Stress Distribution of Post–Core Applications in Maxillary Central Incisors

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ABSTRACT: The purpose of this study was to evaluate the stress distribution in a maxillary central incisor restored with various post–core applications.

The study used a three-dimensional finite element method. The tooth was assumed to be endodontically treated with a porcelain crown. Two different sizes of Flexi-post, Cera-post, and Composipost were compared for 200 N palatal and incisal loads.

It was determined that, purely from the point of view of strength considerations, core material was determined to be of greater importance than post material or size. Higher elastic moduli of the posts resulted in lower stresses throughout the tooth.

KEY WORDS: finite element analysis, post–core.

INTRODUCTION

Post and core applications are often utilized in the restoration of endodontically treated teeth [1–3]. Cast or prefabricated posts are

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generally used [4]. Prefabricated posts are made of a variety of metallic and nonmetallic materials. Recently, ceramic and carbon fiber composite posts have been introduced [5–9]. Depending on the requirements of the endodontic treatment straight, tapered, cylindrical, and threaded cylindrical prefabricated posts are utilized [10,11]. Prefabricated posts are always used together with a core material of either amalgam or composite resin [6,12,13]. Posts basically provide retention to the core that replaces lost coronal tooth structure [4,13–16]. Various researchers have reported the stress distribution [17–22], the influence of different post and core materials [22] and the effects of post size [23] on post retain crowns.

The aim of this study was to investigate the effect of different post and core materials on loading of the restored teeth by using a three-dimensional Finite Element Method. In addition, the effects of varying the application region of the load and the loading angle were also studied.

MATERIALS AND METHODS

This study analyzed the stress distribution in a maxillary central incisor. The prefabricated post and cores were modeled to an endodontically-treated tooth restored with a porcelain crown [22]. The mechanical effectiveness of a stainless steel (Flexi-post, EDS, S. Hackensack, N.J.), a zirconium ceramic (Cera-post, Brasseler, GmbH & Co, KG, Lemgo, Germany), and a carbon fiber-reinforced composite (Composipost, RTD, Technoparc-Esparé, Gavaniere, France) posts were compared. The core materials studied were lanthanide and titanium-reinforced composite Ti-Core (EDS) and Tetric Ceram (Ivoclar, AG/Vivident Ets, Schaan, Liechtenstein). In addition, the possible effects of loading regions were also compared by considering a 200 N load at the palatal region and at the incisal edge [22]. Increasing the load angle to the axis of the tooth increases the component of the load perpendicular to the tooth axis [24]. Therefore, the possible effects of load angle variation was also studied by considering the loading angles of 26° and 45° to the longitudinal axis of the tooth.

The study was conducted using a three-dimensional finite element method [22,25,26] and the ANSYS® software package (ANSYS Inc. Southpointe 275 Technology Drive, Canonsburg, PA). Results are presented by considering Von Mises criteria [24,27].

In a three-dimensional Finite Element Analysis, the system is divided into a large number of elements and each finite element is assigned a
predetermined number of nodes. Those elements are then connected at their nodes. The element stiffness matrix is formed by considering the force–displacement relations of the nodal displacements and the rotations of each element. These element matrices are then combined to give the global stiffness matrix. The utilization of the initial conditions, boundary conditions, and given loading characteristics yields the nodal displacements. The resulting strains are obtained from the strain–displacement relations, and the required tensile, compressive, and shearing stresses are found through the stress–strain relationships. Those values are further manipulated to obtain the resultant element stresses [28].

In this study, the geometry of the maxillary central incisor was adapted from Wheeler [29]. The constructed model had 294 elements and 420 nodes. The elements used were eight-node solid brick elements, which are well suited to three-dimensional analysis. Previous studies provide detailed information about the modeling process [22,25,26].

The following assumptions were made in terms of the properties of the dental materials used in the study: (a) The tooth under consideration was modeled as being composed of dentin, gutta-percha, post, core, and the porcelain crown. (b) The materials considered were homogeneous, isotropic, and linearly elastic. (c) The effects of the periodontal ligament and cementum were omitted because of their very small thicknesses. (d) The alveolar bone that supports the tooth was assumed to be rigid.

