry^{15,16}. An article reported using Modified PEEK as endocrown¹⁷, another study evaluated possible application PEKK (Polyetherketoneketone) as a cast post⁹, which is a similar material to PEEK with a minor difference in thermal properties and compression strength^{18,19}.

Regarding the design of prefabricated posts, a wide range of recommendations are found in the literature; as general rule increasing the length of the post enhances the retention and the resistance of the post. However, long post jeopardizes the apical seal as a small volume of obturation material remains in the root canal to act as a barrier against microbial penetration along the root canal to prevent periapical inflammation^{20,21}. The post diameter has less effect than the post length on retention²² and the enlargement of the root canal space leads to unrepairable failure and cannot be compensated²³. Recently proved that prefabricated post head design also affects the stress distribution in the core and crown structure²⁴.

Normally teeth are encountered stress loadings during the mastication process^{25,26} and thermal stresses during the hot and cold beverage and food intake^{27,28}. These repeated effects of thermal fluctuations and

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mechanical loadings on endodontically restored teeth should be analyzed as a whole, in order to locate the areas of high-stress concentration which subsequently jeopardize the long-term survival rate of bonding between layers of restoration and remaining tooth structure leading to coronal leakage, degradation of the tooth tissues and restoration^{29,30}.

Fortunately, with rapid improvements in computer technology, finite element analysis (FEA) enables the user to accurately simulate a complex design like a post-crown endodontic restoration system and natural condition of oral cavity by entering various environmental parameters and tissue properties, overcoming the ethical issues and difficulties regarding medical studies³¹. The majority of the FE based studies in literature focuses on biomechanical behavior of post-endodontic restoration system under mechanical loadings^{25,32–35}. However, a limited number of studies in literature examined the effect thermal loading on stresses that created as a result of different thermal properties of the materials and remaining tooth structure^{36–39}. To the extent of our knowledge, there is no previous study in the literature focusing on the effect of PEEK material under oral thermal stress.

Of the modeling techniques used in this study, a cone-beam computed tomography (CBCT) based modeling was used to obtain more accurate mimicking of dental structures and restorative materials⁴⁰. Unlike most previous studies, which used simplified model of 2D or 3D geometry, neglecting some parts, or fixing the tooth inside the block of bone^{9,25,41}, a realistic modeling of the surrounding maxillary bone with a proper volumetric and geometric accuracy of tooth socket, cancellous and, cortical bone is important in the term of boundary conditions as it has direct effect on in stress distributions results^{42,43}.

The main objective of this study was to investigate the biomechanical behavior of prefabricated post made from PEEK after choosing the head design that produces the least amount of stress on the core and remaining tooth structure by 3D FEA. In addition, a transient thermal FEA simulating hot and cold liquid exposure was used to investigate variations in thermal stresses in different tissues with the studied posts. These results were compared with prefabricated titanium and fiber post.

MATERIALS AND METHODS

3D modeling of geometry

A CBCT scan of a 28-year old volunteer with normal occlusion was acquired with (NewTom Giano HR, Cefla, Italy) after taking written informed consent from the patient, as data from CBCT can be used accurately to reconstruct a 3D tooth geometry with high linear, volumetric, and geometric measurements^{43,44}. A series of image datasets were utilized with total of 185 slices, voxel dimension of 68 mm, field of view 11×8 cm, and a slice thickness of 0.3 mm, then saved in DICOM format, after that, imported into image-processing software

(Mimics, version 21, Materialise, Leuven, Belgium) for construction of 3D surface model and segmenting the scanned objects into separate elements. The size of the 3D geometry was reduced by applying global image thresholding, the maxilla in the area related to the central incisor with its supporting structure was selected and segmented. Then the data transferred as (STL) files into Autodesk Meshmixer software version 3.0 (Autodesk, Germany) to view and assemble the dimensions of the tooth with its supporting structure, where mesh improvement and refinement was carried out.

