Australian Journal of Basic and Applied Sciences, 6(12): 492-498, 2012
ISSN 1991-8178

The Effect of Post Materials on stress Distribution on Endodontically Treated Lower first premolar: Finite Element Analysis study

[1]Mohamed Zaazou, [2]Mohamed El-Anwar, [3]Mohamed El-Zawahry and [4]Mohamed Abou Elnaga

[1]Assistant Professor, Restorative and Dental Materials Research Dept, National Research Centre, Egypt.
[2]Assistant Professor, Mechanical Engineering Dept, National Research Centre, Egypt
[3]Assistant Professor, Prosthodontics Department, National Research Centre, Egypt
[4]Resident, Dental Operative Dept, University of Iowa, United States of America

Abstract: The aim of this Study is to evaluate and compare the effect of vertical and oblique loading on stress distribution and displacement of four types of post materials and their effect on root dentine of endodontically treated lower first premolar. Material and methods: four post materials were tested (St.St., Ni-Cr, Gold and RFP-GF). Finite element analysis (FEA) was used to study the effect of vertical and oblique load of 100N. The geometrical models for all parts were created manually using commercial 3-D CAD/CAM modeling package. Conclusions: stiff post materials transfer less stresses to the root dentine with less displacement. Therefore using rigid post materials will not endanger the root of the tooth. Finite element analysis is considered a reliable method to evaluate the effect of stresses on the tooth and restorations.

Key words: vertical and oblique, stress distribution, post materials, root dentine, endodontically.

INTRODUCTION

Endodontic treatment may be necessary due to deep decay, wide restorations, and dental fractures. Endodontically treated teeth are known to present a higher risk of biomechanical failure due to both lack of pulp tissue (Assif, D. and C. Gorfil, 1994) and loss of dental structure (Schwartz, R. and J.W. Robbins, 2004). Root posts have been used to retain coronary restorations (Schwartz, R. and J.W. Robbins, 2004) and to improve the distribution of stress through dental structure (Nerildo Luiz Ulbrich, 2011). Posts of various types are available: precious metal cast posts or prefabricated posts made up of stainless steel, titanium, ceramic, carbon fiber, glass fiber, composite post, fiber composite laminate post etc. (Amandeep, K., 2010). In recent years, various types of fiber reinforcement have come into widespread use as an alternative to cast or prefabricated metal posts in the restoration of endodontically treated teeth (Torbjφrner, A., 1996). The advantages of using reinforced fiber to construct an intracanal post include translucency, and relative ease of manipulation (Torbjφrner, A., 1996; Galhano, G.A., 2005).

Preferences of dentists have evolved from very rigid material for post system to a material that closely resembles the properties of dentin, so as to produce a homogeneous unit and result in reduction of stresses in the root structure. Studies suggest the use of dentin bonded resin composite for intraradicular reinforcement to help strengthen damaged and weakened root (Assif, D. and C. Gorfil, 1994). There is a strong co-relation between the elastic modulus of the posts and the resulting stress and root fractures (Nerildo Luiz Ulbrich, 2011; Amandeep, K., 2010). Materials such as: carbon fiber post (Torbjφrner, A., 1996; Galhano, G.A., 2005) have modulus of elasticity, which is nearly identical to that of dentine and reported to cause less stress in the tooth and fewer root fractures (Ho, M.H., 1994).

Biomechanical analysis is important to dental research, since it involves all rehabilitation treatments. Finite Element Analysis (FEA) has been of great value to conducted generated stress studies, and studies regarding the material behaviour on dental structures during the use of root posts while these receive a certain amount of force (Mc Andrew, R. and P.H. Jacobsen, 1998; Rengo, S., 1999; Yaman, S.D., 1998). The technique was developed to create mathematical models, in which the behaviour of a physical system can be reproduced, i.e., a physical prototype can be studied through the creation of a mathematical model. In this method, a computer system is used to simulate the physical properties of the structures in analysis, and through a great number of mathematical equations it determines the generated stresses and deformations resulted from an applied force (Galhano, G.A., 2005).

Therefore, the aim of this investigation was to evaluate, through FEA, the stress distribution of prefabricated root posts of different materials.