Table 1 presents the mechanical properties of the materials used in the study [22,26]. The post and core material properties were taken to be those supplied by the relevant manufacturers.

Upon loading a three-dimensional finite element model, three normal and three shearing stresses were obtained at each nodal point in the structure. The further analyses of evaluating the strength characteristics and possibility of structural failure are conducted through an appropriate failure criterion [24]. The selected failure criterion, depending on what it is aimed to provide, combines the effects of those normal and shearing stresses into a single, physically meaningful parameter and provide more sound ways of analysis [24,27].

Depending on the type of the material used and the loading characteristics, various criteria exist. This study was conducted by considering the three-dimensional Von Mises Criteria. It is given as [24,27]:

$$\sigma_e = \frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2}$$  \hspace{1cm} (1)
where $\sigma_1$, $\sigma_2$, $\sigma_3$ are known as principal stresses and $\sigma_e$ is the Von Mises stress. The principal stresses are normal stresses, acting on principal planes on which the shearing stresses are zero, and are calculated by using the existing six normal and shearing stress components $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{xz}$, and $\tau_{yz}$ [24,27].

**RESULTS**

The results are presented in terms of the Von Mises stress values. The possibility of failure was decided by the assumption that, a higher Von Mises stress value is a good indication of a greater chance of failure. Effects of different post types, different post diameters, different core materials, different loading angles, and loading regions were presented. In all the situations analyzed, the maximum Von Mises stress values occurred in the tooth elements at which the loading was applied.

**Effect of Different Post Types and Post Sizes**

Composite Tetric Ceram was selected as the core material, and the Cera-post, Composipost, and Flexi-post were modeled with 1.5 mm diameters. A 200 N load was applied at the palatal region making an angle of 26° with the tooth longitudinal axis. The maximum Von Mises stresses in the teeth were found to be 34.9 MPa for Cera-Post, 37.7 MPa for Composipost, and 34.8 MPa for Flexi-post. Flexi-post and Cera-post
values were smaller than the value obtained for Composipost; the former values were comparable. Furthermore, a different stress distribution was observed for Composipost than those of Cera-post and Flexi-post, where the former distributions were also comparable. A similar trend was observed when the posts were modeled with 2.0 mm diameter while keeping the parameters of the core material, the load, the loading region, and the loading angle same as those used for 1.5 mm posts. For the case of 2.0 mm diameter posts, the maximum Von Mises stresses in the teeth were found to be 33.5 MPa for Cera-Post, 36.8 MPa for Composipost, and 33.3 MPa for Flexi-post. Again the Flexi-post and Cera-post stress distributions and values were comparable with each other and the stress values were smaller than the Composipost value. A comparison with the results of 1.5 mm post applications, where except for the post size (diameter) all the other parameters were kept constant, indicated that the increasing diameter from 1.5 to 2.0 mm reduced the maximum Von Mises stresses approximately 4.3% for Flexi-post, 4.0% for Cera-post, and 2.38% for Composipost.

**Effect of Core Material**

A 2.0 mm diameter Flexi-post with 200 N and 26° palatal load was then modelled with the core material being Ti-Core. The maximum Von Mises stress in the tooth was found to be 30.1 MPa. A comparison with 2.0 mm diameter Flexi-post application having the same post size and loading characteristics but using Ti-Core instead of composite Tetric Ceram core resulted in an approximately 9.6% reduction in maximum Von Mises stress value. Cera-post and Composipost were also considered with 2.0 mm diameter, 200 N and 26° palatal load but with core materials of Ti-Core and Tetric Ceram. It was again determined that the utilization of Ti-Core caused a reduction in the Von Mises stress values. The reduction in the maximum Von Mises stress was approximately 9.4% for Cera-post and 8.8% for Composipost. All three posts were also compared for 1.5 mm diameter, 200 N and 26° palatal load. The reduction in the maximum Von Mises stress value was 9.5% for Flexi-post. That value was 9.7% for Cera-post and 9.3% for Composipost.

