QUALITATIVE EVALUATION OF THREE-DIMENSIONAL STRESS FIELDS DEVELOPED IN ENDODONTICALLY RESTORED SUPERIOR INCISIVE TEETH USING THE FINITE ELEMENT METHOD

FREITAS, VALÉRIA DA PENHA, **valpfreitas@yahoo.com.br**
Universidade Federal do Espírito Santo, Vitória-ES/Brasil
GUERRA, SELVA MARIA GONÇALVES, **selvaguerra@terra.com.br**
Universidade Federal do Espírito Santo, Vitória-ES/Brasil
RANGEL, ANGELO GIL PEZZINO, **gilrang@gmail.com**
Universidade Federal do Espírito Santo, Vitória-ES/Brasil
LAS CASAS, ESTEVAM BARBOSA, **estevam@dees.ufmg.br**
Universidade Federal de Minas Gerais, Belo Horizonte-MG/Brasil
DUTRA, ÍTALO GUSTAVO MARTINS RIBEIRO, italo@dees.ufmg.br
Universidade Federal de Minas Gerais, Belo Horizonte-MG/Brasil

Abstract. *Strength of materials considerations have been considered relevant factors affecting the reconstruction of destroyed dental elements. Restoring materials and teeth are subjected to mechanical forces raised by the masticatory cycle. Hence, it becomes fundamental to know the mechanical behavior of different restoration systems previous to its application. For the restoration of endodontically treated teeth presenting structural loss, post and core systems are commonly used. They are made of both metallic and non metallic materials of different size and forms. Even though there are alternative restoration techniques used to restore the dental element, failures can occur in the tooth itself or in the whole system. Thus, the decision leading to the clinical indication of a post and core system can profit from a previous analysis of tooth's mechanical behavior. In this paper, four three dimensional finite element models of a maxillary central incisor tooth undergoing occlusal forces simulate: (i) a sane tooth; (ii) an endodontically treated tooth restored with a gold cast metallic post and core; (iii) an endodontically treated tooth restored with a glass fiber post and core; and (iv) an endodontically treated tooth restored using a composite resin core with a glass fiber post. The superior maxillary bone where the tooth model is indented is also considered. A ceramic crown is applied to the restored teeth models, so that the dentistry clinical routine can be simulated. The finite element result shows that there occurs a higher stress in the vestibular and lingual surfaces in the cervical sections of the sane model. Higher stress level is developed in the metallic post, while reduced stresses are found in the cervical section. A better stress distribution shows up in models for which fiberglass posts were used, whereas stresses in the cervical section are similar to the ones found in the metallic post and core model. Results indicated that the placement of a post changes the pattern of stress levels along the wall of the radicular canal when compared to the sane tooth behavior.*

Keywords*: endodontically restored teeth, stress distribution, finite elements.*

1. INTRODUCTION

In Dentistry, endodontic procedures are frequently made in pulpal altered teeth and in teeth in which structural losses due to cavities or fracture occurred. For restoring endodontically treated teeth, post and core systems are frequently used to help aesthetical and functional recovery (Albuquerque, 1999). There are systems consisting in cast metallic posts and core systems manufactured in dental prostheses laboratories through a casting pattern and that are obtained by molding the patient´s radicular canal. Besides those systems, there exist fabricated posts which are produced and commercialized out of metallic and non metallic materials (Duret et al, 1996). Fabricated posts are cemented inside the radicular canal and are externally lined with a restoring material in order to build up the core, which is the system´s coronal portion which offers retention to the prosthetics crown. Core can be manufactured out of direct restoring materials, as composite resins, amalgam and glass ionomers. Presently, there are commercial pre-fabricated core which can be cemented over the post, since they are manufactured with a receptacle which can be assembled to the post´s external wall.

Even though there are a variety of systems used for the reconstruction of structurally damaged teeth, failure of the tooth itself, or of the restoration material itself can occur. Literature shows many studies in which resistance to fracture and the stress distribution in restored teeth are analyzed using different restoring systems. One of the most important aspects in the stress distribution in dental remainings has been considered the modulus of elasticity of restoring materials. According to Yaman e Thorsteinsson (1992), radicular fracture occurs when stresses slightly exceed tooth strength. Assif et al. (1993) stated that the large difference in the modulus of elasticity of the metallic post and dentin result in a high stress gradient at the tooth´s root and, consequently, in a catastrophic failure due to fracture of that tooth´s root. For this reason, Duret et al. (1996) have stated that restoring materials and dentin should present moduli of elasticity close to one another.

