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Finite element analysis of endodontically treated tooth restored with different posts under thermal and mechanical loading

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Key Words

Finite element analysis, thermal FEM, post, carbon post, titanium post

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Abstract

Aim: This study compared the stress distributions of endodontically treated tooth restored with carbon and titanium post under thermal and mechanical loading conditions.
Methodology: A 3-dimensional finite element model was created to represent in a labiolingual cross-sectional view of an endodontically treated maxillary central incisor tooth with its supporting structures. It was modified according to two post systems with different physical properties consisting titanium, and carbon fiber. Stress distribution and stress values were then calculated by considering the three dimensional von Mises stress criteria.
Results: A 100-N static vertical occlusal load was applied on the node at the center of occlusal surface of the tooth. The von Mises stress values for carbon post model was on the coronal third and the cervical area of the root in the range of 436,16 and 3,59 MPa, for titanium post model was 590,55 and 3,05 MPa. Thermal stress values for carbon post model showed that maximum stress concentrations were noted on the coronal third and the top of the post area of the root in the range of 509,94 and 6,38 MPa. Titanium post model showed that maximum stress concentrations were noted on the coronal third and top of the post area of the root in the range of 1165,06 and 3,06 MPa.
Conclusion: This study shows that the titanium post yields larger stresses than the carbon post under thermal conditions.
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Introduction

Endodontically treated teeth are usually weakened as a result of dental hard tissue structure loss due to decay, removal of previous and older restorations and root canal treatment procedure. To prevent further destruction of these teeth, post-and-cores are frequently used to restore endodontically treated teeth (1, 2). Traditionally, posts were made of metal, such as cast nickel–chromium (NiCr), prefabricated stainless steel and titanium. Due to their good physical properties, these three metals were shown to be predictable and successful post materials (3).

Generally cast metal dowel and core were used but recently there is an increasing trend towards the use of fiber dowel systems (4). Recently, the advance of materials and technology, in addition to the post systems, several new post materials have been introduced in accordance with elevated clinical requirements non-metal post and core systems, including carbon fiber post system, glass fiber post system and quartz fiber post system (5, 6, 7, 8). Prefabricated posts are either metallic posts such as stainless steel, titanium alloy and metal posts, which have been luted with zinc phosphate cement, or non-metallic posts such as posts of zirconia and carbon fiber or glass fiber reinforced resin composite, which are adhesively bonded in the root canal system (9). Fiber dowels provide a more esthetic result than the metallic dowels. They have a modulus of elasticity similar to dentin structure, thus reducing the stress areas at the dowel dentin interface (10). Carbon fiber posts have modulus of elasticity, which is nearly identical to that of dentine and reported to cause less stress in the tooth and root fractures.

The oral environment is subjected to thermal stimulant from hot and cold foods and beverages (11). Palmer et al determined the maximum and minimum temperatures for hot and cold liquids by using an intraoral digital thermometer probe in which reported temperature extremes that ranged from 0°C to 67°C (12). Thermal conductivity and thermal expansion of nonmetallic restorative materials, metal, and dentin are significantly different (12). With rapid improvements and developments of computer technology, the finite element method (FEM) which has been shown to be a useful tool is a powerful numerical method for solving the differential equations (13, 14). Design and Finite Element Method methodologies play an important role in investigations of clinical and biomechanical situations in different dental fields. The computer program allowed the calculations of stresses, strains, and deformations in discretionally shaped 3D finite element model representing a structure under static loading on tooth-restoration complex (15, 16).

The aim of this study was to evaluate and compare the stress distributions of endodontically treated tooth restored with carbon and titanium post under thermal and mechanical loading conditions.

Materials and Methods

A 3-dimensional finite element model was created to represent an endodontically treated maxillary central incisor tooth with its supporting structures. The model contained a simulated periodontal ligament (PDL) and alveolar bone structure (Fig. 1). The root canal was assumed to have been shaped to accommodate a commercially available fiber post.

