Finite element stress analysis of endodontically treated teeth restored by prefabricated posts.

Biland M. S. Shukri B.D.S., M.Sc [1]
Walid N. Al-Hashimi B.D.S., M.Sc.[2]

ABSTRACT

Background: Endodontically treated teeth are restored by different types of posts. The study is to evaluate the stress distribution in endodontically treated teeth restored with prefabricated post: parallel (with different thread numbers and different materials) and tapered (with different coronal diameter and different materials).

Materials and methods: The models are two-dimensional bucco-lingual section of maxillary central incisor with its supporting structure restored with parallel and tapered prefabricated post mad of two types of material, composite core and ceramic crown. A 100N force applied separately in three directions vertical, oblique and horizontal.

Results: the maximum equivalent Von Mises stresses of all models subjected to vertical load are located within post material, while with oblique and horizontal loads are located at post surface on the labial side.

Conclusion: Load directions and post materials have much greater effect than post designs on the stress distribution. The thickness of the dentin wall is directly proportional to the ability of the tooth to withstand the occlusal loads.

Keywords: Finite element, stress distribution, post. **(J Bagh Coll Dentistry 2005; 17(3): 27- 32)**

INTRODUCTION

Dentists are presented with a multifaceted restorative challenge when confronted with an endodontically treated tooth complicated by substantial loss of coronal tooth structure [1].

Endodontically treated teeth are commonly reinforced with posts, but there is lack of scientific evidence to support this practice. Former in-vitro mechanical testing indicated that post increased the fracture loads of pulpless teeth [2].

Prefabricated posts have become popular with dentists because of their simplicity; cost, time saving, and increased retentiveness compared with traditional cast posts [3].

The main method for measuring the stress values distribution in tooth structure has been done by means of indirect experimental techniques, like two or three-dimensional photoelasticity, electrical resistance strain gauge techniques and finite element method. However, the finite element method is a modern technique of numerical stresses analysis, through special software used by computer. It gave more detail about different types of stress analysis with short time and reasonable accuracy. Which has the greatest advantage of being applicable to solids of irregular geometry and heterogeneous material properties; it is therefore ideally suited to examination of the structural behavior of teeth [4].

(1) Assistant lecturer, Department of Conservative Dentistry, College of Dentistry, University of Almostanseria.
(2) Professor, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.

Structures of various shapes are modeled and subdivided with a digital computer into simpler geometric shapes or elements whose apexes meet to form nodes. The elastic constants E (Young's modulus of elasticity) and v (Poisson's ratio) of the modeled material are specified for each element. Because the variables may be manipulated with computer precision, chance variation resulting from sampling error is eliminated [5]. The same FEM analysis repeated any number of times would yield identical results 100% of the time. Thus it is certain that the results are always caused by the manipulation of the variables and not by chance. For this reason conventional inferential statistical analysis is not normally required in an FEM study to reach a conclusion [6].

This study evaluates the stress distribution in endodontically treated teeth restored with prefabricated post: parallel (with different thread numbers and different materials) and tapered (with different coronal diameter and different materials).

MATERIALS AND METHODS

For this study the Ansys package (Finite element program version 5.4 Swanson Analysis system. Houston, Pennsylvania) was used as platform; the models are two-dimensional bucco-lingual section of maxillary central incisor with its supporting structure. The selection of maxillary central incisor is due to single-root tooth with dimensional regularity of the canal anatomy with circular cross section. The models will design to represent endodontically treated 23.5 mm long, 13 mm root length and 10.5mm crown length. The dimensions of the model obtained from work of Wheeler 1984 [7] and maxillary central incisor. The tooth model was because their mechanical properties are similar the cementum treated as part of dentin [7,9-12]. The average thickness of periodontal ligament and cortical bone are 0.3 mm and 0.4 mm respectively [13] (Figure 1).

The models restored with two types of prefabricated posts design (parallel-threaded and tapered-threaded post) with two different types of material for each one (Titanium and Stainless steel), based on the Dentsply-Maillefer System, post dimensions shows in (Figure 2).