In addition to *in vitro* tests made to analyze fracture strength of the tooth-restoration set, some studies were performed in which photoelasticity experimental techniques and computational methods, such as the Finite Element

Method, were used. They have been applied mainly to determine the stress distribution in sane and restored teeth when submitted to masticatory loads only. The application of computational analysis in Dentistry has allowed low research costs and to understand tooth´s mechanical behavior in situations where clinical procedures would be physically impossible, or ethical procedures would be easily violated.

The development of innovative research and new materials used in the manufacturing of dental products has led to the evolution of new post and core systems. Among the fabricated systems commercially available there exists the fiberglass fabricated core system, which has been developed based on the anatomic shape of anterior and premolar teeth and offered in different sizes. According to its manufacturer, this material shows higher mechanical strength and a modulus of elasticity close to the dentin´s. However, it remains unknown clinical and laboratorial test results of endodontically restored teeth using this system.

The Finite Element Method is hereby used as a tool to qualitatively analyze the stress distribution in a three-dimensional mathematical tooth model for a sane maxillary central incisor tooth and in three other tooth models in which maxillary central incisors are restored with different post and core systems. A three-dimensional model developed by Albuquerque (1999) was enhanced to improve periodontal ligament behavior and supporting force distribution.

2. GEOMETRIC AND FINITE ELEMENT MODELS

2.1. Geometric modeling

One of the advantages of using computational methods is reducing costs, while very closely simulating the original material and environmental conditions in the computer. Nowadays, the Finite Element Method has been soundly established as a tool to investigate the physical behavior of systems without having to build up real models which are expensive, in general, or even physically unfeasible. It is also possible to change specimens´ dimensions and materials quite easily. Specific applications of the method, as in Orthopedics and Dentistry present the enormous advantage of simulating the behavior of bones and teeth without the need of using actual pieces. After having the computational model validated by extensive simulation and tests, real material can be spared for nobler applications and time usually consumed for approving research in Biology ethical commissions saved. However, analyses need the collaboration of a specialist in orthopedics, or a dentist with sufficient knowledge and the expertise to understand the biological implications of the application of loads and the response of organic tissues in the presence of prosthesis.

To carry out the present investigation, a three dimensional geometric model of a maxillary central incisor tooth developed by the Laboratório de Mecânica Computacional, from Escola de Engenharia at UFMG (Albuquerque, 1999) was used. The model was the basis to generate the four different configuration models used hereby. Improvements were then introduced in the support conditions of original model with the definition of a periodontal ligament between the tooth and the bone surrounding its root, allowing for small movements of tooth and helping in the distribution of the considerable masticatory forces (Zhang, 2001). Facial and lingual cortical bone dimensions were redefined to better represent the tooth´s actual position in skull, according to Katranji et al. (2007). Figure 1 shows Model 1, the geometric model of a maxillary central incisor sane tooth displaying enamel, dentin and pulp, as well as the skull supporting structure (bone and periodontal ligament).

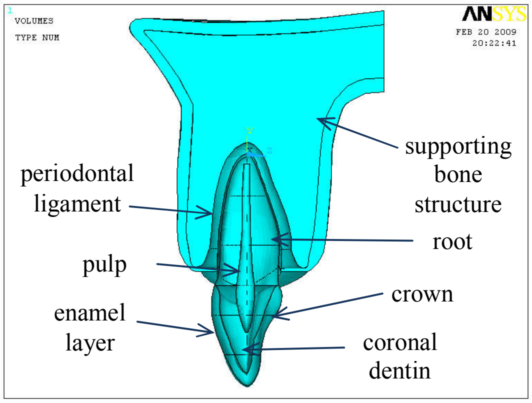

Figure 1. Geometric model of the maxillary central incisor sane tooth and its supporting structure.

From this geometrical model, three other geometrical models of an endodontically treated maxillary central incisor tooth were created. The three of them present a 4 mm gutta-percha apical sealing, a ceramic whole crown and each one have a different post and core system. The first one has a metallic post and core in gold which will from now on be called Model 2; the second one, Model 3, was modeled with a fiberglass post and core system; and the last one, Model 4, had a fiberglass post with the composite resin core. A summary of these models is presented in Tab. 1.