**Effect of Loading Angle**

The case with 2.0 mm diameter Flexi-post, Ti-Core, and 200 N palatal load was again considered and the loading angle was increased from 26°
to 45° with the longitudinal axis of the tooth. The maximum Von Mises stress in the tooth was determined to be 41.5 MPa. The increase in the loading angle from 26° to 45° resulted in an increase of approximately 38% in tooth stress. If only the core material is changed to composite Tetric ceram while keeping the post size, load, and the loading region of the application as constants, the increase was approximately 33%. For the case where the size of the Flexi-post was changed to 1.5 mm and 200 N palatal load was again applied to the Ti-Core restored tooth, the increase in the maximum Von Mises stress value was approximately 35%.

**Effect of Loading Region**

Load applied along the incisal edge instead of the palatal region on a 1.5 mm diameter Cera-post, composite Tetric Ceram core with 200 N and 26° loading resulted in a maximum Von Mises tooth stress of 97.2 MPa in the tooth at the incisal edge. Comparison with the case of 1.5 mm diameter Cera-post application, in which only the loading region was changed from palatal to incisal, yielded that not only different stress values but the stress distributions were also totally different. The core material of 1.5 mm diameter Cera-post, was then changed to Ti-Core and 200 N, 26° incisal loading was applied. The maximum Von Mises tooth stress increased to 88.3 MPa as compared to 31.5 MPa of palatal loading and the maximum stress again occurred at the incisal edge.

In order to highlight the effects of each constituent stress of the resultant Von Mises stress, one case was selected and the resulting Von Mises and all six constituent stress distributions are presented. Figures 1–7 give the Von Mises stress distribution and the corresponding normal and shear stress distributions of 2.0 mm Flexi-post and Ti-Core application in which the 200 N load was applied at 26° to the longitudinal axis. The values in the upper and lower right hand side of each pattern indicate the range covered by that unique pattern. The maximum and minimum values of each pattern in each figure are different. The inevitable differences in the limiting values of the ranges stem from the fact that, all FEM package programs automatically calculate and present the values applicable to the individual situation considered. In the figures, in order to highlight the internal element stress distributions, some elements on the outer face of the buccal side were intentionally removed. This removing process was conducted after the analysis had been completed and during the postprocessing phase.
**Figure 1.** Flexi-post Von Mises distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).

**Figure 2.** Flexi-post $\sigma_x$ distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).
Figure 3. Flexi-post $\sigma_y$ distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).

Figure 4. Flexi-post $\sigma_z$ distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).
Figure 5. Flexi-post $\tau_{xy}$ distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).

Figure 6. Flexi-post $\tau_{zx}$ distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).
Figure 1 gives the Von Mises stress distribution and Figures 2–7 represent the \( \sigma_x \), \( \sigma_y \), \( \sigma_z \), \( \tau_{xy} \), \( \tau_{xz} \), and \( \tau_{yz} \) distributions in turn. It is apparent that each stress pattern gave different stress values and distributions than corresponding Von Mises distribution. Furthermore in the figures, which illustrate the constituent normal and shearing stresses of the resultant Von Mises stress, some values are negative and some values are positive. In terms of the normal stresses \( \sigma \), positive \( \sigma \) values indicate that the corresponding elements are subjected to tensile stresses; negative \( \sigma \) indicate that the related elements are subjected to compressive stresses \([24,27]\). In terms of shearing stress, \( \tau \), patterns, since the \( \tau \) value is actually related to the amount of angular deformation in an otherwise right-angled prism, being positive or negative only indicate which angles are distorted; however, overall distortion characteristics remain the same \([24,27]\). Figures 2–7 demonstrate that \( \sigma_x \), \( \sigma_y \), \( \sigma_z \), \( \tau_{xy} \), \( \tau_{xz} \), and \( \tau_{yz} \) may have any sign, any pattern, and any location for the maximum values. Table 2 gives the maximum values in the tooth as well as in the post for all the stresses presented in Figures 1–7. As described earlier, the Von Mises value contains contributions from each of those components and reflects their total

Figure 7. Flexi-post \( \tau_{yz} \) distribution. (2.0 mm diameter, Ti-Core, 200 N palatal load, 26° loading angle).
effect. Hence it is apparent that, an estimation based only on one of these constituent values will provide far from a meaningful answer.