The dimensions of the tooth were modified based on the anatomical measurements suggested by Wheeler dental anatomy⁴⁵. The morphology of enamel, dentin, and pulp was adjusted according to previous studies^{46,47}. The thickness of cementum is considered to be 50 µm in the cervical area and increased gradually to 200 µm in the apical area⁴⁸, while the periodontal ligament covered 11 mm of root surface with a thickness of 0.18 mm^{49,50}. The supporting bone was divided into lamina dura, cancellous bone, and cortical bone, which re-designed to standardize the geometry of each component^{51–54}.

After the setup of the basic model of the sound incisor, a second modeling step was performed to obtain endodontically treated tooth restored with classical All-ceramic crown with a prefabricated post and a composite resin core as shown in Fig. 1.

The solid model was altered through a simulation of a clinical preparation protocol in extensively damaged endodontically treated teeth. The crown portion of the model was removed until 2 mm above the cemento-enamel junction (CEJ) to represent the ferrule effect.

The length of gutta-percha assumed to be 5 mm^{55,56}, following the shape of the pulp, while the resin cement layer was created occupying the space between the post and dentin with 120 µm thickness⁵⁷.

The crown was modeled based on the enamel structure of the natural maxillary incisor and the same technique was applied for the core, where it was developed following the shape of dentin, after that the undercut of the core was removed and 6-degree

Fig. 1 Exploded mode and constructed geometry models for three types of post integrated into endodontically treated maxillary central incisor.

angulation was created to follow standard general protocol for all-ceramic crown preparation⁵⁸⁾, finally a layer of luting cement was created with 25 μ m thickness between the core and the crown⁵⁹⁾.

Accordingly, three types of prefabricated posts were simulated as follow:

Group 1: Prefabricated titanium post (Unimetric 0.8 mm, Dentsply, Switzerland).

Group 2: Glass fiber post (Radix® Fiber Post, Dentsply).

Group 3: Proposed PEEK post (PEEK optima dental disc, Juvora, Switzerland).

To evaluate the influence of the post materials only, excluding the influence of the size, the main dimensions of the posts kept constant and modeled based on the existing dimensions obtained from a manufacturer (size 2L, length 9 mm, width of 0.8 mm at apical end, 1.47 mm cervically, length of the head 2.25 mm, 1.3° passive taper) as in Fig. 2.

Four designs of proposed prefabricated PEEK head were tested in the work as shown in Fig. 2, to select the head design with the least stress concentration in the core material and the internal surface of dentin.

The titanium post is considered as an active post unlike fiber and PEEK, which cannot be bonded chemically to dentin, so the thread was generated on the surface of the post with the exact geometry of the manufacturer.

The materials used in the present simulation were assumed to be homogenous, isotropic and linear elastic. Since the analysis was performed for two purposes, mechanical and thermal properties of all materials (Young's modulus, Poisson's ratio, density, specific heat, thermal expansion coefficient, and thermal conductivity) were defined for every part of the assembly according to previous literature data^{41,60-64)}, and have been presented in Table 1.

After constructing each part as a solid geometry, Para solid XT file, we will be able to assemble the whole model, then the assembled model imported to ANSYS software (Ansys, Houston, TX, USA). In ANSYS the mechanical and thermal properties in the Table 1 of all of the parts were introduced. To do the mechanical and

Fig. 2 Geometry of endodontic posts.

Table 1 Thermal and mechanical properties of materials and tooth tissues

Material	Elastic modulus (GPa)	Poisson's ratio	Density (g/cm ³)	Specific heat [J/(g°C)]	Thermal expansion (1/°C)	Conductivity [J/(s mm °C)]
Dentin	18.6	0.31	2.14	1.172	1.06×10 ⁻⁵	0.63×10 ⁻³
Cementum	15.5	0.31	2.06	0.824	1.1×10 ⁻⁵	0.62×10 ⁻³
Periodontal ligament	0.069	0.45	1.04	2.290	1.06×10 ⁻⁵	0.59×10 ⁻³
Cortical bone	14.7	0.30	2.06	1.26	1.0×10 ⁻⁵	0.38×10 ⁻³
Cancellous bone	0.49	0.38	0.62	1.16	1.0×10 ⁻⁵	0.38×10 ⁻³
Resin luting cement	7.7	0.30	1.10	0.824	3×10 ⁻⁵	1.091×10 ⁻³
Guttapercha	0.69	0.45	2.70	1.042	16.2×10 ⁻⁵	332.4
Composite resin (Hybrid/Ivoclar-Vivadent)	12	0.30	2.26	1.40	3.94×10 ⁻⁵	197×10 ⁻³
Ceramic crown (E-max)	91	0.23	2.40	989	1.7×10 ⁻⁵	1.467
Glass fiber post	40	0.30	2.50	0.26	0.85×10 ⁻⁵	1.3×10 ⁻³
PEEK optima post	4.2	0.36	1.30	1.700	52×10 ⁻⁵	0.25×10 ⁻³
Titanium post	112	0.30	4.51	11.9	54×10 ⁻⁵	21.9×10 ⁻³