Table 1 – Summary of tooth models used in analyses.

Model #	**Description**			
	Apical sealing	**Crown**	**Post**	**Core**
1	Sane tooth			
2	4 mm gutta-percha	Ceramic	Gold (metallic)	Gold (metallic)
3	“ “	“	Fiberglass	Fiberglass
4	“ “	“	Fiberglass	Composite

Dimensions of the post and core systems were kept the same in the three endodontically treated teeth. Fiberglass and metallic posts were modeled using dimensions of a commercial product (Reforpost® nº. 3, Angelus, Ind. de Produtos Odontológicos, PR-Brasil) as reference, as shown in Fig. 2. They are slightly conic but their dovetail like retaining profile was neglected, since the system anatomic shape was not taken into consideration.

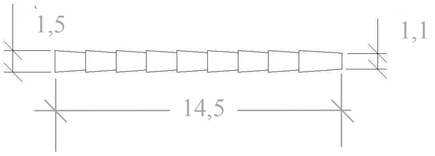

Figure 2. Dimensions of the Reforpost ® No. 3 post used in as reference in modeling the endodontically treated teeth.

Ceramic crown in endodontically treated Models 2, 3 and 4 replaced the enamel region present in the sane tooth, while keeping its original geometric shape. Similarly, the region occupied by the coronal dentin in the sane tooth was substituted by the core in endodontically treated teeth models, as shown in Fig. 3.

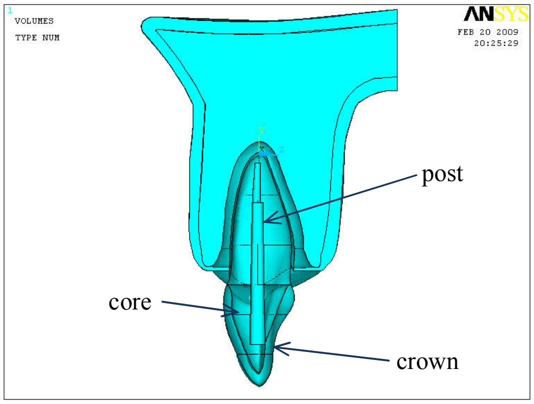

Figure 3. Standardized geometric image of the incisive tooth, Models 2, 3 and 4.

2.2. The finite element model

Many combinations of element meshes for each region were tested in the geometric models before useful and reliable results could be achieved. The final mesh combination was set up based on the assumption all four geometric models were the same but their material properties were replaced in each model. This procedure greatly reduced the amount of work done during the preprocessing phase. Commercial code Ansys® Rev.10.0 was used for the modeling and mesh generation. Results for meshes using tetrahedral element SOLID45 have shown more stable behavior than results for other element types. This is probably due to the necessary simplicity of the element in such a complex problem. Tetrahedral element edge was chosen as approximately 0,8 mm, which is close to 1/10th of the largest dimension found in the mesio-distal measure in the modeled tooth.

2.3. Material properties

Properties of the different materials used in the analyses can be found in Tab. 2. All materials were considered as homogeneous and isotropic.

2.4. Loading and boundary conditions

Loading was considered as static and slowly applied to the palatine fossa of the tooth, along the occlusal line. It was assumed that the load was equally distributed on the element nodes along that line [Fig. 4 (a)]. Freire (2007) has established force intensity in the direction determined by the interincisal contact angle, as seen in Fig. 4 (b). Hence, a 100 N force was statically distributed along the occlusal line, 3,2 mm away from the incisal edge. Boundary conditions were imposed on surfaces connecting the upper bone region to the skull. For surface A, shown in Fig. 5, all nodes were clamped, and a simply supported condition was applied to nodes on surface B.

Table 2 – Properties of materials used in the three-dimensional models.