Corresponding Author: Mohamed El-Anwar, Assistant Professor, Mechanical Engineering Dept, National Research Centre, Egypt

MATERIALS AND METHODS

A comparative study was performed, for four different post materials, gold, nickel chromium (Ni-Cr), stainless steel (St.St.), and Reinforced Fiber Post - Glass Fiber (RFP-GF) in endodontically treated lower first premolar. The model include bone (cortical and trabecular), periodontal ligament, root dentin, resin cement and the post. The geometrical models for all parts were created manually using commercial 3-D CAD/CAM modeling package (Inventor version 8). Bone geometry was simplified and simulated as cylinder that consists of two co-axial cylinders. The inner one represents the spongy bone (diameter 14 mm & height 22 mm) that filling the internal space of the other cylinder (shell of 1mm thickness) that represents cortical bone (diameter 16 mm & height 24 mm). Post geometry was taken from a previous study by Guang-Quang Song (2005), neglecting the shape and design differences by using a plain cylindrical post of 1.4mm diameter, and 12.5 mm length (where 2/3 of its length was impeded inside root cavity). On the other hand root geometry was simplified as hollow cylinder of 6mm outer diameter and 4 mm inner diameter, which was covered from its bottom by a hemi-sphere to form the root as shown in Figures 1, 2. The meshing software was ANSYS version 13.0 and the used element in meshing all parts of the three dimensional models is 8 nodes Brick element (SOLID45), which has three degrees of freedom (translations in the global directions) (Peter Kohnke, 1994).

The base of the finite element model was assumed to be fixed in all directions, which defined the boundary condition, while loading was applied as 100 N single compressing (vertical) loading on the center node at the top of the post. Oblique loading with 45° was also applied to each post material at the central top point of the post head. (These loading conditions simulate occlusal loading which of order 50N, 100N, and 150N as S. González-López *et al.,* 2005).

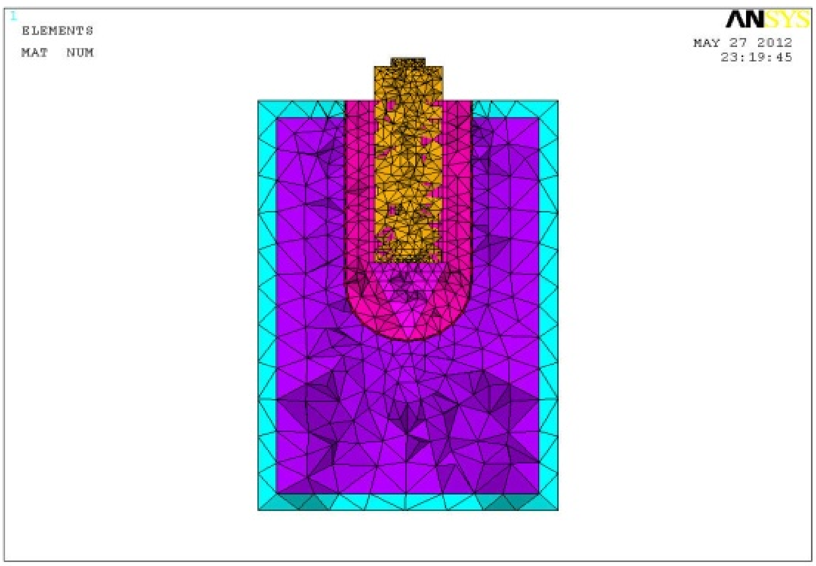

Fig. 1: Meshed model, showing different materials in the F.E. model, and a schematic of the tested problem.

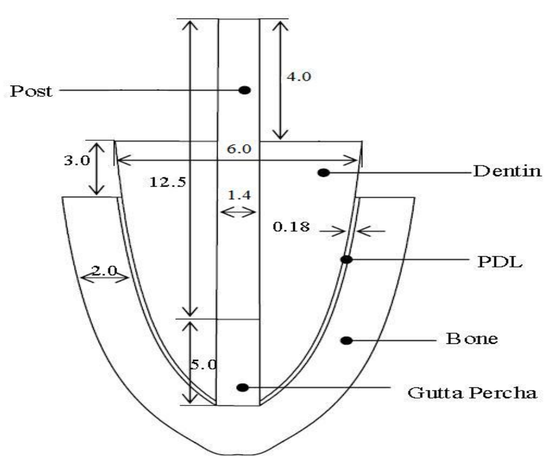

Fig. 2: Schematic of the model composed of Bone, PDL, Dentine, Cement, Post and Gutta Percha.