The final models represent maxillary central incisor, 3.5mm apical gutta-percha, core, which assumed to be made of composite, PDL, cortical bone, and 4 different post designs with two different materials. The crown is assumed to be made of ceramic with 1.5 mm incisally, 1 mm thickness buccally and lingually and 1 mm shoulder finishing line [8,9,14]. From these standard data and by changing material types of the post during solution, eight models are designed (Figure 3). From these models a fine mesh of the finite element model was obtained using 5878 quadrilaterals 8-node (figure 4), which is the most delicate element and provides more accurate results and can tolerate irregular shapes without much loss of accuracy.

The mechanical properties used in this study, Elastic modulus and Poisson's ratio were obtained from the table of material properties used in previous studies as listed in table1.

Finite element models, however, assumed that the materials are homogenous, isotropic and liner elastic.

The lower border of all models was considered fixed in all direction to avoid the model from sinking when loads are applied (Figure 4). Three static loads were applied to the models: Vertical load on the incisal edge, Oblique load 2mm Lingual to the incisal edge directed at 45^{o} to the long axis of the tooth and horizontal load to the labial surface of the tooth, the value of external load used in this study is 100 N, this is less than the actual maximum load in the oral cavity during normal mastication, but it is within the measured values in many pervious studies in this area of oral cavity [2,7,9,12,14-16]. The loads applied separately on selected nodes that fixed for all models (Figure 4).

Based on the Von Mises theory, which state that failure occurs when the equivalent stress for the actual case is equal to the yield strength of the material, the results of this study were represented by equivalent Von Mises stress [2,14,15]. Specified nodes were selected on the both buccal and palatal sides of the post at the cervical area (A), middle area (B), post apex area (C). Area (A) and (B) consists of three line and each line consist of three nodes from middle of the post, post-dentin interface, midway between post and root surface and at root surface (buccally and palatally), while at area (C) two lines one at post apex and the second line 1mm apical to the post apex Figure 5 illustrate nodes positions. The points were fixed for all models to monitor the stress changes in these regions [12,17].

Table 1: Mechanical properties of the materials used in the analysis.

Material	Modulus of elasticity (MPa)	Poisson's ratio	Reference
Dentin	18600	0.31	9
Cementum	18600	0.31	7
PDL	68.9	0.45	15
Cortical bone	13700	0.3	15
Spongy bone	1370	0.3	15
Gutta-percha	0.96	0.45	15
Ceramic	69500	0.28	12
Composites resin	16600	0.24	16
Titanium	112000	0.33	20
Stainless steel	200000	0.33	9

RESULTS

The maximum equivalent Von Mises stresses of all models subjected to 100N vertical load are located within post material reaching 53 MPa in model with tapered titanium post of 1.83mm coronal diameter; also the highest dentinal stresses are located in model with parallel stainless steel post of 8 threads which reach 26 MPa. Also the result shows that model with stainless steel post have highest stress concentrations than models with titanium post. Figure 6 show the peak equivalent Von Mises stresses, while figure 7 shows the equivalent Von Mises stress contour for all models subjected to 100N vertical load.

The maximum equivalent Von Mises stresses of all models subjected to 100N oblique load are located at post surface by cervical / coronal and middle third of the root on the labial side, reaching 180 MPa in model with tapered stainless steel post of 1.83mm coronal diameter, also the highest dentinal stresses are located in model tapered titanium post of 1.64mm coronal diameter. Also the result shows that the models with stainless steel post have higher stress concentration than model with titanium post while the stress distributions in model with stainless steel post are less than in model with titanium post. Figure 8 show the peak equivalent Von Mises stresses, while figure 9 shows the equivalent Von Mises stress contour for all models subjected to 100N oblique load.

The maximum equivalent Von Mises stresses of all models subjected to 100N horizontal load are located at post surface mainly at the middle third reaching 180 MPa in model with tapered stainless steel post of 1.83mm coronal diameter; while the highest dentinal stress located reach 102 MPa in model with tapered titanium post of 1.64mm coronal diameter. As with oblique load the highest stress concentration are found in models with stainless steel post with less stress distributions in surrounding dentin. Figure 10 shows the peak equivalent Von Mises stresses, while figure 11 shows the equivalent Von Mises stress contour for all models subjected to 100N oblique load.