Structure	Modulus of Elasticity (GPa)	Poisson´s ratio	Reference
Enamel	84,1*	0,33**	*Craig et al. (1961) **Farah et al. (1989)
Dentin	18,6	0,31	Toksavul (2006)
Gold Alloy	77,0	0,33	Ko et al. (1992)
Glass Fiber Post	40,0	0,22	Angelus®
Glass Fiber Core	40,0	0,22	Ângelus®
Composite Resin Z100	21,0*	0,30**	*Willems et al.(1992) **Chung et al. (2004)
Resin Cement C&B	7,0	0,28	Lanza et al. (2005)
In-Ceram Alumina	271,0	0,2	Rizkalla e Jones (2004) JIA et al. (2007)
Feldspatic Ceramic (VM7)	58,0	0,25	Bona (2005)
Gutta-percha	6,9 e-04	0,45	Ko et al. (1992)
Periodontal Ligament	68,9 e-03	0,45	Ko et al. (1992)
Cortical Bone	14,7*	0,30**	*Moroi (1993) **Farah et al. (1989)
Trabecular Bone	49,0 e-02*	0,30**	*Moroi (1993) **Farah et al. (1989)
Pulp	2,0 e-03	0,45	Rubin et al. (1983)

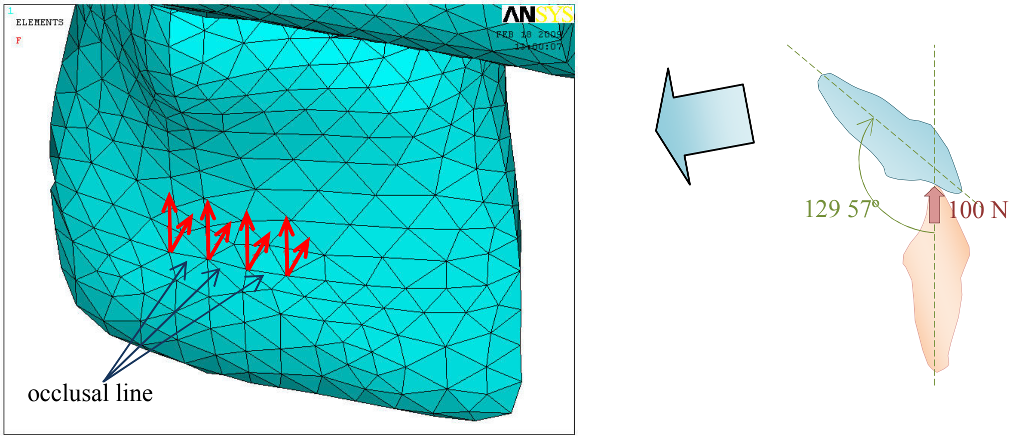

Figure 4. (a) Loading with forces applied on chosen nodes of the palatine surface along the occlusal line; (b) occlusal angle and loading condition.

3. RESULTS AND DISCUSSION

Figures 6 to 9 show the stress distribution obtained from the finite element analysis for each one of the four proposed models. Stress range is the same for all images, thus allowing a direct comparison between them.

For the recommended applied force, the sane tooth developed very low stress levels throughout its whole structure. That aspect was repeated in the dental structure of the endodontically treated teeth, Models 2 to 4, as seen, in Figs. 10 to 13, respectively, in which the stress distribution is shown at the tooth´s sagittal plane. There was no significant difference between the behavior of the sane tooth and the one belonging to the endodontically treated teeth with respect to stress distribution.

One can identify that in all models stresses were higher in the region around the nodes where loads were applied. These stresses decayed very rapidly towards the regions where there is no support. However, as one approaches the cervical area, stresses increased due to the bending moment that arised from the force component transversal to the tooth vertical axis.

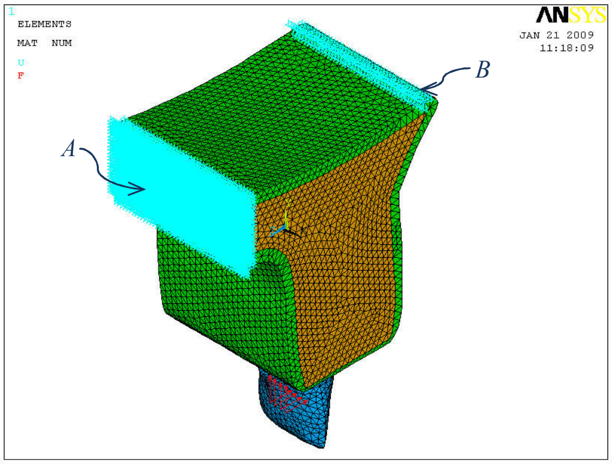

Figure 5. Clamped boundary conditions imposed on nodes at surface *A*, while surface *B* is simply supported.

