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Evaluation of Different Post Systems: Finite Element Method

Evaluación de Diferentes Sistemas de Postes: Método de Elementos Finitos

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ABSTRACT: The aim of this study was to analyse the stress distribution in maxillary canines restored with different post systems and definitive crowns. The models of restored teeth with glass fiber, quartz fiber, titanium posts and crowns were developed with the Finite Element Method (FEM) in order to analyse their stress distribution when subjected to external compressive loads. Von Mises stress distribution values, which are considered potential fracture indicator, showed that natural tooth and glass fiber post-restored tooth, under a load of 550 N, presented similar stress values. The behaviour of a glass fiber post-restored tooth is similar to that of a natural tooth, since it produces an appropriate stress distribution, and in this investigation, they have the best biomechanical performance.

KEY WORDS: glass fiber post, quartz fiber post, stress distribution, finite element method.

INTRODUCTION

Restorative methods for pulpless teeth with post-core systems have been widely investigated with the aim of achieving long-term promising prognosis (Hayashi *et al.,* 2006).

Some of the reasons for the failure of restorations for many years have been root fracture, microleakage, decementation, and metal corrosion in clinical practice (Reeh *et al.,* 1989). Some of the fractures affecting post restorations could be related to concentration of forces (Sorrentino *et al.,* 2007).

In recent years, various types of fiber posts have been introduced and excellent long term clinical performances of pulpless teeth restored with a combination of fiber posts and resin in conjunction with dentin bonding systems were reported (Li *et al*., 2006; Pierrisnard *et al*., 2002; Holmes *et al*., 1996; Zienkiewics, 1986; Torsavul *et al.*, 2006).

As is well-known, loads are produced during all the functions of the oral cavity. The average maximum bite force in human was measured at 911 N (Newtons) in the molar region and at 569 N in the incisal region (Craig, 1980).These forces applied to the dental restoration materials are a potencial cause of deformations due to the dimensional changes (lengths, volumes) they produce in most of the cases (Craig).

Recent Finite Element Analyses presented the different stress distributions in pulpless teeth restored with different post core systems (Zarone *et al*., 2006; Eskitas¸cıog˘lu *et al.*, 2002). Searching the literature, the majority of papers based on FE modelling of stress distributon in post and crown restored teeth is based on two dimensional (2D) models (Schillinburg & Kessler, 1982; Zarone *et al*.) and only few on three dimensional (3D) ones (Toksavul *et al*.; Mannocci *et al.,* 1999; Malferrari *et al.*, 2003).

For the purpose of making a comparison between the behaviours of natural healthy teeth and restored teeth subjected to different loads, the FEM (Finite Element Method) was applied in this study.

Through the FEM, it is possible to design a mathematical 3D model that simulates the geometry and load conditions of the structure under analysis. It facilitates the evaluation of deformation and stress behaviours at some point of the model and it can also

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determine high deformation or stress concentration areas (Pierrisnard *et al.*).

The aim of this study was, by using the finite element method, to make an analysis of stress distribution under different load levels applied to healthy maxillary canines and to others restored with different post systems and definitive crowns.

MATERIAL AND METHOD

The methodology developed for this study was based on the creation of finite element models. Through the implementation of FEM, different load values were applied and stress distribution was observed in each model (Li *et al.*; Pierrisnard *et al*.; De Jager *et al*., 2006; Pegoretti *et al*., 2002).

Four finite element models were predesigned with CATIA, a CAD software. Three-dimensional solid geometric models were generated from healthy maxillary canines and canines with alternatives of restorative treatment (Table I). These treatments included a titanium post, a glass fiber post and a quartz fiber post, all of them with resin cores and ceramic crowns (Fig.1) (feldspathic all-ceramic crown).

Through the import of the CATIA geometry into a mesh-generating program called ABAQUS/CAE, Version 6.4 (USA, 2003), four finite element models and three submodels were built. Tetrahedrons, thus, had to be formed from 4-node solid elements and hexaedrons from 8-node solid elements.