thermal analysis, a proper mesh was generated and the initial condition, boundary condition, and loading were introduced in ANSYS.

Biomechanical stress analysis

All prepared assembly has meshed for finite element simulations. 3D 10-node tetrahedral elements were used to be compatible with model irregular meshes and complex geometries of dental structures⁽⁶⁰⁾. The standard convergence tests were applied to all models in each test stage, the mesh was considered satisfactory when even with decreasing the size of elements, and the highest stress levels remained constant to represent the original geometry accurately.

For simulating the interface between model components, bonded contact was prescribed along with all model interfaces. The lateral surface of the maxillary bone was assumed to be rigidly fixed in the x, y, and z directions.

A static bite load with a constant intensity of 100 N was applied 3 mm apical to the incisal margin of the palatal surface of the crown at an angle of 45 degrees relative to the longitudinal axis of the tooth for calculating stress distribution in normal occlusal contact with the antagonist tooth^(26,42).

Thermal stress analysis

A transient thermal FEA was conducted as a time-dependent behavior of applied thermal loads on the outer surface of the crown to represent thermal loadings during the hot and cold liquid/food intake.

The initial temperature of the entire assembly was set to 36.5°C to simulate the temperature inside the oral cavity⁽⁶⁵⁾.

For each model, the outer surface of the crown was subjected to 60°C for 2 s corresponding to the normal duration of exposure to hot thermal loading. After that, the temperature was relaxed to retrieve an oral cavity temperature of 36.5°C within 5 s, this analysis was repeated 3 times for 5-s-time intervals. For the cold thermal simulation, the same procedure was performed for a temperature of 5°C. These thermal loads and time intervals were established based on the measurements from previous literature^(30,60,64), while the FEA should not be used to represent long term effects of low-order heating or cooling of the teeth that might occur during eating or drinking, because it is not possible to give a large number of typical results, as a few representative situations will be noted⁽⁶⁶⁾.

The convection coefficient values on the outer surface of the all-ceramic crown were assumed to be constant and equal to $7.37 \times 10^{-4} [\text{J}/(\text{s mm}^2 \text{ K})]$ for 5°C sink temperature describe the consumption of cold liquid and, $5.0 \times 10^{-4} [\text{J}/(\text{s mm}^2 \text{ K})]$ for 60°C sink temperature assumes the hot liquid drinking^(28,66).

RESULTS

Mechanical load

The results of the stress distributions are presented in

contour graphics with a color scale in Megapascal (MPa), with maximum Equivalent von Mises (EVM) stress concentration in each dental model component.

The influence of PEEK post with four head designs was taken into account on each individual component of the restored system by recording maximum EVM stress distributions. As in Fig. 3a, the highest stresses were found in cubic head design followed by conical and no-head design, while the spherical head presented with the lowest value in each component. It is possible to note that the main effect of the head design was in composite core with the peak stress of 57.87 MPa for the cubic design and only 7.75 MPa for the spherical head design as shown in Fig. 3b. Based on these results, the spherical head design was chosen as the proposed design of the PEEK prefabricated post.

For each component of all simulations, both the

Fig. 3 (a) maximum values of EVM stresses on model layers for each head design of PEEK post, (b) color code plot of the tested post head design.

