
Effect of post materials on the biomechanical behaviour of endodontically treated tooth

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Abstract: Objectives: To study the stress distributions in maxillary central incisor restored with Ni-Cr custom-made, gold custom-made, prefabricated titanium and prefabricated glass fibre dental posts subjected to oblique occlusal load at 100 N. Materials and Methods: Four three dimensional finite element models of a maxillary central incisor restored with Ni-Cr (Model I), gold custom-made (Model II), prefabricated titanium (Model III) and prefabricated glass fibre (Model IV) dental posts were constructed and oblique loading of 100 N was applied. Stress analysing at the along the centre of the post and post-surrounding structure interfaces were computed. Results: The result of this study indicates that the clinical three-dimensional image provided information about the behaviour of teeth under function in all directions. The results obtained from a finite element model on the restored system contain information about the stress distribution of each component of the restoration. The maximum von Mises stress distribution at post center was recorded with Model I (38.6 MPa), followed by Model III (22.4 MPa) and Model II (20.8 MPa) respectively; whereas the minimum amount of stress was noticed in Model IV (10.9 MPa). At post dentin interface, the highest von Mises stress distribution was noticed with Model I (29.8 MPa), followed by Model III (18.9 MPa) and Model II (18.8 MPa) respectively; whereas the smallest amount of stress was noticed in Model IV (10.16 MPa). Conclusions: Glass fibre posts generated the least amount of stress concentration at middle and apical part of the posts compared to other dental posts.

Keywords: Finite Element Model, Custom-Made Dental Posts, Prefabricated Dental Posts, Stress Analysis

1. Introduction

Restoration of an endodontically treated tooth is considered as challenge for most dental practitioners. Dental post is often used after root canal treatment when restoring a damaged tooth with extensive loss of coronal tooth structure.

^[1] Post insertion should be avoided if adequate retention can be achieved from the remaining coronal tooth structure.^[2] Unfortunately, these teeth that have been restored endodontically have been shown to exhibit a significantly shorter service life when compared with vital teeth.^[3]

Dental posts are a way of building up and thereby retaining coronal restoration, however, posts do not reinforce the roots of the tooth. The development of the different post and core systems goes along with a paradigm shift in the restorative philosophy of treatment. Traditionally, custom-made posts and cores were the system of choice, but today, prefabricated metal and non-metal posts, combined with resin cores are

considered a viable alternative. The prefabricated post and core system is one of the most popular systems because it requires less time in the dentist's chair.^[4]

Some authors assert that posts may interfere with the mechanical resistance of treated teeth, leading to an increased risk of damage to the remaining tooth structure.^[2,5] To date, there is still no agreement about what is the ideal dental post for restoring endodontically treated teeth.^[5] Therefore, this was selected as the theme of the current study.

Three-dimensional Finite element method (3D FEM) has been used for stress analysis of teeth. What is more, the 3D FE method shows internal stress enabling predictions to be made about potential failure.^[1] Therefore, the study was aimed at comparing the stress distributions in maxillary central incisor restored with Ni-Cr and gold custom-made, prefabricated titanium and glass fiber dental posts.

2. Materials and Method

2.1. Modelling of a Maxillary Central Incisor

A three-dimensional (3D) model of an adult maxillary central incisor was developed using a Computed Tomography (CT) scan image set. Using Mimics (Materialise NV, Belgium) and Hounsfield's Unit, 3D models of a maxillary central incisor were constructed along with its surrounding cortical and cancellous bones. Restoration methods for endodontically treated teeth such as dental posts, composite cores and dental crown, were modeled based on the geometry of the root using a 'Solid Works' (Dassault Systèmes, USA). The dimension of each component was based on the data from literature.^[7-9] A periodontal ligament (PDL) was modeled based on a tooth root with a thickness of 0.25 mm^[10], and was subtracted from the volume of the cortical and cancellous bone (Figure 1). Since any cement and cementum is very thin. Thus, they are ignored and considered as the part of dentine.^[11]

2.2. Mesh Generation

The tetrahedral elements (C3D4) were used with fine meshes to obtain accurate data. As constant stress tetrahedral elements exhibit slow convergence, during pilot study, a tetrahedral mesh of 148465 was used after a revealed that the error remained below 0.1% for two mesh sizes of 148465 and 236906 (Figure 1).