The restorative material properties like density, elastic modulus, plastic behaviour curve, and the characteristics of the forces to apply were simulated as well as the components of the finite element models and submodels: dentine, enamel, cement, feldespathic-ceramic crown, post, core and cancellous bone support (table II). The gutta-percha and the periodontal ligament were not included in the models because they would not influence the results significantly

In relation to the comparative nature of the structural evaluations, the following arbitrary commercially available post geometry was used:

· 1.5 mm diameter.
· 10 mm insertion depth (about two thirds of the root length).
· 3 mm coronal tissue over the cement-enamel junction (CEJ).
· 1.5 mm-thick vestibular and proximal surface.
· 1.2 mm-thick palatal surface.
· 2 mm-thick incisal surface.
· 7 mm length abutments.

Other characteristics to introduce are the Poisson's ratios which define the relation between deformations of the material in the longitudinal direction of the applied load and also in transversal directions (Mannocci *et al*.).

Some of the restorative materials used in this study were isotropic and others anisotropic. Table II shows the elastic modulus and the Poisson's ratio for isotropic materials. Table III shows the values of the independent elastic constants, i.e., the elastic modulus in longitudinal and transverse directions, and the Poisson's ratio for anisotropic materials. For example, the titanium are assumed to be an isotropic material because their properties are measured in any direction and the results obtained are identical (Malferrari *et al.,* 2003). In the case of glass fiber post, their properties can also be measured, but the results obtained vary according to the direction in which they are measured or observed.

Table I. Experimental models.

Material/ component	Young Moduli (Mpa)	Poisson's coefficient
Dentine	18000	0.31
Bone	1370	0.30
Ceramic crown	69000	0.28
Titanium post	103400	0.33
Resin	18530	0.28
Enamel	41000	0.30
Cement	2700	0.30

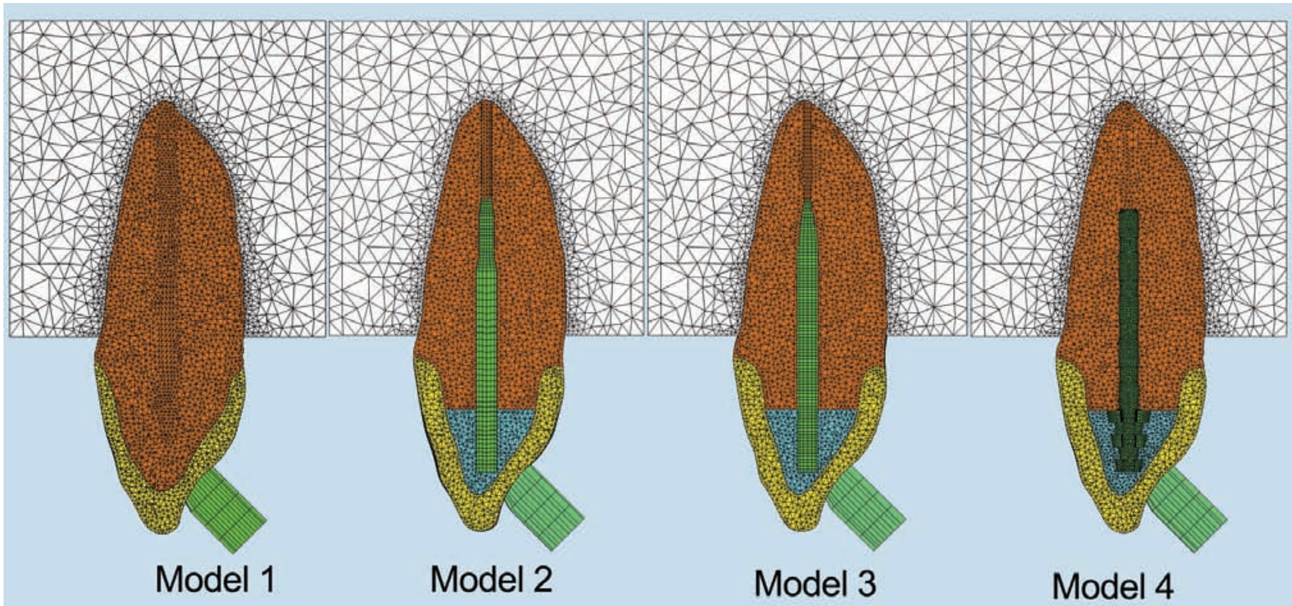

Fig. 1. Finite element models. Note the reproduction of all its components including the alveolar bone. Model 1 : natural teeth (maxillary canine). Model 2: finite element model of teeth restored with quartz fiber post. Model 3: a finite element model of teeth restored with glass fiber post. Model 4: finite element model of teeth restored with titanium posts; all of them have porcelain crowns.