Fig. 4 Maximum values of EVM stress in the dental post-endodontic restoration system with different posts.

stress contour plot and the maximum stress distribution were reported.

The maximum values of EVM stress in the dental post-endodontic restoration system with different posts were shown in Fig. 4. In general, all systems show symmetric behaviors regarding the distribution of stress on each part of the model with higher values of a titanium post, followed by glass fiber post and PEEK posts. The major value differences were found on the post with a peak value of 81.11 MPa of a titanium post, 29.26 MPa for glass fiber post, and only 3.17 MPa of PEEK post.

As it can be seen in the contour plot Fig. 5, in all simulations the peak stress concentrated on the lingual surface just below the cervical line for dentin, and on the labial cervical edge of the crown and luting cement, while for composite cores the maximum EVM were located on the incisal tip lingually. On the other hand, the position of peak stresses was different in both post and post cement between the three simulations.

Since the position of maximum stress is crucial clinically to decide the type of failure in endodontic post system either repairable or not, stress distribution line was created at the interface of dentine to cemented post along the middle plane in longitudinal axis cervico-apically of the three models as shown in Fig. 6. In both fiberglass and PEEK post cases, the maximum values of EVM stress were located above the bone level in the ferrule area of dentin as in Fig. 6a, while in titanium post case, the stress distribution was higher than that of the others and located at the middle third of the root.

Fig. 5 EVM stress contour plots in MPa of components of (a): Titanium post (b): Glass fiber post (c): PEEK post.

The fluctuation of the stresses in Fig. 6b was due to the changes in the geometry for the Titanium thread.

Thermal load

The results of temperature distribution from the transient thermal analysis are presented in Fig. 7. Six data points, A, B, C, D, E, and F were selected along a middle longitudinal plane to represent the variations in temperature distributions at different tissues as a function of time. The selection of the points was based on the results of the mechanical part of the study where

Fig. 6 (a) EVM stresses values along a vertical line at the interface of dentin and post cement from cervical to apical for the three models, (b) sagittal section views the position of maximum EVM along that line.

Fig. 7 Temperature distribution in selected points in all the models (a), temperature change per time in PEEK post group (b), temperature change per time in glass fiber post group(c), and temperature change per time in titanium post group (d).

the type of post has an influence on these components of the model. It can be observed in the Fig. 7a set of twelve curves of temperature, corresponding to each point, these curves are therefore distributed in two subsets of six curves, one subset for hot exposure and the other for cold exposure.

Application of the hot thermal load on tooth restored with PEEK post increased the temperature in point A until 56.5°C, while maximum temperatures through points B, C, D, E, and F were 54.4, 51.6, 46.4, 42.9 and 41.5°C respectively. For cold thermal application, the temperatures at point A reduced to 8.3°C, while the minimum temperatures through points B, C, D, E, and F were 11, 14.5, 21.4, 25.7, and 39.5°C respectively as seen in Fig. 7b.

Temperature distributions of the tooth restored with glass fiber post are shown in Fig. 7c. The maximum and the minimum temperatures were found between points A and F with the range of 56.0 to 39.6°C for the hot application, while it varies between 8.3 to 30.6°C for the cold thermal loading.

Finally, for the tooth restored with Titanium post

the maximum temperature between point A and F were 56.7 to 41.2°C, and the minimum temperature was 7.6 to 29.2°C for the same points as seen in Fig. 7d.

Accordingly, the maximum temperature gradient between the A to F data point after cold application was highest in the glass fiber group, followed by the PEEK post group, while the least temperature gradient was seen in titanium post.

Regarding the variation of stress distribution induced by the applied thermal loads among studied groups, EVM stress distribution of the measurement points (A to F) was measured as a function of time illustrated in Fig. 8.

Overall, as shown in Fig. 8, the cold loading induced more stresses than hot loading on the same point at the same time, additionally, the effect of the post type was more significant on the D, E, and F points.

The maximum EVM stress on the six tissue layers of each group was presented in Fig. 9 after thermal application, the group that restored with Titanium post introduced the highest maximum EVM stress on the core, post, post luting cement, and dentin. Followed by the group restored by fiber post and PEEK post respectively, while there was little or no difference between the groups in the crown and crown luting cement layers.