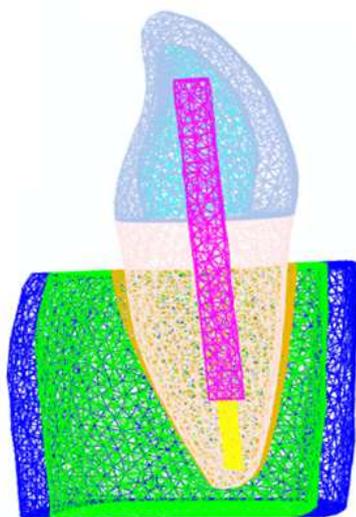


Figure 1. Schematic illustration of the three dimensional geometric model.

2.3. Loads and Boundary Condition

The boundary conditions for the nodes were placed along the bottom end line of the models and fixed to the supporting structure of the central incisor as prescribed by the system. An oblique load, angled at 45°, to simulate the masticatory force; $P_2 = 100$ N was chosen.^[12] All forces were applied on the aforementioned area as distributed pressure. Any stresses that are likely to be introduced during the endodontic treatment were neglected.

2.4. Elastic Properties

Mechanical properties of the restorative materials were created for each part of the FE model. The materials used for modeling each part of model tooth parts were assumed to be linearly. The elastic properties of Ni-Cr custom-made (Model I), gold custom-made (Model II), prefabricated titanium (Model III) and glass fiber (Model IV) dental posts and other restorative materials used in the geometric model are presented in Tables 1 and 2.

Table 1. Mechanical properties of isotropic materials.

Material	Elastic modulus (MPa)	Poisson's ratio
Cortical bone	13700	0.3
Cancellous bone	1370	0.3
Dentin	18600	0.32
PDL	0.069	0.45
Porcelain	69000	0.28
Gutta-percha	140	0.45
Composite resin	12000	0.33
Titanium post	116000	0.33
Ni-Cr alloy	200000	0.33
Gold alloy	93	0.33

Table 2. Mechanical properties of orthotropic materials.

Property	Glass fiber post
Ex (MPa)	37000
Ey (MPa)	9500
Ez (MPa)	9500
Vxy	0.27
Vxz	0.34
Vyz	0.27
Gxy	3100
Gxz	3500
Gyz	3100

2.5. Finite Element Analysis

The calculation of the von Mises stresses distributions and processing was carried out using ABAQUS/CAE software, Professional Version. Von Mises stresses were evaluated within the tooth, along the centre of the posts and at post and surrounding structures interfaces.

3. Results

The result of this study indicates that the clinical three-dimensional image provided information about the behaviour of teeth under function in all directions. The results obtained from a finite element model on the restored system contain information about the stress distribution of each component of the restoration.

In all the models the peak values of von Mises stresses stress was recorded at the middle third of the buccal aspect of the root surface. However, the smallest values were observed at level of both the apical portion of the post and the root apex.

The high stresses are also evidenced around the loading area and the outer surface of the dentine. Stress progressively decreases from the outer to the inner part of the root. The peak stress distribution was recorded with Model I followed by Model III and Model II respectively;

whereas the minimum amount of stress was noticed in Model IV (Figures 2-5).

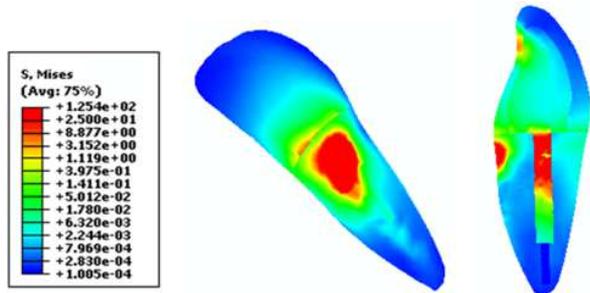


Figure 2. Contour plots for von Mises stress distribution in Model restored with Ni-Cr custom-made dental post.