Loading conditions. In order to apply the loads over the canines, a 3 mm cylinder was used. The compressive loads were applied at 45 degrees with respect to its longitudinal axis, at the level of the cingulum (middle third of the palatal surface) simulating the load conditions in the oral cavity.

A progressive and compressive non-destructive load was initially applied over the teeth in order to detach the crown from the core of restorations but without producing other visible damages. In this way, we observed the changes in the crown margin of the analysed models.

The submodel technique was implemented and three submodels were developed with a greater number of finite elements, namely with a more dense mesh. The reasons for the application of this technique were the analysis of specific areas of the models, and the observation of changes produced when a non-destructive load was applied in that specific area: the crown margin (Fig. 2).A second progressive and compressive load was applied to all the finite element models (both healthy and restored ones) until the dentine fracture occured.

The analysis of the results was made considering Von Mises criterion for three dimensional stresses. Von Mises stresses indicate the presence of localized high stress areas, but it is not possible to determine the nature of such stresses (traction or compression). (De Jager *et al.*). A selection of pure traction stresses (S33) was made, like in other studies (Ko *et al.*, 1992; Barjau-Escribano *et al.*, 2006), because the fracture of dentine could be due to traction, so, these stresses could be also responsible for cracks.

Table II. Elastic properties of the isotropic materials.

Models	Crown	Core	Post/cement
1	Natural tooth	Natural tooth	
2	Feldspathic ceramics	Enforce core(resin core)	Quartz fiber post (BISCO)/ C&B resin cement (BISCO)
3	Feldspathic ceramics	Enforce core(resin core)	Glass fiber post (GLASSIX,NORDIN)/ C&B resin cement (BISCO)
4	Feldspathic ceramics	Enforce core(resin core)	Titanium post (KOMET)/ C&B resin cement (BISCO)

Table III. Anisotropic properties of the posts.

Elastic moduli (E: Mpa), Shear moduli (G) and Poisson's ratio(n)	Post Material	
	Glass fiber post	Quartz fiber post
E11: longitudinal modulus of elasticity (MPa)	40000	48200
E22: longitudinal modulus of elasticity (MPa)	11000	8200
E33: longitudinal modulus of elasticity (MPa)	11000	8200
G12: cross-sectional modulus of elasticity(MPa)	4200	3000
G13: cross-sectional modulus of elasticity (MPa)	4200	3000
G23: cross-sectional modulus of elasticity (MPa)	4100	1300
n12: Poisson's coefficient	0.26	0.32
n23: Posson's coefficient	0.26	0.32
n13: Poisson's coefficient	0.32	0.4

RESULTS

Figure 3 (a, b, c, d) shows the stress (S33) distribution in every finite element model analysed. After the load application in the fiber post systems, a higher stress (S33) concentration was detected at the level of the crown cervical margin, almost at the junction with the alveolar bone.