Linear static analysis was performed on a personal computer Intel Pentium IV, processor 2.8 GHz, 1.0GB RAM, using commercial multipurpose finite element software package (ANSYS version 13.0). The model contains 30,733 elements and 8,188 nodes, and each run takes about half an hour.

Material properties used in this study are listed in table 1, values of Young's modulus in MPa and Poisson's ratio (non-dimensional), where all materials were considered to be isotropic.

Table 1: Material properties.

Material	Young's modulus [MPa]	Poisson's ratio
Cancellous Bone	1,370	0.30
Cortical Bone	13,700	0.30
Periodontal Ligament (PDL)	60,000	0.45
Root (Dentine)	18,600	0.31
Luting Cement	8,300	0.35
Post (Gold)	95,000	0.33
Post (Ni-Cr)	188,000	0.33
Post (St.St.)	210,000	0.30
Post (RFP-GF)	73,000	0.34
Guttapercha (GP)	140,000	0.45

The displacement method of finite element stress analysis is used to calculate the linear and nonlinear (if any) response of structures subjected to static and dynamic loads. Linear elastic (small displacements and small displacement gradients) response of structures subjected to static loads may represent the current study cases. The governing equations for the linear elastic response of an idealized structure subjected to static loads are:

$$[K]\{u\} = \{F\}$$

where $[\mathbf{K}]$ = the system stiffness matrix;

$\{F\}$ = the prescribed system nodal load vector; and

$\{u\}$ = the developed system nodal displacement vector.

The system stiffness matrix [K] is obtained by assembling the element stiffness matrices consistent with the compatibility requirements between the system or global displacements and the element or local displacements. The state of stress of the idealized structure is obtained by compiling the results for the states of stress of the individual elements. The state of stress of an individual element is obtained by solving the above equation for the system displacements, identifying the element displacements, solving for the element strains, and then solving for the element stresses.

Results:

Huge number of graphical representation of the analysis results was obtained. Sample of graphical results obtained by the F.E.A. package on root (Von mises stress) and post (total deformation) under vertical load of 100 N for St.St. post were presented in Figures 3 and 4.

Summarizing and comparing tons of numeric results and pictures that were obtained from the few F.E. solver runs with changing post materials, and load direction (vertical to oblique) by casting it in tables. Table 2 showed the effect of compressive loading on the four post materials used and the other component of the model. It was found that RFP-GF has the greatest displacement (U_{sum}) followed by Gold post, then the Ni-Cr post. The least displacement was at St. St. post. While St. St. post showed the highest stress (S_{von}) and the least stress was at RFP-GF. Both of Gold and Ni-Cr posts showed equal stresses. When comparing the root displacement with different post materials; it was noted that the maximum root displacement with Gold post followed by FRF-GF, Ni-Cr and the least root displacement was at St. St post, the highest root Von Mises stress was found at the Gold post followed by RFP-GF, Ni-Cr and the least was St.St. (as presented in Figures 5, 6 for compressive and oblique loading).

Table 3: showed the effect of oblique loading on every part of the model. The four post materials were tested and it was noted that RFP-GF has the greatest displacement (U_{sum}), followed by Ni-Cr post then St.St post. The least displacement was found by the Gold post. While the St.St post showed the highest Von Mises stress (S_{von}) and the least value was found by RFP-GF post, on the other hand both Gold and Ni-Cr posts showed equal stresses. When comparing root Displacement with different types of posts, it was noted that the maximum root displacement was at the Gold followed by RFP-GF, Ni-Cr posts and the least displacement was at the St.St post. The maximum root stress was found at the Gold post followed by RFP-GF, Ni-Cr with the least stress at the St.St. post (as presented in Figures 7, 8 for compressive and oblique loading respectively).