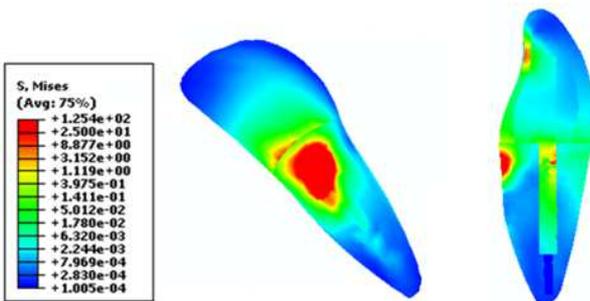


Figure 3. Contour plots for von Mises stress distribution in Model restored with gold custom-made dental post.

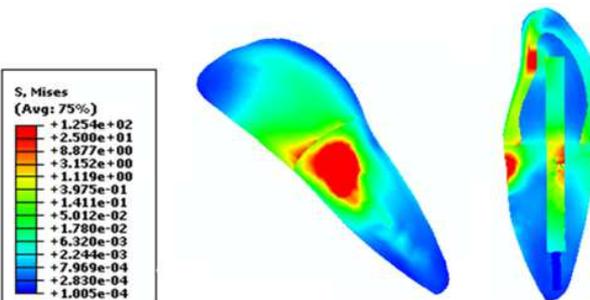


Figure 4. Contour plots for von Mises stress distribution in Model restored with prefabricated titanium dental post.

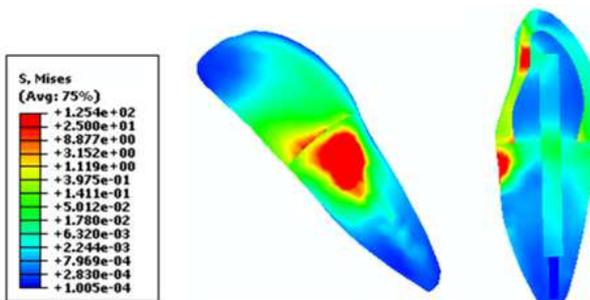


Figure 5. Contour plots for von Mises stress distribution in Model restored with prefabricated glass fibre dental post.

3.1. Stress Distribution along the Center of the Posts

Figure 6 exhibited the stress distribution inside the Ni-Cr custom-made (Model I), gold custom-made (Model II), prefabricated titanium (Model III) and glass fiber (Model IV)

dental posts. The maximum stress distribution inside the post is observed with the Ni-Cr custom-made (38.6 MPa), followed by prefabricated titanium (22.4 MPa) and gold custom-made (20.8 MPa) dental posts respectively; while the minimum amount of stress was observed in glass fiber posts 10.9 MPa) as shown in Figure 6.

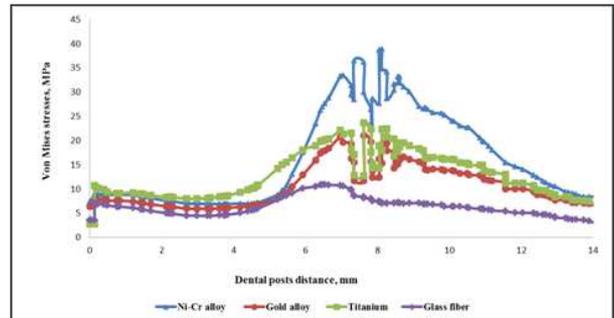


Figure 6. Von Mises stress distribution at the post centre.

3.2. Stress Distribution at the Posts and Surrounding Structured Interfaces

Figure 7 showed the stress distribution at post and surrounding structure interface. The highest stress distribution at the post and surrounding structure interface is observed with the Ni-Cr custom-made (29.8 MPa), followed by prefabricated titanium (18.9 MPa) and gold custom-made dental posts respectively; while the smallest amount of stress (18.8 MPa) was observed in glass fiber posts (10.16 MPa).

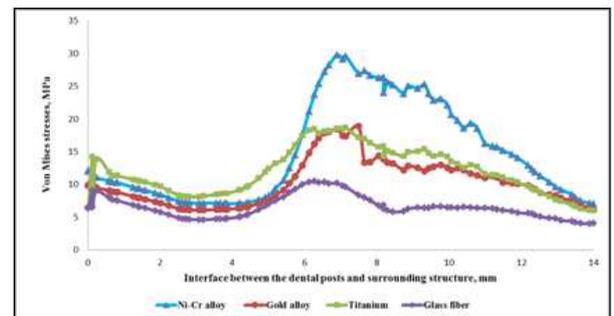


Figure 7. Von Mises stress distribution at the post and surrounding structures interface.