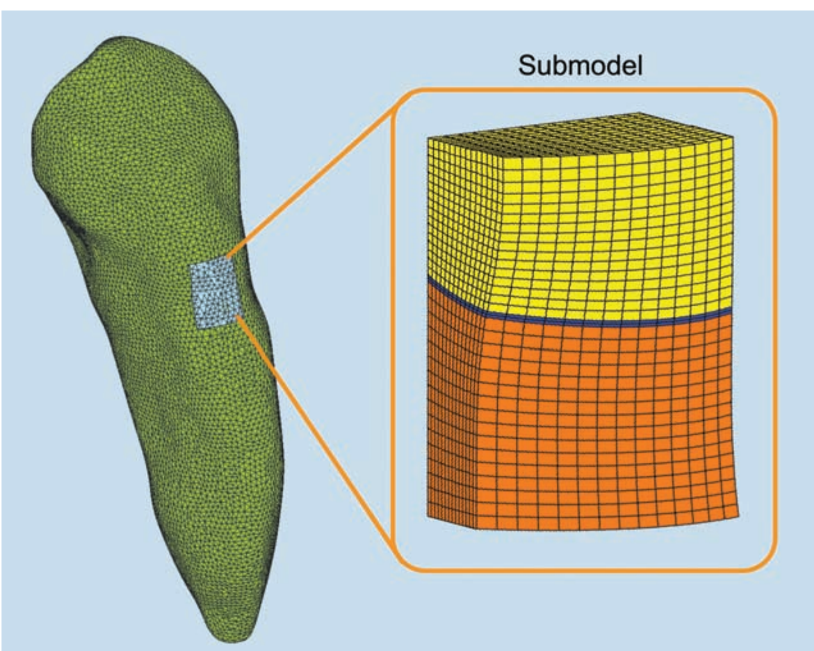

Fig. 2. Submodel of crown margin.

Figure 4 shows the stress concentration inside the posts as a result of a compressive load greater than 550 N applied to posts. The titanium post absorbed a greater stress while the glass fiber post showed low stress concentration.

Figure 5 shows the load levels applied on the finite element models in order to generate restoration displacement and detachment of the crown.Fiber post-restored teeth required a greater load (490 N) compared to metal post-restored teeth (420 N).

Figure 6 shows the Von Mises stress distribution values, which are considered potential fracture indicators. Model 1 (natural tooth) and model 3 (glass fiber post-

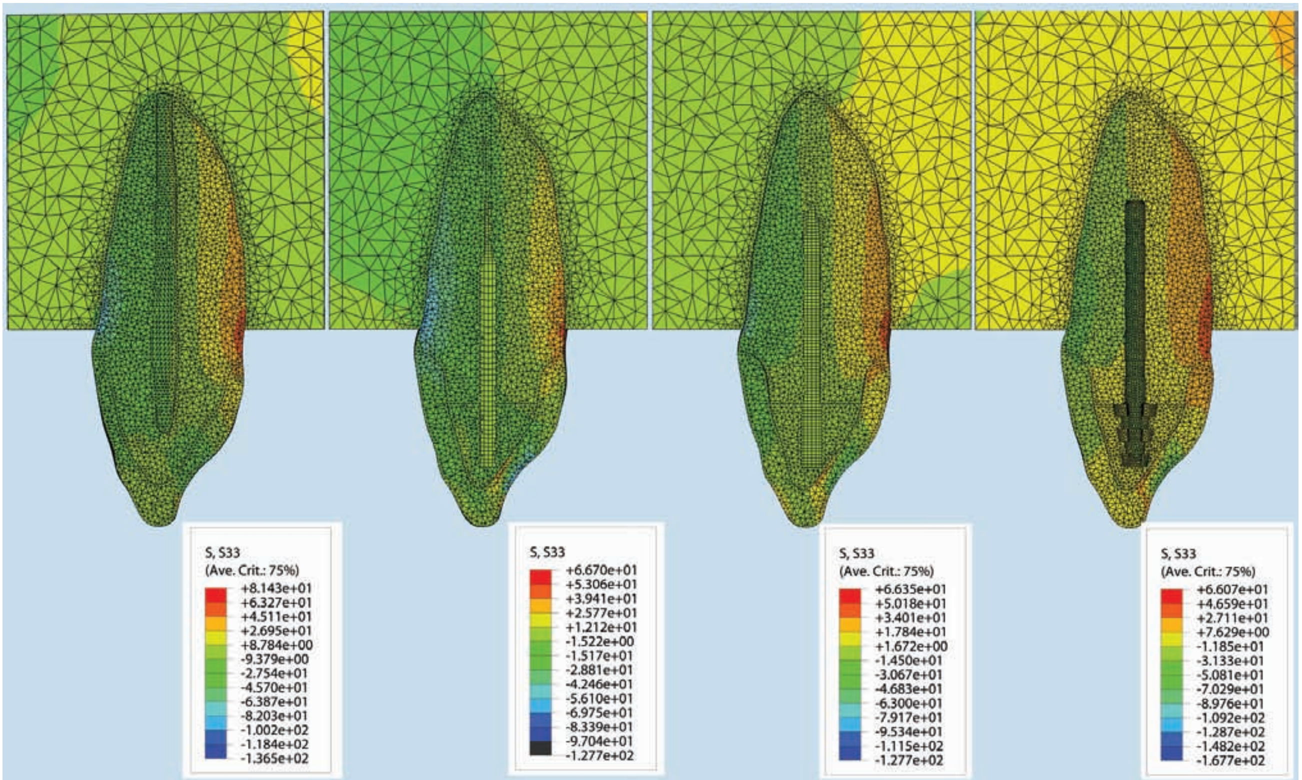

Fig. 3. Stress (S33) distribution of model 3a (natural teeth), model 3b (quartz fiber post), model 3c (glass fiber post), and model 3d (titanium post).