DISCUSSION

Vertical load

The maximum values of Von Mises stresses are distributed inside the metallic post and at post-dentin interface. These results agree with previous FE study by Hong-So et al., 2001 ([15] and Pegoretti et al., 2002 [14]

In dentin the higher stress are located at apical area this is probably due to metal post that alter and absorbed more vertical load, resulting in lower dentinal stresses around the post, the higher values of dentinal stresses in apical area were found in models with parallel post this may due to less amount of dentin around the parallel post apex, these results agree with previous photoelastic investigations by Assife et al., 1989, and agree with FE study by Hong-So et al., 2001 [15].

Oblique load

The maximum values of Von Mises stresses are located on the post surface by the coronal and middle third of the root on the labial side these results agree previous FE study by Ming et al., 1994 [2]; David et al., 1996 [9] Pegoretti et al., 2002 [14], also agree with photoelastic study by Kishen and Asundi, 2002 [19].

In models with parallel post the intensity of stresses in dentin at the cervical and apical areas almost equal with higher values of stresses at cervical area, while in models with tapered post, the higher stress values in dentin are located at cervical area. The values of these stresses are lower in models with tapered post than in models with parallel post, this due to preserving more dentin around tapered post, that increase the ability of tooth structure to withstand occlusal force, these results agree with photoelastic investigation by Assife et al., 1989 [18] Kishen and Asundi, 2002 [19], and also agree with FE study by Hong-So et al., 2001 [15]; Cimini et al., 2003 [5].

Horizontal load

The maximum values of Von Mises stresses in the post are located on the post surface at the middle third on the labial side, this agree with the finding of Hong-So et al., 2001 [15].

In dentin the maximum values of Von Mises stresses in models (B), (C), (D), (E), (F) and (H) are located at the cervical third on the labial side of the post this result agree with Ming et al., 1994 [2]; Pegoretti et al., 2002 [14]. But disagree with Hong-So et al 2001[15], which shows that the greatest dentinal stresses were found at the middle of the root on the labial side of the root and around post apex, while the maximum values of dentinal stress in models (A) and (G) are found around post apex, which agree with Hong_So et al 2001 [15]. The result of this study shows that under horizontal loading the tapered post has greater stress distribution than parallel post this may due to much dentin present around tapered post this agree with the finding of Hong-So et al., 2001.

Ming et al., 1994 stated that the equivalent stress distribution under traumatic loading was similar to masticatory loading with stress on the labial side was slightly greater and all peak dentinal stresses on the models with posts were reduce similar to masticatory loading [(2)].

During masticatory (oblique) or traumatic (horizontal) loading, the incisor subjected to bending along the cervical region and the mid-region of the root dentin toward the buccal direction, and it is important to note that the tensile strength of dentin is considerably lower than its compressive strength. The presence of post significantly altered the stress distribution on healthy tooth, modifying it from compressive to tensile stress. This fact can be explained by the nature of the problem; the applied loads can be decoupled into its two components on the X and Y direction. The X component generates bending on the root structure and the Y component is responsible for axial compression. The natural tooth has root pulp chamber filled with a very soft tissue, while the treated tooth has posts made of a very stiff material introducing into the root canal, the post absorbs most of the compressive loading leaving the task of bending resistance to the adjacent dentin, thus introducing a tensile stress concentration on a region that was before in compression on the healthy tooth [(2,9,19)].

Post materials

The result shows maximum values of stress distribution at post-dentin interface, this may due to the difference in modulus of elasticity between post materials and dentin; this is in agreement with M. Toparli, 2003 [(11)].

The models with stainless steel post shows less stress values in dentin than models with titanium post this may due to high modulus of elasticity of stainless steel that increase tooth stiffness, this in agreement with Ming et al., 1994, who reported that tooth with a stainless steel predicated the upper limit of effects of a prefabricated post in dentin stress reduction, also this agree with Hong-So et al., 2001 [(15)], who reported that the presence of relatively high modulus dowel substantially reduce the stress levels in the surrounding dentin.