4. Discussion

Medical imaging can play a central role in the global healthcare system as it contributes to improved patient outcome and more cost-efficient healthcare in all major disease entities. Medical imaging techniques are a tool for mapping of anatomy and for detection and localization of a disease process. It produces important biological information about physiology, organ function, biochemistry, metabolism, molecular biology and functional genomics.

Finite element analysis is a powerful computational tool for modelling soft tissue deformation. It shows positive results for same-subject non-rigid image registration and for medical simulation applications. [13-15]

In the area of dentistry, studying dental structures and

surrounding tissues in the oral cavity presents the basis for understanding the occurrence of pathological process and enables the correct approach and treatment. The success of restorative materials depends on their properties to withstand and resist occlusal forces and successfully support the remaining oral structure.^[16] FEA has been used to study internal stresses in teeth and different dental materials, and to optimize the shape of restorations. It eliminates the need for large number of experimental teeth due to variations in biological material properties and anatomy, mechanical testing involving biomaterials usually require a large number of samples. It has been used to represent simulated tooth mechanical behavior under occlusal loads in details.^[17]

The reduction of stresses in the brittle material, like dentine, is advantageous as dentine can resist larger cyclic loading and chance of root failure is reduced. The reduction in the interface shear stress reduces the chances of the post losing from dentine as the stress on bonding cement comes down.

FE method was used to study the stress generated in endodontically treated teeth which are that had been restored with a posts. It has been shown to be a useful tool when investigating complex systems that are difficult to be standardized during *in vitro* and *in vivo* studies.^[18-20]

In this study, the model of the incisor was created from a CT scan image of an adult maxillary central incisor along with its surrounding structures. This provided a realistic rendition of clinical conditions. Toksavul et al.^[11] have omitted the cement layer. In this study, the cement layer was not included to simplify the model.

It was observed that von Mises stresses were distributed along the posts, as expected, and that stress was concentrated on along the labial aspect of the posts, due to the direction of loading. However, higher stresses were observed Ni-Cr custom-made, followed by prefabricated titanium and gold custom-made dental posts respectively; while the smallest amount of stress was observed in glass fiber posts. On the contrary, the stress distribution for glass fiber posts was concentrated mainly within the root dentine. Glass fiber post reduce the concentration of stress is likely to be due to a lower stiffness of this post. These results are in agreements with Joshi et al. [12] who reported that posts with high stiffness produced a created higher stress concentration compared to glass fiber posts. Posts with a higher elastic modulus have been found to cause amplification of stress within the post itself, yet a reduced stress distribution in the root dentin.

The results also agree with an earlier theoretical, *in vitro* investigation of the resistance of post-restored teeth to a cyclical loading^[21] and with a theoretical study using FE analysis.^[22] Silva et al.^[23] compared four different metal posts to glass fiber posts. They reported that the stress distribution within the tooth restored with a glass fiber post was more homogenous than those restored with metal posts. Furthermore, they found that stress tended to be concentrated at the outer boundary of metal posts. Asmussen et al.^[24] analyzed the stress distribution in endodontically treated teeth restored with glass fiber, titanium, and zirconia posts, reporting that an increase in the elastic modulus of the

post caused a decrease in the stress within the dentin.

For the interface between the post and the surrounding structure, Ni-Cr custom-made post exhibited the highest stresses, while the smallest amount of stress was observed in glass fiber post compared to other types of post. Similarly, the results of this study revealed that glass fiber posts show a more balanced stress distribution at the post and dentine interface, as well as the cervical area of the tooth. This is agreement with Boschian et al.^[25], who reported that reinforced fiber glass composites distribute stress better than titanium or stainless steel posts. This concurs with the results of the present study which shows that metallic posts generate the highest stress values.

5. Conclusions

Glass fiber posts reduced the distribution of stress at the middle and apical parts of the post compared to other dental posts. However, Ni-Cr custom-made dental post increased the distribution of stress at the middle and apical parts of the post compared to other dental posts. Therefore, the chosen dental post with low elastic properties, practically when it is near to the elastic properties of dentine, is preferred in order to diminish the stresses in dentine and at the interface. This in turn will resist larger cyclic loading and minimize the root failure and chance the post losing from dentine.

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