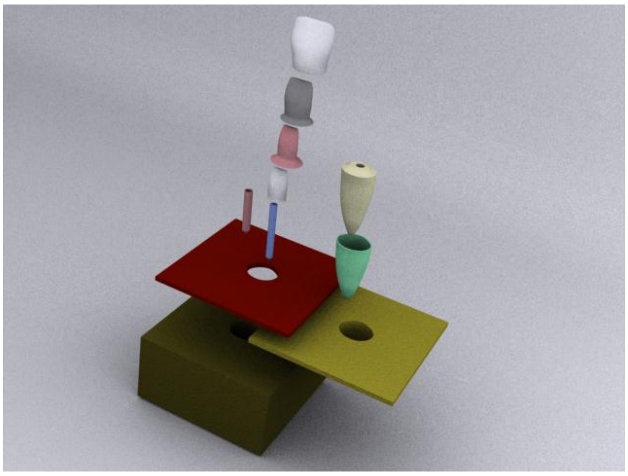

Figure 1. Three-dimensional finite element model and illustration of materials.

All of the materials were assumed to be homogenous, isotropic and linear elastic. Mechanic and thermal properties of materials (Young's modulus (E) and Poisson's ratio (μ)) were assigned according to literature data and given in Table 1.

One finite element model was investigated to evaluate how the different occlusal loads changed the stress distribution:

Model: A 100-N static vertical occlusal load was applied on the node at the center of occlusal surface of the tooth (Figure 2a and 3a). Rhinoceros 4.0 (3670 Woodland Park Ave N ,Seattle, WA 98103 USA) and Algor Fempro (ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA) softwares were used for the modelling and stress analysis. Stress distribution and stress values were then calculated by considering the three dimensional von Mises stress criteria.

The thermal load applied to the 3D tooth model, having an initial temperature of 0 °C, simulated the draught of a hot liquid (65 °C) (Figure 2b and 3b). Thermal stress values were measured after 5 seconds.

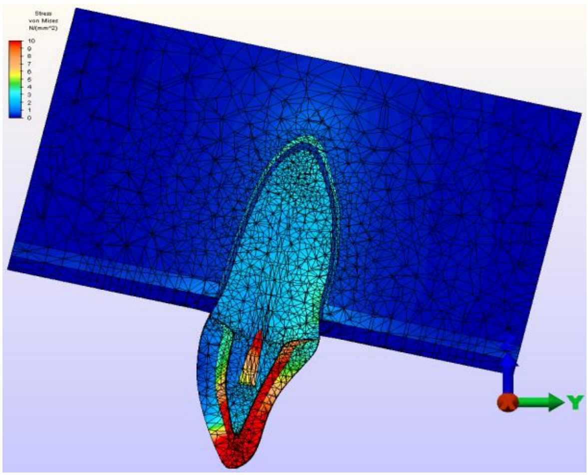

Figure 2a. Carbon post model

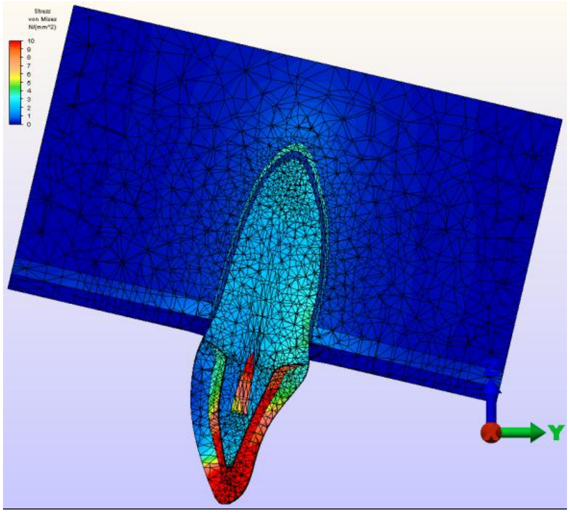

Figure 2b. Carbon post model with thermal load (65 °C)