The positions of thermal stress distributions for the different study groups after the 21st second of heat and cold applications were summarized in Fig. 10. For all the groups, the largest stresses introduced in similar positions on different component, for example, the position the maximum EVM stress on the crown was located on the middle of palatine surface, while on the

Fig. 8 EVM stresses per time in the selected points after cold and hot applications of all post groups.

Fig. 9 Maximum EVM stresses on six tissue component after thermal application.

Fig. 10 Stress distributions in MPa of different tissue components of each post group after cold and hot applications at the end of 21st second.

core located on the cervical edge with the exception for the post layer, where the position of maximum EVM stress is located on different area in each group. In the titanium post group, the largest stress situated on the labial surface of the post head, a tip of the head in fiber post group, and finally the maximum stress is distributed in larger areas on the neck of a post in PEEK post group.

DISCUSSION

The risk of tooth fracture is an undesirable incident usually related to insufficient coronal tooth structure after endodontic treatment^{67,68}. Rebuilding of the tooth structure by a post prior to crown restoration sometimes is mandatory to provide a stable and solid restoration of the tooth^{69,70}.

The present study investigated the effect of prefabricated post materials and head design on the amount and distribution of stress created by masticatory and thermal loads on each layer of the post-endodontic restoration system using 3D FEA.

Various methods are used to analyze stress distribution in post-core-restored endodontically treated tooth but the applicability of stress analyses is difficult *in vivo* this might attribute to difference in mechanical and physical properties of post-core-restored endodontically treated tooth tissues making it difficult to control

related factors like amount of remaining tooth structure, load direction, and magnitude, tooth position...etc. On the other hand *in-vitro* tests the simulation of the oral environment is impossible⁷¹⁻⁷³. To overcome these difficulties, FEA was used in this study to simulate the natural condition in the complex design. In addition, EVM stress have been used for evaluating the stress distribution on important area as it combines normal and shear stresses at a given point which can lead to failure due to the brittle nature of tooth tissues⁷⁴.

Recently, high-performance PEEK polymer has been successively used in dentistry as indirect extra-coronal restorations^{12,75}. Its application as indirect intra-coronal restoration is promising since it has elastic modulus close to dentin³⁷, but their use as cast post or endocrown is still needed laboratory preparation which is expensive and time-consuming. In this respect fabricating a large number of PEEK either by milling or pressing procedure with standardized geometry getting the advantage of appropriate mechanical strength of the material that can be manipulated easily in the clinic during the application, is possible to save time and money.

The post design has the major effect on stress concentration which in turn depend on material properties of the post whether the retention of the post can be achieved with adhesive luting cement or the post derived their primary retention directly from the root dentin by the use of threads². In order to assess the influence of post head design on the stress distribution of endodontically restored tooth, the magnitudes of EVM stresses under mechanical loading conditions were examined. It can be concluded from the results, the head design of the post has a dramatic effect on stress concentration on the core material, and the maximum stresses are mainly located at the line angles even after reducing the sharp edges by inducing fillets to the head design. As a consequence, these stress concentration areas act as a predisposing factor to initiate a crack in the core structure that ends with fracture. This is in a good agreement with the findings of the study²⁴ that concluded using ball-head metal post reduce stress concentration in the core material, however, a ball-head metal post is proved to be less retentive⁷⁶, but this is not a problem in case of PEEK post, as later can bond chemically to composite core⁷⁷.

Regarding the effect of post material to the tooth structure and remaining restorative materials, the maximum values of EVM stress in the dental post-endodontic restoration system was seen in titanium post, followed by glass fiber post and PEEK posts. This difference is due to the different material properties of the posts like elastic modulus^{34,78,79}. Biomechanically, post with mechanical properties closer to dentin allows the restored system to carry the masticatory load of the natural tooth as a single unit without minimizing stress transfer into the vulnerable root.

In general, all systems of the study show similar behaviors concerning the distribution of stress on each component of the model, and the effect of type of post was significant on the component of the model from the

crown until cementum, while the type of post did not influence periodontal ligament and the maxillary bone. This is due to the property of the periodontal ligament, as it contributes to the attenuation of any stresses^{80,81}.