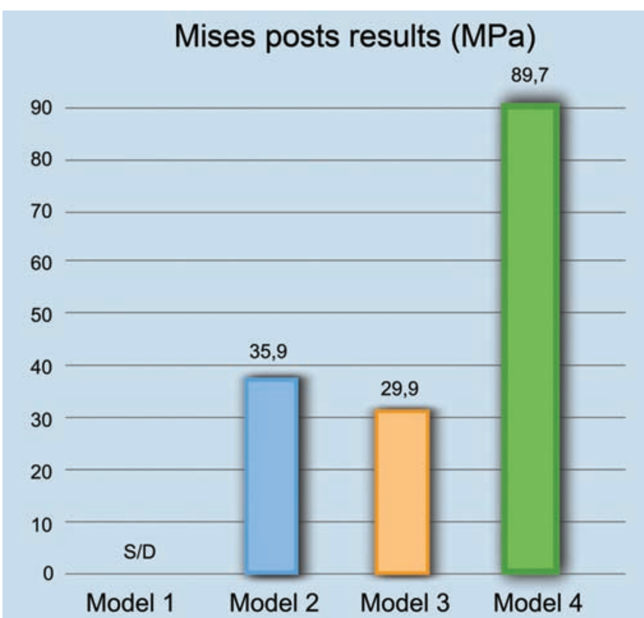

Fig. 4. Titanium posts absorb more stresses than other posts. They do not dissipate them uniformly over the other system components (cement-dentine).

restored tooth) under a load of 550 N showed similar stress values.

The static compressive force that was applied to overcome the fracture resistance of the restored teeth, produced stresses of vestibular compression and palatal traction at the junction with the alveolar bone. When the load was applied, vestibular compression reached values distant from a 297 MPa compressive strength of dentine. This indicated that samples were not fractured by compression, but by palatal traction that overcome a 85 MPa tensile strenght of healthy dentine. Therefore, the palatal traction was responsible for initiating the dentine fracture.

Figure 7 shows a comparison between the stress (S33) distribution values in finite element models. Stresses S33 were traction stresses detected in the palatine area of the tooth at the cervical level.

Stresses in the natural tooth and in the glass fiber post model were similar and lower than in the other two models. The tensile strength measured in the dentin was 85 Mpa, and similar values were obtained in model 2 (quartz fiber posts) and model 4 (titanium posts). Therefore, it is deduced that quartz fiber and titanium post restored teeth are fractured earlier than natural teeth and glass fiber restored teeth.

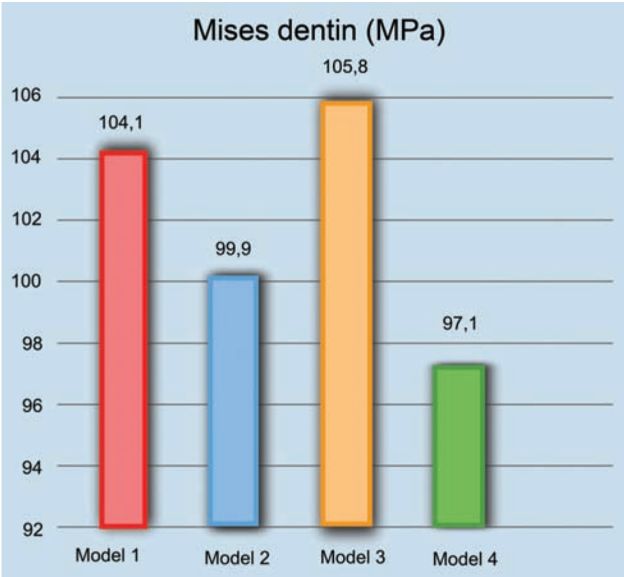

Fig. 5. The Von Mises stresses, potential fracture indicators, under a load of 550 N show similar values for model 1 and model 3.