The ideal post is the one that has the stiffness as close as possible to the dentinal tissue with smaller post diameter to preserve as much as possible of dentin tissue [(9,16,18,19)].

REFERENCES

1- Baraban DJ. The restoration of endodontically treated teeth: an update. J Prosthet Dent 1988; 59: 553-8.

2- Ming H, Shyh L, Hsiang H, Maw L. Three-dimensional finite element analysis of the effects of posts on stress distribution in dentin. J Prosthet Dent 1994; 72: 367-72.

3- Weine F. Endodontic therapy. 5th Ed, Mosby, St. Louis, Missouri, USA. 1996.

4- Joshi S, Mukherjee A, Mehta A. Mechanical performance of endodontically treated teeth. Finite Element in Analysis and design. 2001; 37: 587-601. www.elsevier.com

5- Cimini Jr, Castro De, Polleto Dr, Fontana RH. Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil 2003; 30: 936-43.

6- Iplikcioglu H, Akca K. Comparative evaluation of the effect of diameter, length and number of implant supporting three-unite fixed partial prostheses on stress distribution in the bone. J Dent 2002; 30(1); 41-6.

7- Major M. Ash. Wheeler's dental anatomy, physiology and occlusion. 6th Ed. W. B. Saunders Company Philadelphia. 1984.

8- Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed Prosthodontics. 2nd Ed, St. Louis, CV Mosby, 1995 Ch 11: 238-67.

9- David C, Ana MD, James ML. Influence of post dimension on stress distribution in dentin. J Prosthet Dent 1996; 75:140-7.

10- Yettram AL, Wright KWJ, Pickard HM. Finite Element Stress Analysis of the crowns of normal and restored teeth. J Dent Res 1976; 55(6): 1004-11.

11- Toparli M, Gokay N, Aksoy T. Analysis of a restored maxillary second premolar tooth by using three-dimensional finite element method. J Oral Rehabil 1999; 26: 157-64.

12- Toparli M. Stress analysis in a post-restored tooth utilizing the finite element method. J Oral Rehabil 2003; 30: 470-6.

13- Lindhe J. Textbook of clinical Periodontology. 2nd Edition, Munksgaars. 1989.

14- Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of glass fiber reinforced composite endodontic post. J Biomaterial 2002; 23:2667-82.

15- Hong-So Y, Lisa AL, Anthony M, David AF. The effects of dowel design and load direction on dowel-and-core restorations. J Prosthet Dent 2001a; 85:558-67.

16- Rees JS, Jagger DC. Abfraction lesion formation in maxillary incisor, canine and premolar: A finite element study. Eur J Oral Sci 2003; 111:149-54.

17- Aykul H, Toparli M, Dalkiz. A calculation of stress distribution in metal-porcelain crowns by using three-dimensional finite element method. J Oral Rehabil 2002; 29:381-6.

18- Assif D, Oren E, Marshak B, Aviv I. Photoelastic analysis of stress transfer by endodontically treated teeth to the supporting structure using different restorative techniques. J Prosthet Dent 1989; 61: 535-43.

19- Kishen A, Asundi A. Photoelastic investigations on post endodontically rehabilitated teeth. J Biomedical Optics 2002; 7(2): 262-70.

20- Robert G. Craig, Marcus L. Restorative Dental Materials. 10th Ed. Mosby, St. Louis, Missouri, USA, 1997.

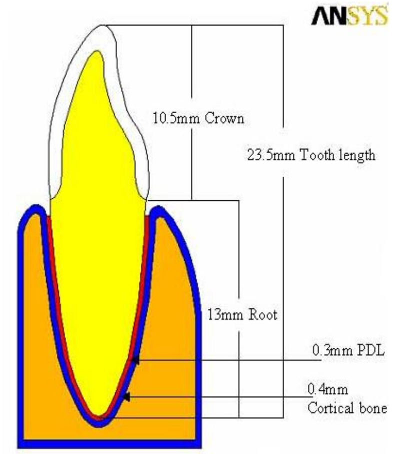


Figure 1: Dimension of the Tooth and supporting structure dimensions.