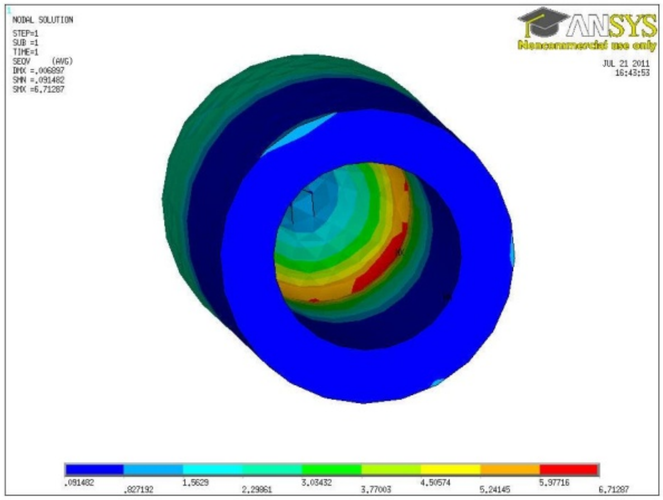

Fig. 3: Sample result of St. St. post results on Root (S_{von}).

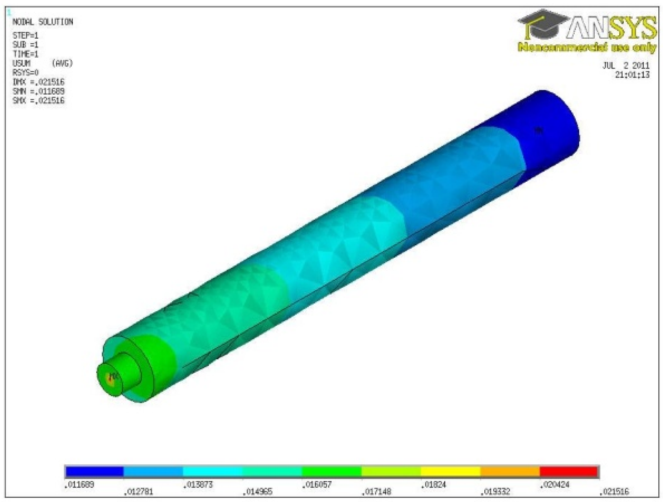

Fig. 4: Sample result of St. St. post results (U_{sum}).

Table 2: Compressive loading results.

		Gold		Ni-Cr		St-St		RFP-GF	
		U_{sum}	S_{von}	U_{sum}	S_{von}	U_{sum}	S_{von}	U_{sum}	S_{von}
#	Part	μ	MPa	μ	MPa	μ	MPa	μ	MPa
1	Cortical	*1.862*	*3.89822*	*1.838*	*3.80338*	*1.837*	*3.80245*	*1.841*	*3.81634*
2	Spongy	*4.707*	*1.80231*	*4.761*	*1.82746*	*4.761*	*1.82772*	*4.753*	*1.82392*
3	Ligament	*7.006*	*1.9084*	*6.855*	*1.86136*	*6.853*	*1.86088*	*6.876*	*1.86799*
4	Root	*7.049*	*8.60011*	*6.899*	*6.72929*	*6.897*	*6.71287*	*6.921*	*6.96341*
5	GP	*6.645*	*0.075457*	*6.613*	*0.054872*	*6.613*	*0.054848*	*6.617*	*0.05561*
6	Filling	*15.645*	*289.043*	*12.1*	*134.26*	*12.068*	*133.075*	*12.525*	*149.813*
7	Post	*23.556*	*1996.35*	*22.52*	*1996.35*	*21.516*	*2086.07*	*39.141*	*1963.78*

U_{sum}: Equivalent deformation of all components,
S_{von}: Von Mises stress distribution values, which are considered potential fracture indicator

Table 3: Oblique loading results.