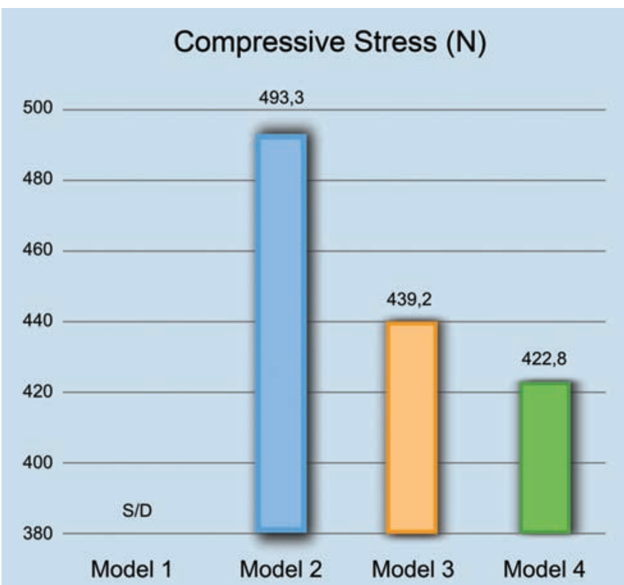

Fig. 6. FEM shows that a load of 493.3 N is needed to overcome the adhesive resistance of the cement joining the crown to the tooth in the models with quartz fiber posts; a load of 439.2 N in glass fiber posts, and a load of 422.8 N in titanium posts, without causing visible changes.

DISCUSSION

Every structural and design analysis of the finite element models requires full knowledge not only of the forces to be applied, but also of the mechanical properties

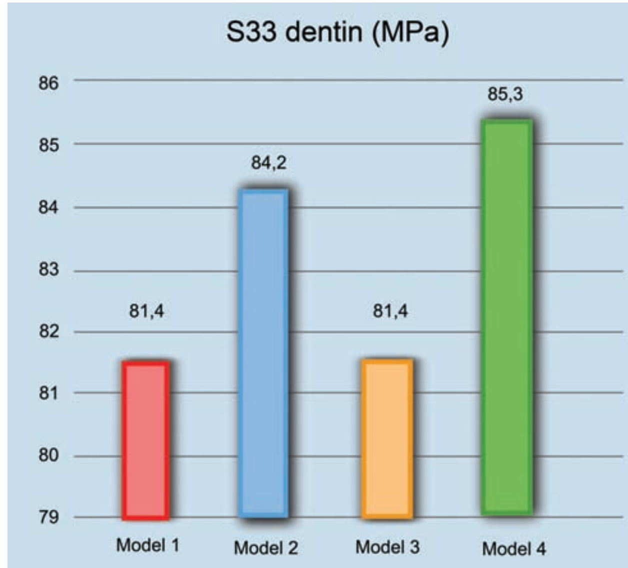

Fig. 7. Stresses S33 are traction stresses that occur in the palatal cervical area. They are similar in the natural tooth and in the glass fiber post, but lower in the other two models.

of the materials to be subjected to those forces. In oral rehabilitation, this is difficult because of the complex loads that are produced in the oral cavity, as well as the oral tissue response (Toksavul *et al.*).

According to the results of the present study, fiber post systems produced stress concentration at the level of the crown cervical margin, almost at the junction with the alveolar bone (CEJ). This may be due to the relatively lower Young's modulus of the material of the core, compared to that of the surrounding materials, for example, porcelain used in the crown. Since metal posts have a stiffness similar to that of the crown material, the cervical area showed less stress (Toksavul *et al.*).

As regards the stress concentration generated within posts under a compressive load of 550 N, this study proved that not only a greater stress area exists at the junction of the middle and apical third of the post and tooth producing fractures at that level, but also the titanium post absorbs the greatest stress.

Moreover, the lowest stress concentration was proved in the glass fiber post model, which may result in failures in the interface (post-cement-dentine), as stated by other studies (Toksavul *et al.*; Eskitas¸cıog˘lu *et al.*).