There was no significant difference between the behavior of the sane tooth and the one shown by the endodontically treated teeth with respect to stress distribution. In metallic cast system, Model 2, slightly higher stresses developed in the region surrounding post´s facial surface, which is seen in Fig. 11. However, in the cervical area of the post, stresses were much lower than those obtained for the sane tooth. In Models 3 and 4, in which a fiberglass post was used, stress gradients were softer than in Model 2, in which post was metallic.

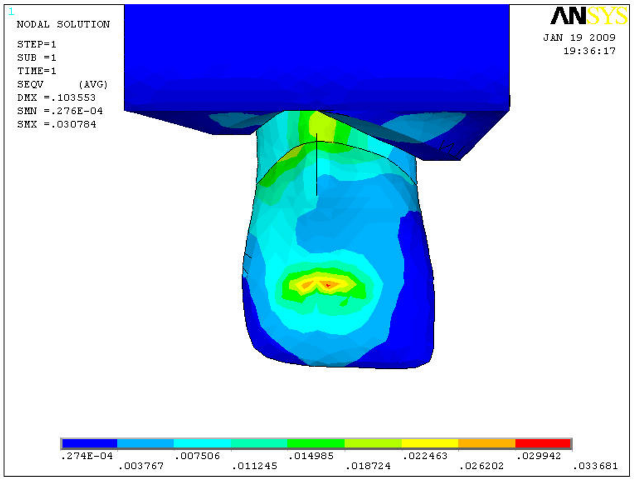

Figure 6. Stress distribution over palatine surface in sane tooth (Model 1).

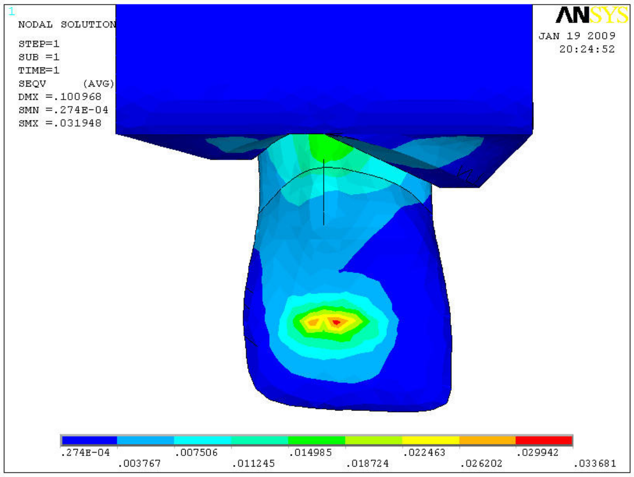

Figure 7. Stress distribution over palatine surface in endodontically treated tooth (Model 2).

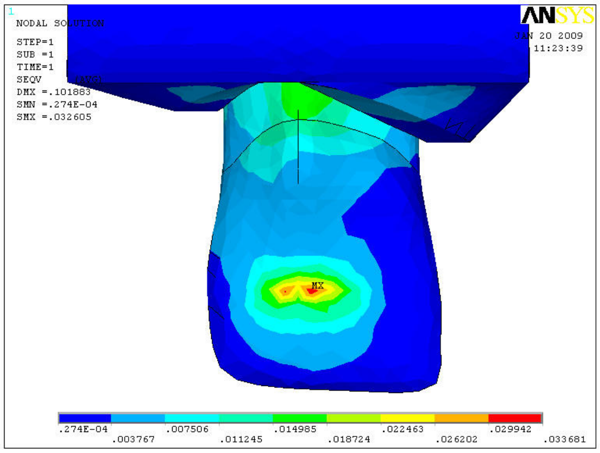

Figure 8. Stress distribution over palatine surface in endodontically treated tooth (Model 3).

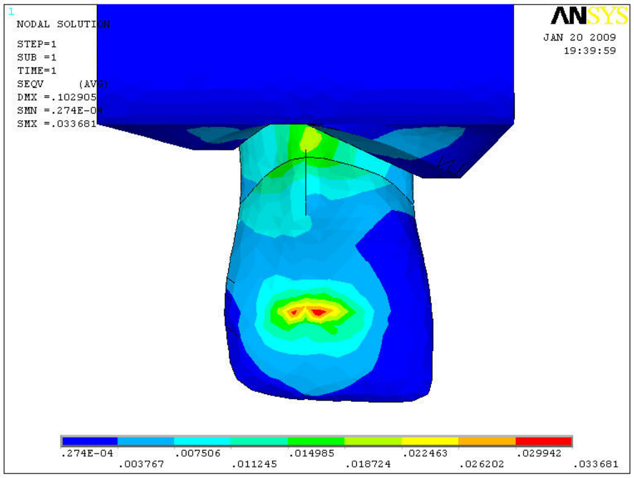

Figure 9. Stress distribution over palatine surface in endodontically treated tooth (Model 4).