		Gold		Ni-Cr		St-St		RFP-GF	
		U_{sum}	S_{von}	U_{sum}	S_{von}	U_{sum}	S_{von}	U_{sum}	S_{von}
#	Part	μ	MPa	μ	MPa	μ	MPa	μ	MPa
1	Cortical	*1.317*	*2.75646*	*1.299*	*2.6894*	*1.299*	*2.68874*	*1.302*	*2.69856*
2	Spongy	*3.328*	*1.27443*	*3.366*	*1.29221*	*3.367*	*1.29239*	*3.361*	*1.2897*
3	Ligament	*4.954*	*1.34944*	*4.847*	*1.31618*	*4.846*	*1.31584*	*4.862*	*1.32087*
4	Root	*4.984*	*6.0812*	*4.878*	*4.75833*	*4.877*	*4.74672*	*4.894*	*4.92388*
5	GP	*4.699*	*0.053356*	*4.676*	*0.0388*	*4.676*	*0.038783*	*4.679*	*0.039323*
6	Filling	*11.063*	*204.384*	*8.556*	*94.771*	*8.533*	*94.0986*	*8.856*	*105.934*
7	Post	*14.394*	*1411.63*	*15.924*	*1411.63*	*15.214*	*1475.08*	*27.677*	*1388.6*

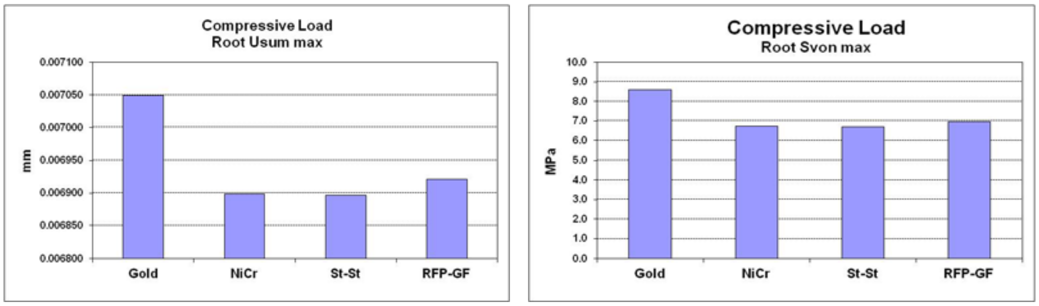

Fig. 5: Equivalent deformation and stress on the root under compressive loading.

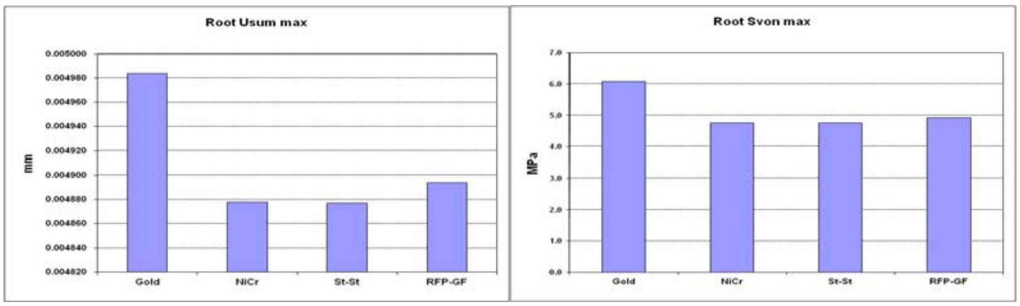

Fig. 6: Equivalent deformation and stress on the root under oblique loading.

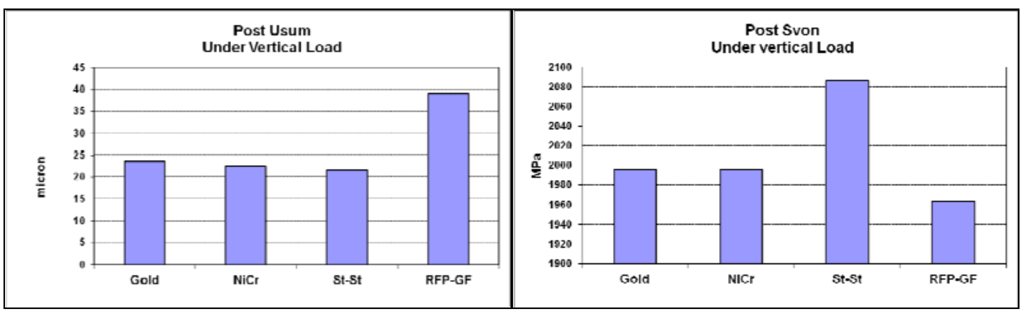

Fig. 7: Equivalent deformation and stress on the posts under compressive loading.