**DISCUSSION**

The materials considered in this study were homogeneous, isotropic, and linearly elastic. Although an exact analysis requires them to be treated in their actual form as being anisotropic materials, the contemporary approach in dental finite element studies is generally to assume those materials as being isotropic. This approach was followed in the current study as well. Due to the modeling difficulties, the surface threads of the posts were not modeled neither were the split-shank features of the Flexi-post. Furthermore, posts and cores were modeled as if they were fused to the adjacent materials which may not be the case with the usage of resins and cements. Nevertheless, the results were determined as the means of qualitative comparison.

Within the aforementioned limitations of this study, the results showed that among the parameters considered, core material was the most important parameter in post–core applications. In all the cases simulated where the post size, load magnitude, loading angle, and the loading location were kept constant, those containing Ti-Core outperformed those with composite Tetric-Ceram core and resulted in lower stresses in the entire tooth. This is related to the fact that Ti-Core are stiffer as compared to the Tetric-Ceram and the utilization of Ti-Core resulted in a stronger restored tooth.

The effects of changing the sizes of the post diameters resulted in some minor differences in the developed stress values, but were not found to be as significant as the core material effects.

The loading angle was determined to be an important parameter, which should be taken into consideration in an analysis and evaluation.
The increase in loading angle profoundly affected and increased the stress values in the cases considered. This drastic increase stemmed from the fact that increasing the component of the load perpendicular to the longitudinal axis of the tooth resulted in the development of large shearing stresses [24,27]. These large shearing stresses consequently caused larger Von Mises stress to develop.

The loading area was also found to be a key factor. The maximum stress always occurred in the region where the load was applied. Different application regions resulted in different stress distributions. With incisal loading, the stresses were locally and drastically increased toward the incisal side.

The assumption about the rigidity of the tooth bone, although might be considered to be a limitation in the study, was accepted on the grounds that the omitted deformability of the bone would lead to higher stresses in the root of the tooth which in turn would enhance the loading scenario.

The results of the study gives only a qualitative comparison between the effects of the parameters studied. In terms of the quantitative values, the results are only exact within the assumptions and limitations of the methods and programs used. However, the determined features and trends are always valid results.

Within the limitations and assumptions of this study it was determined that the core material characteristics were the most important parameter in prefabricated post and core applications. The mechanical characteristics of prefabricated posts also proved to be a significant factor in terms of the strength of the treated tooth. It was shown that the higher the elastic modulus of the posts, the lower the resultant stresses. The dimensions of the posts, on the other hand, did not yield considerable effects on the developed stresses. Other factors, which were found to be important for a comprehensive study, are the effects of the loading angle and the loading region.

The evaluation of stress distributions should be based on proper failure criteria, and those criteria should contain information related to all the existing stress components. An evaluation based on a single stress component cannot properly reflect the structural behavior and may cause misinterpretation and consequently misunderstanding.

REFERENCES


**BIOGRAPHY**

**Prof. Dr. Sis Darendeliler Yaman**

Prof. Dr. Sis Darendeliler Yaman obtained her PhD from Gazi University, Faculty of Dentistry, Department of Endodontics, Ankara, Turkey in 1988. Her thesis was “Study of Various Preparation Techniques and Pin Utilizations on Maxillary Central Incisors for the
Determination of Optimum Restoration Type by using Three-dimensional Finite Element Method and Stress Analysis”. Since 1984 she was working in the Department of Endodontics of Gazi University, Faculty of Dentistry. She was with McGill University, Montreal in 1998 during her sabbatical period. Since January 2003, she is a full professor.

Her main fields of interest are the finite element modeling and analysis of tooth structures, post and core applications and rotary root canal instruments.