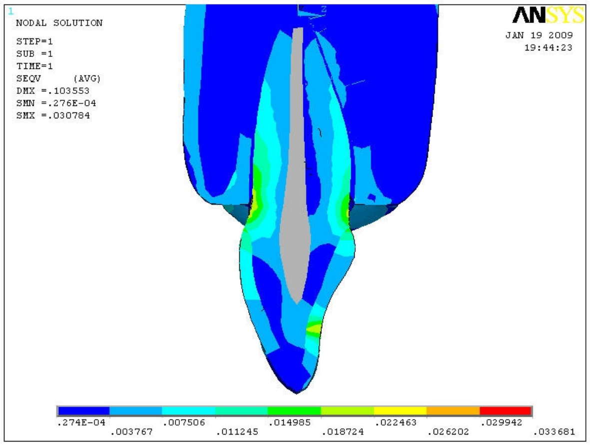

Figure 10. Stress distribution on the sagittal plane of the sane tooth , Model 1.

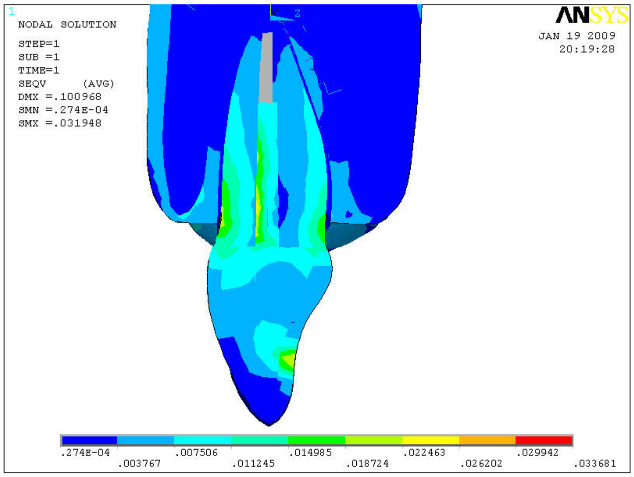

Figure 11. Stress distribution on the sagittal plane of the endodontically treated tooth, Model 2.

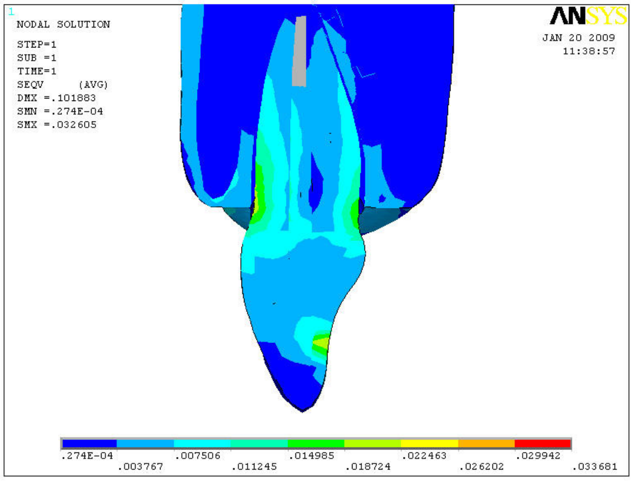

Figure 12. Stress distribution on the sagittal plane of the endodontically treated tooth, Model 3.

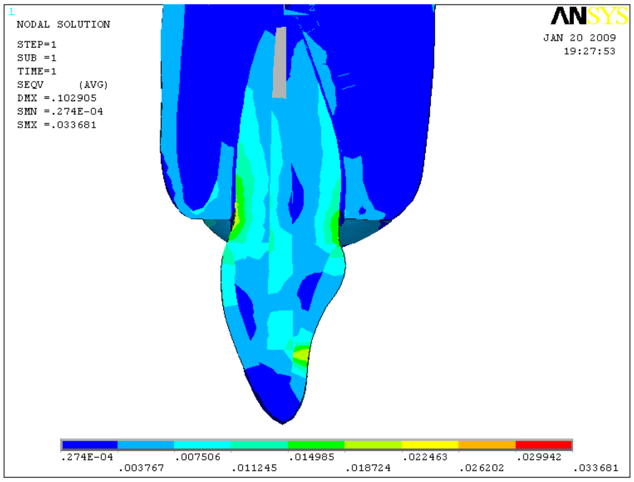

Figure 13. Stress distribution on the sagittal plane of the endodontically treated tooth, Model 4.