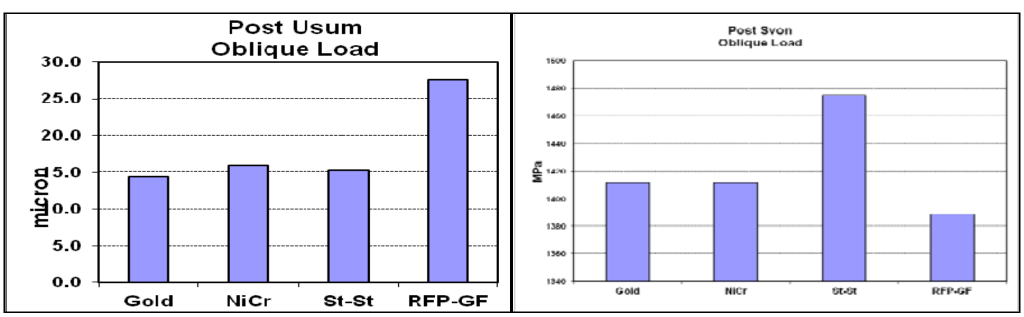

Fig. 8: Equivalent deformation and stress on the posts under oblique loading.

Discussion:

In the studied model, the post design was cylindrical not tapered because cylindrical metal posts are more retentive than tapered posts (Standlee, J.P., 1978; Johnson, J.K. and J.S. Sakamura, 1978) and this also is reported to be true for fibre posts (Qualtrough, A.J., 2003). Parallel posts induce less stress into the root, because there is less of a wedging effect, and are reported to be less likely to cause root fractures than tapered posts (Martinez-Insua, A., 1998). In a retrospective study, Sorensen and Martinoff 1984 reported a higher success rate with cylindrical posts than tapered posts (Sorensen, J.A. and J.T. Martinoff, 1984).

The stress values of the four post materials are far from yield point for the post and all other parts under investigations in this study. Therefore static analysis can replace the cyclic loading analysis, that the resulted stresses are less than the materials endurance stress limits. In each displacement component (U_x, or U_z, or U_{sum}), variation did not exceed 3-4% between lowest and highest values resulted from using the four post materials. In each stress component (S_1, S_3, S_{int}), variation did not exceed 1-3% between lowest and highest values resulted from using the four materials. Von Mises stress (S_{von}), can be used in judgment on post material effect (behavior). Therefore equivalent deformation and stress for all cases discussed in this paper were tabulated in tables 2, and 3. Although the differences can be neglected in engineering applications, but it is very important to understand the load transfer mechanism in the two case studies of compressive and oblique loading.

The stresses generated on the root surface could be correlated to the Young's modulus of the material used for the post system. Poisson's ratio is not the dominant factor for evaluation stress transformation in post systems. As the young's modulus increases from gold, to RFP-GF, to St.St., to Ni-Cr the displacement of all parts of the studied system decrease, which matches with the physics, that the stiff (rigid) the post material showed the less deformation to be obtained in the other parts of the system. The softer post material resulted in higher post deformation and stress, which will be transferred to the other parts of the system (GP, filling, root, ligament, spongy, and cortical). St.St. post is nearly equivalent to the Ni-Cr post in behavior. Both represent stiff post materials. On the other hand Gold and RFP-GF represent soft post materials. Stiff post material, with high constraints in positioning, showed better behavior and load transfer to the other parts of the systems (less energy transfer to the other parts of the system).

In terms of energy, for highly constrained parts, soft materials can absorb certain amount of energy with relatively high deformation on the other hand stiff materials can give similar result with relatively smaller deformation and this is in agreement with Bessone and Fernandez 2010.

Conclusions:

1- Within the limitation of this study it can be concluded that stiff post materials transfer less stresses to the root dentine with less displacement. Therefore using rigid post materials will not endanger the root of the tooth.
2- Finite element analysis is considered a reliable method to evaluate the effect of stresses on the tooth and restorations.