Furthermore, the position and magnitude of stress concentration in the post-dentin interface are very important as it determines the position of future crack progression in dentin shifting the fracture pattern towards repairable fractures is a well-known phenomenon when the position of maximum stress is located above the level of the bone^{7,8}. It was found that the stresses in PEEK post and glass fiber post were located above the bone level while in the titanium post located in the middle third of the root. These results are consistent with the findings reported previously^{32,34,82,83} and other researcher⁸⁴ have pointed out that PEEK endocrown distribute the stresses more evenly in contrast to rigid materials which produce stress concentrations at critical areas that might cause cohesive failures in the endocrown and dentin.

It should be pointed out in the present study that the interface between the post and the composite core considered adhesively bonded to mimic the clinical situation where the post bonded either mechanically, or chemically by bonding agents to the core without sliding or frictional movements. As it mentioned by He in 2016; an accurate FEA model of adhesive bonded joint is able to predict failure in the adhesive and at the adhesive–adherent interfaces, and also account for full non-linear material behavior⁸⁵.

Mechanical and thermal stress distribution in the complex geometry of endodontically treated tooth restored with a post, depending on the geometry, physical and thermal properties of different materials and dental tissues. However, the variable stress gradient can contribute to damage the bonding system and cracking of the filling material and remaining dental tissues as well^{36,86}.

In the present investigation, post materials with a low thermal conductivity increased the thermal gradient between the outer and the inner region in a given time. That is to say glass fiber posts produced a higher temperature gradient, followed by PEEK post, and titanium post. This is in agreement with previous findings^{39,62}. It is obvious that this difference can contribute to the loosening of an endodontic post with time, which is the main type of failure in fiber-reinforced posts⁸⁷.

Overall, temperature changes and resulting stresses on restorative materials and remaining tooth layers induced by the cold thermal loading simulations were found to be higher than those of hot thermal loadings. This result was in agreement with the other studies^{30,60,86}, as they pointed out that the tensile stress occurs on the surface of restoration as a result of the temperature difference and larger convection coefficient during cold thermal loading may increase the risk of failure compared to hot thermal loading.

Based on simulation results, the effect of the type of the post was more obvious on dentin, post luting

cement, and the post itself. It can be also concluded from the results that titanium post produced the highest stress followed by the group restored by fiber post. The outcomes of this study corroborate earlier findings which have revealed that metallic post yields larger stresses than metal-free posts^{32,41,64}. On the other hand, in PEEK post the resulted stresses were homogeneously distributed over larger areas resulting in the least stress concentration.

It should be noted that the simulation materials of the restorative parts and oral structures used in this study were considered to be linearly elastic, homogeneous, isotropic, and ideally bonded, which is not absolutely same as that of natural tooth structure and supporting tissues which they present heterogeneous and anisotropic behaviors^{32,60}. However, to guarantee the accuracy of the finding, direct comparison between the results of FEA study and clinical trial with *in-vitro* studies are necessary to support or modify the outcome of the present study and evaluate the combined effects of thermal changes and mechanical loading.

CONCLUSIONS

Within the limitations of this study, the following conclusions could be drawn:

1. A proper design of the post head produces a more benign stress distribution and minimizes the risk of failure after post-endodontic treatment.
2. Endodontically treated teeth restored with PEEK prefabricated posts may survive masticatory and oral thermal loading stresses better than titanium and glass fiber post.
3. PEEK prefabricated post, exhibited a favorable stress distribution pattern at the intra-radicular dentin, indicating a lower possibility of vertical root fracture than stiffer post materials.
4. Glass fiber post produced the highest temperature gradient between components of the restored tooth model, followed by PEEK post, while titanium post produced the least temperature gradient.
5. Cold thermal loading produced larger temperature changes and stress concentrations than hot thermal loading regardless of the type of post used.

The results of this study can be considered of clinical significance, providing a better understanding of the stress and thermal distribution between the components of post endodontic restoration to select the most appropriate combination of materials to meet the overall system objective.

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