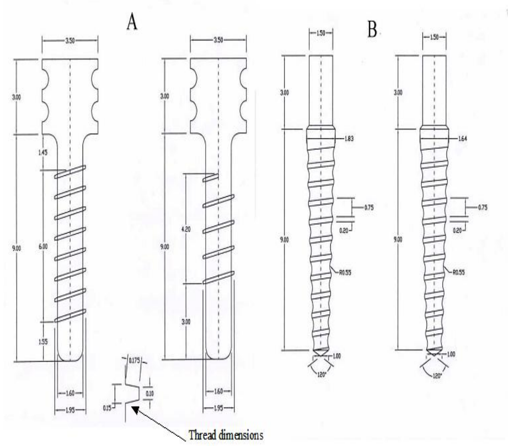


Figure 2: Post dimensions A parallel post. B tapered post.

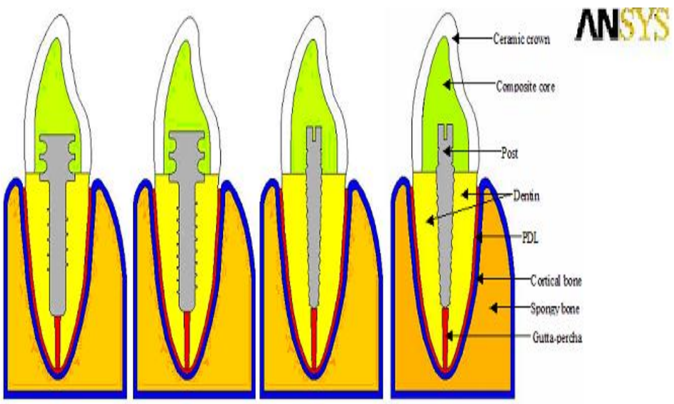


Figure 3: Diagram show bucco-lingual cross-section view of endodontically treated maxillary central incisor with various post designs threaded post.

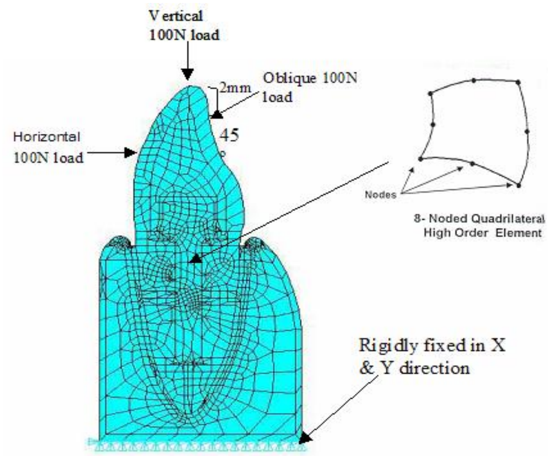


Figure 4: Two-dimensional plane strain mesh of maxillary central incisor with boundary condition and load directions.

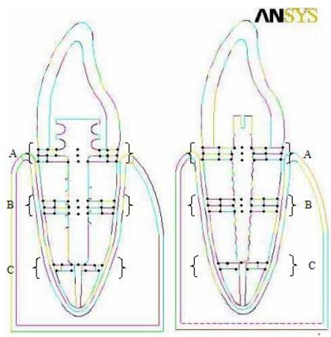


Figure 5: Illustrate the selected areas and points for measuring the stress values.

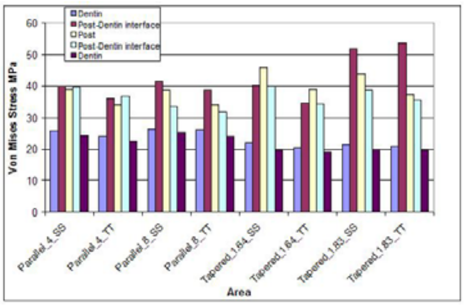
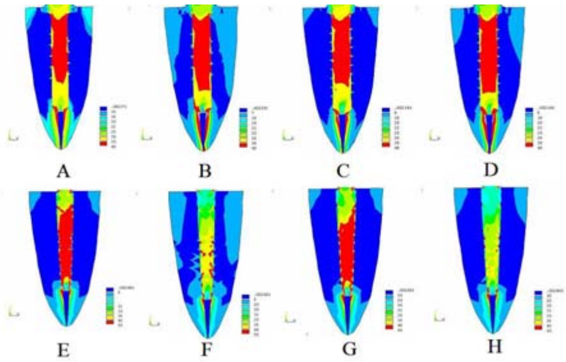


Figure 6: The maximum equivalent Von Mises stresses of all models subjected to 100N vertical load in (MPa).