Eraslan *et al*. (2009) studied and compared the stress distribution of dentine and the restoration-tooth complex, using the FEM. Three-dimensional finite element simulating an endodontically treated maxillary central incisor restored with an all-ceramic crown were prepared. At rigid zirconium oxide ceramic post system, stress levels, both at dentine wall and within the post, were higher than that of fiber posts. As can be seen, the results of those recent studies coincide with the observations of this work.

In this study, the applied static compressive force of 550 N produced vestibular compression and palatal traction stresses at the level of the junction with the alveolar bone. The vestibular compression was not sufficient to overcome the fracture resistance of samples. In this regard, it is concluded that palatal traction generated in the FEM models was responsible for the tooth fracture at that level.

The behaviour of a fiber post restored tooth was similar to that of a natural tooth since it produces an homogeneus stress distribution. On the contrary, the metal post system concentrated stresses that not only affected the interface post-cement, but also produced the tooth fracture.

Pegoretti *et al*. used the FEM in a study and observed that glass fiber posts restored tooth showed a low stress concentration inside the root, in comparison with metal and carbon fiber posts restored tooth (Pegoretti *et al*.). The greater the difference is between the Young's modulus of the dentine and the posts, the less homogenous is the stress distribution on the dental surface, and thus stress concentration areas are produced on the dentine.

Through the finite element analysis, Lanza *et al.* compared carbon, quartz and steel posts (Lanza *et al.*), appling a 10 N force on 125 maxillary incisors. It turned out that the steel post (E= 200 GPa) transmitted most of the stress to the root, the quartz post transmitted the least stress, and the carbon post was close to the quartz post. Their results were similar to those of this study.

Other authors like Adanir *et al*. (2008), in a recent investigation evaluated the effects of different post materials on the stress distribution in an endodontically treated maxillary incisor using a three-dimensional finite element model of a maxillary central incisor that was modified according to five posts with different physical properties consisting of stainless steel, titanium, gold alloy, glass fiber (Snowpost), and carbon fiber (Composipost). Under different loading conditions, posts made of Metallic posts showed greater stress concentration at the post-dentine interface than fiber posts. However, fiber posts produced the highest stress values at the level of one-third of the cervical area of the crown. Their conclusion was that the physical characteristics of posts were important on stress distributions. Glass fiber post revealed more balanced stress distribution under compressive loads.

The finite element analysis method is a technique that uses computer-based simulations and that allows the calculation of stress distribution on complex structures. The validity of the study depends on the approximation to the clinical reality of the observed model. Several authors through in vitro experiments have proved the validity of the finite element analysis as the approximate procedure for predicting the biomechanical and clinical behaviour of post-restored teeth (Ko *et al*.; Eraslan *et al*.).

CONCLUSIONS

Within the limitation of this study we concluded that:

· Quartz fiber post-restored models require a greater compressive load to generate minimum displacements, to detach crowns, and more specifically, to lead to the restoration failure.
· Posts affect the load distribution in the dentine, a fact that is directly related to their modulus of elasticity.
· The method proved that the behaviour of fiber posts is similar to that of natural teeth because the stress distribution produced over their components is uniform, unlike systems restored with metal posts.
· The dentine fracture initiation load in every analysed model was determined to be 550 N.
· The behaviour of a glass fiber post-restored tooth is similar to that of a natural tooth, since it produces an appropriate stress distribution, and in this investigation, they have the best biomechanical performance.

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RESUMEN: El próposito de este estudio fue analizar la distribución de tensiones en caninos superiores restaurados con diferentes sistemas de postes y coronas definitivas. Los modelos de dientes restaurados con postes defibra de vidrio, fibra de cuarzo y titanio y coronas fueron desarrollados con el Método de Elementos Finitos (FEM) para analizar la distribución de tensiones cuando fueron sometidos a cargas compresivas externas. Valores de distribución de stress de Von Mises, que fueron considerados como potenciales indicadores de fracturas, mostraron que los dientes naturales, y los dientes resturados con postes de fibra de vidrio, bajo una carga compresiva de 550N, presentaron valores semejantes. El comportamiento de los dientes restaurados con postes de fibra de vidrio fue similar al de los dientes naturales, mostrando una homogénea y más uniforme distribución del stress, y en esta investigación, presentaron una mejor performance biomecánica.

PALABRAS CLAVE: Poste de fibra de vidrio, poste de fibra de cuarzo, distribución de tensiones, método de elementos finitos.

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