REFERENCES

Amandeep, K., N. Meena, N. Shubhashini, K. Anitha and S. Ashish, 2010. "A Comparative Study of Intra Canal Stress Pattern in Endodontically Treated Teeth with Average Sized Canal Diameter and Reinforced Wide Canals with Three Different Post Systems Using Finite Element Analysis", J Conservative Dent. 2010 Jan-Mar., 13(1): 28-33.

Assif, D. and C. Gorfil, 1994. "Biomechanical Considerations in Restoring Endodontically Treated Teeth", J. Prosthet Dent., 71(6): 565-7.

Bessone, L. and B.E. Fernandez Jr., 2010. "Evaluation of Different Post Systems: Finite Element Method", Int. J. Odontostomat, 4(3): 229-236.

Galhano, G.A., L.F. Valandro, R.M. de Melo, R. Scotti and M.A. Bottino, 2005. "Evaluation of Flexural Strength of Carbon Fiber, Quartz Fiber and Glass Fiber Based Posts", J. Endod., 31: 209-211.

González-López, S., F. De Haro-Gasquet, M.Á. Vílchez-Díaz, L. Ceballos and M. Bravo, 2005. "Effect of Restorative Procedures and Occlusal Loading on Cuspal Deflection", *Operative Dentistry,* 30-1: 33-38.

Guang-Quang Song, 2005. "Three-Dimensional Finite Element Stress Analysis of Post-Core Restored Endodontically Treated Teeth", M.Sc. Thesis, University of Manitobia.

Ho, M.H., S.Y. Lee, H.H. Chen and M.C. Lee, 1994. "Three Dimensional Finite Element Analysis of the Effects of Posts on Stress Distribution in Dentin", J. Prosthet Dent., 72: 367-372.

Johnson, J.K. and J.S. Sakamura, 1978. "Dowel Form and Tensile Force", J. Prosthet Dent., 40: 645-649.

Martinez-Insua, A., L. da Silva, B. Rilo and U. Santana, 1998. "Comparison of the Fracture Resistances of Pulpless Teeth Restored with a Cast Post and Core or Carbon-Fiber Post with a Composite Core", J. Prosthet Dent., 80: 527-532.

Mc Andrew, R. and P.H. Jacobsen, 1998. "Finite Element Analysis of Post Configuration", J. Dent. Res., 77(8): 340-355.

Nerildo Luiz Ulbrich, Ana Paula Gebert de Oliveira Franco, João César Zielak and Alvaro Luiz Mathias, 2011. "The Stress Evaluation of Root Posts Using the Finite Element Analysis", RSBO (Online), 8(2) Joinville June 2011.

Peter Kohnke, 1994. "ANSYS Theory Reference Manual", Ansys Inc.

Qualtrough, A.J., N.P. Chandler and D.G. Purton, 2003. "A Comparison of the Retention of Tooth-Colored Posts", Quintessence Int., 34: 199-201.

Rengo, S., 1999. “Behaviour of RTD Fiber Posts in Finite Element Analysis (FEM) on Three-Dimensional Models”, Proceedings of the 3rd International Symposium, S. Margherita Ligure, 26-7.

Schwartz, R. and J.W. Robbins, 2004. “Post Placement and Restoration of Endodontically Treated Teeth: a Literature Review”, J. Endod., 30(5): 289-301.

Sorensen, J.A. and J.T. Martinoff, 1984. “Clinically Significant Factors in Dowel Design”, J. Prosthet Dent., 52: 28-35.

Standlee, J.P., A.A. Caputo and E.C. Hanson, 1978. “Retention of Endodontic Dowels: Effects of Cement, Dowel Length, Diameter, and Design”, J. Prosthet Dent., 39: 401-405.

Torbjφrner, A., S. Karlsson, M. Syverud and Hensten-Pettersen, 1996. “A Carbon Fiber Reinforced Root Canal Posts”, Eur. J. Oral Sci., 104: 605-611.

Yaman, S.D., T. Alacam and Y. Yaman, 1998. “Analysis of Stress Distribution in a Maxillary Central Incisor Subjected to Various Post and Core Applications”, J. Endod., 24(2): 107-111.