Figures 7: Distribution of equivalent Von Mises stress contour in all model subjected to 100N

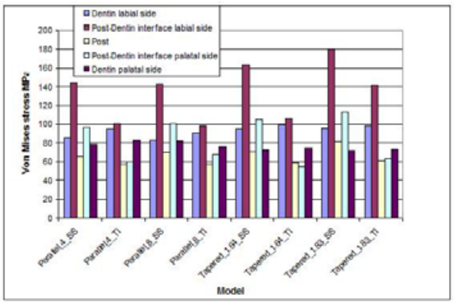
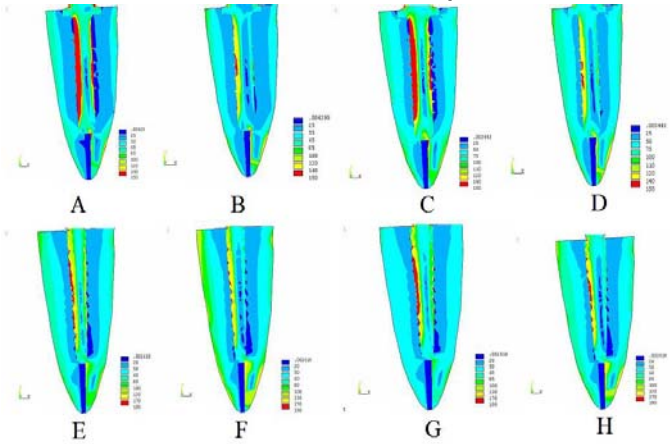


Figure 8: The maximum equivalent Von Mises stresses of all models subjected to 100N oblique load in (MPa).



Figures 9: Distribution of equivalent Von Mises stress contour in all model subjected to 100N oblique load.

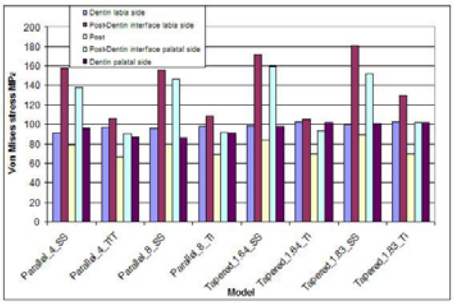
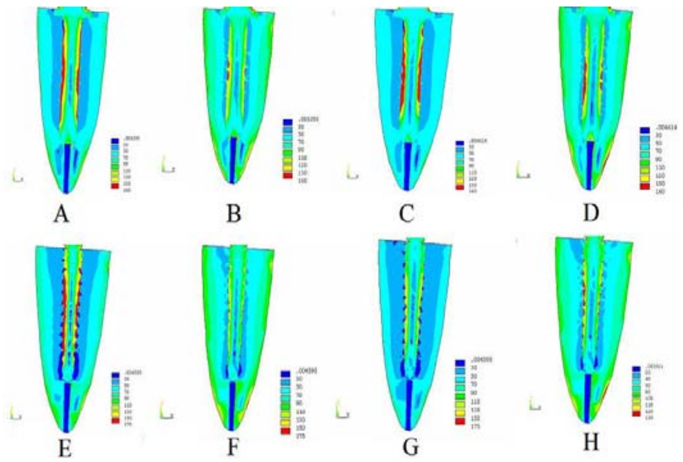


Figure 10: The maximum equivalent Von Mises stresses of all models subjected to 100N horizontal load in (MPa).



Figures 11: Distribution of equivalent Von Mises stress contour in all model subjected to 100N oblique load.