Restored teeth models showed lower stress levels in the cervical area than those observed for the sane tooth model. In sane model, one find higher stress levels in the cervical area, both in buccal and palatine aspects, while restored models present a decrease of stress levels in buccal and palatine aspects of the root. This change in the stress distribution was also identified by other authors (Veiga, 1996, Albuquerque, 1999), thus suggesting that most of the force is transmitted by the post itself and not by dentinal structures.

Model 2, in which there is a cast metallic post and core system (see Fig. 11), has shown higher levels of stresses in the region around the post by the buccal side of the tooth. In agreement with the study by Veiga (1996), stresses developed around the post region seem to be inversely proportional to the modulus of elasticity of the material used. This indicates that the less elastic the material of the post is, the lower the load transmitted to the adjacent dentin.

Results indicated that the placement of a post changes the pattern of stress levels along the wall of the radicular canal when compared to the sane tooth behavior. Models restored with fiberglass posts show small stress gradients in the dentinal region, similar to the results observed in Vasconcellos (2002).

The model with a composite resin core developed higher stresses in the cervical area of the post by buccal side. That may affect the longevity of the fiberglass post system. Barjau-Escribano et al. (2006), in a test of mechanical strength, observed that the location of the fracture in teeth restored with fiberglass post and composite resin core was in the coronal portion, at the cervical region on the buccal side. Ukon et al. (2000) observed that the decrease in the elastic modulus of the core led to higher stress levels in the cervical area and this could lead to fracture transversal to the axis of post-core system, causing the displacement of the restoration. According to Bocangel (1999), the use of systems presenting lower stiffness can also lead to failure of the restoration.

The fiberglass post and core system (Model 3) presented a stress distribution that indicates behavior of a single solid body. This was somewhat expected, since contact forces between then were not taken into consideration in the analysis. As a consequence, they transmit stress more uniformly to the radicular dentin When considering Model 4, in which different materials are used to simulate post and core, one can notice the less flexible post is responsible for resisting to a greater share of loading than the core. Stresses developed in Model 4, with fiberglass post and resin core, can negatively influence in its longevity.

4. CONCLUSIONS

In vitro studies and the Finite Element Method applied to dentistry try to simulate the biological conditions to test the strength of restorative materials and the mechanical behavior of teeth restored with those materials. However, it is known that they have limitations for not providing a real representation of intra-oral conditions. The masticatory forces, the anatomy of the dental tissues and the structural supporting conditions vary from individual to individual. The dentist is not completely aware of the order of magnitude of the patient`s masticatory forces to predict the stresses that can be induced in the teeth and restorations. This indicates how complex an issue the biomechanical behavior of the whole tooth and restoration is.

Results of this study indicated that:

- the use of a post greatly influences the stress distribution along the radicular canal, as compared to the one obtained for the sane tooth;

- the model with cast metallic post and core has shown a higher stress level around the post when compared to other models;
- models restored with fiberglass posts have smaller stress gradients in dentinal region;
- in models restored with fiberglass posts, the mechanical behavior of the fiberglass core system seem to be more favorable to the longevity of restoration than the composite resin core system;
- the mechanical behavior of post and core systems with lower modulus of elasticity induced a stress distribution in dental structure closer to the one found in sane model.

5. REFERENCES

Albuquerque, R. C., 1999. "Estudo da distribuição de tensões em um incisivo central superior reconstruído com diferentes pinos intra-radiculares analisados através do método dos elementos finitos". Thesis (Doutorado em Dentística Restauradora)- Programa de Pós-Graduação em Odontologia, Universidade Estadual Paulista, Araraquara.

Assif, D. et al., 1993. "Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns". J Prosthet Dent, Vol. 69, No. 1, pp. 36-40.

Barjau-Escribano, A. et al., 2006. "Influence of prefabricated post material on restored teeth: fracture strength and stress distribution". Oper Dent, Vol. 31, No. 1, pp. 47-54.

Bocangel, J. A. J. S., 1999. "Estudo das tensões geradas em dentes íntegros e com tratamento endodôntico restaurados com retentores intra-radiculares de diferentes materiais e coroa total em porcelana". Dissertação (Mestrado em Dentística) - Programa de Pós-Graduação em Odontologia, Universidade de São Paulo, São Paulo.

Bona, A. D., 2005. Microstructure characterization and properties of a new ceramic material. http://iadr.confex.com/iadr/2005Balt/echprogram/abstract_63290.htm.

Chung, S. M. et al., 2004 Measurement of Poisson`s ratio of dental composite restorative materials. Biomaterials, Vol. 25, pp. 2455-2460.

Craig, R. G., et al., 1961. "Compressive properties of enamel, dental cements and gold". J Dent Res, Vol. 40, No.. 5, pp. 936-945.

De Jager, N., et al., 2006. "The influence of different core material on the FEA-determined stress distribution in dental crowns". Dent Mater, Vol. 22, pp. 234-242.

Duret, B., et al., 1996. "Long-life physical property preservation and post endodontic rehabilitation with the composipost". Compend Contin Educ Dent, Vol. 17, pp. 50-56.

Farah, J.W., et al., 1989. "Finite element analysis of three- and four-unit bridges". J. Oral Rehabil, Vol.16, pp. 603-611.

Freire, S. M. et al., 2007. "Relationship between dental size and normal occlusion in Brazilian patients". Braz Dent J, Vol. 18, No. 3, pp. 253-247.

Jia, J. et al., 2007. "A three-dimensional finite element analysis of all-ceramic crown of the first mandibular molar". Journal of US-China Medical Science, Vol. 4, No. 1.

Katranji, A., et al., 2007. "Cortical bone thickness in dentate and edentulous human cadavers". J Periodontol, Vol. 78, No. 5, pp. 874-878.

Lanza, A. et al., 2005. "3D FEA of cemented steel, glass and carbon posts in a maxillary incisor". Dent Mater, Vol. 21, pp. 709-715.

Moroi, H.H. et al., 1993. "Numeric approach to the biomechanical analysis of thermal effects in coated implants". Int J Prosthodont, Vol. 6, pp. 564-572.

Rizkalla, A. S. and Jones, D. W., 2004. "Mechanical properties of commercial high strength ceramic core materials". Dent Mater, Vol. 20, pp. 207-212.

Rubin, C. et al., 1983. "Stress analysis of the human tooth using a three-dimensional finite element model". J Dent Res, Vol. 62, pp. 82-86.

Toksavul, S. et al., 2006. "Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications". Operative Dentistry, Vol. 31, No.1, pp. 89-96.

Ukon, S. et al., 2000. "Influence of different elastic moduli of dowel and core on stress distribution in root". Dent Mater J, Vol. 19, No. 1, pp. 50-64.

Vasconcellos, W. A., 2002. "Estudo da distribuição de tensões em dentina em incisivos superiores induzida pela forma geométrica e material dos pinos intra-radiculares via método dos elementos finitos". Dissertação (Mestrado em Odontologia)- Programa de Pós-graduação em Odontologia, Universidade Federal de Minas Gerais, Belo Horizonte.

Veiga, J. A. L. Distribuição das tensões de von Mises em dente hígido e em dente restaurado com coroa metalocerâmica e retentor intra-radicular fundido, sob carga axial e carga horizontal. 1996. 97f. Dissertação (Doutorado em Prótese Dental)- Programa de Pós-Graduação em Odontologia, Universidade de São Paulo, São Paulo.

Willems, G. et al., 1992. "A classification of dental composites according to their morphological and mechanical characteristics". Dent Mater, Vol. 8, pp. 310-319.

Yaman, P. and Thorsteinsson, T.S., 1992. "Effect of core materials on stress distribution of posts". J Prosthet Dent, Vol. 68, No. 3, pp. 416-20.

Yaman, S. D., et al., 1998. "Analysis of stress distribution in a maxillary central incisor subjected to various post and core applications". J Endod, Vol. 24, No.2, pp. 107-111.

Zhang, S., 2001. "Atlas de Histologia". Ed. Guanabara Koogan. Rio de Janeiro, Brazil, 196 p.

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