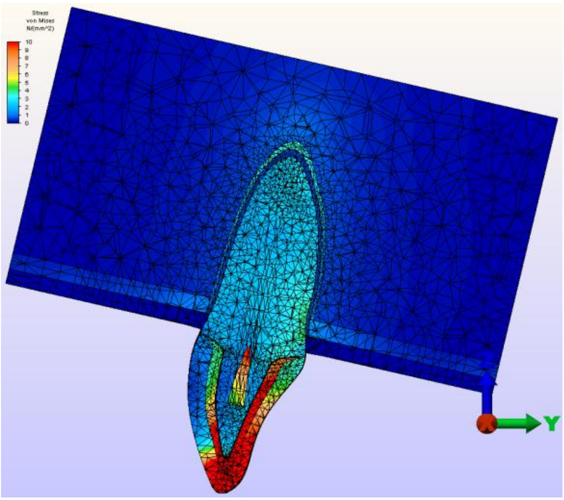

Figure 3a. Titanium post model

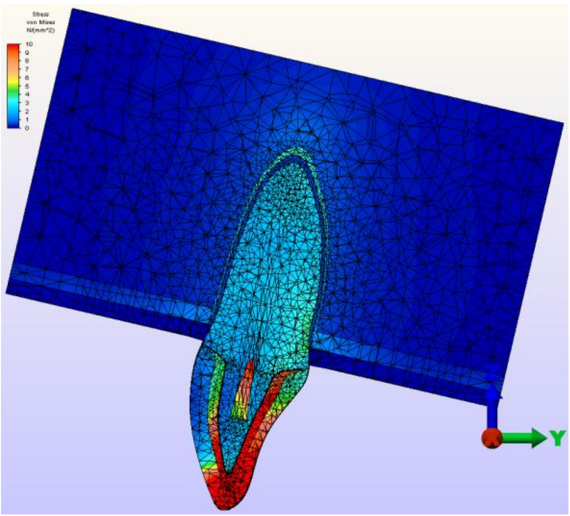

Figure 3b. Titanium post model with thermal load (65 °C)

Results

The values of stress seen at the middle third of the labial aspect of the root surface. On the contrary, the minimum values were noticed at level of both the apical portion of the post and the root apex. Assessments were made established on the color patterns in Figures 2a, 2b, 3a and 3b where warm colors denote higher stresses.

Results were presented by considering Von Mises criteria and calculated numerical data were transformed into color graphics to better visualize mechanical stresses in the models. All stress values were indicated in megapascals (MPa).

The analysis of the von Mises stress values for carbon post model showed that maximum stress concentrations were noted on the coronal third and top of the post area of the root in the range of 436,16 and 3,59 MPa. Titanium post model showed that maximum stress concentrations were noted on the coronal third and top of the post area of the root in the range of 590,55 and 3,05 MPa. Thermal stress values for carbon post model showed that maximum stress concentrations were noted on the coronal third and the top of the post area of the root in the range of 509,94 and 6,38 MPa. Titanium post model showed that maximum stress concentrations were noted on the coronal third and top of the post area of the root in the range of 1165,06 and 3,06 MPa.

TABLE 1. The mechanical and thermal properties of the materials

Material/Component	Elastic Modulus (MPa)	Poisson Raito	Thermal expansion(10–6/°C)	Specific heat (103 J/kg)	Thermal conductivity [J/(mm·s°C)]
Cortical bone (11, 17, 24)	13.700	0.30	10	0,44	0,5868
Cancellous bone (11, 17, 24)	1.370	0.30	10	0,44	0,5868
Dentin (11, 18, 19, 24)	18.600	0.31	11.4	0,588	0,15
Ligament (11, 20, 24)	68.9	0.45	4,1	0,36	0,5
Gingiva (11, 13, 24)	3	0.45	4,1	0,36	0,5
Gutta-percha (11, 17, 24),	0.69	0.45	54,9	0,22	0,48
Adhesive cement (Panavia, Kuraray,Japan) (21, 24)	18.600	0.28	30	0,197	0,976
Composite core (Clearfil Photo Core, Kuraray, Japan)(*) (24)	18.600	0.26	39,4	0,2	1,0878
Nikel-krom (11, 22, 24)	200.000	0.33	14,3	0,11	66,944
Porcelain crown (11, 19, 23, 24)	68.900	0.28	13,1	0.25	0.754
Carbon post (11, 21, 24)	118.000	0.27	2,2	0,3	6,276
Titanium post (11, 13, 24)	112.000	0.33	11,9	0,54	21,9

* Information from company

Discussion

Destructive mechanical tests, such as fracture tests, are important for biomechanical analysis of tooth and dental restorative materials, as they enhance understanding of the behaviour of teeth in high loading situations. However, these tests have limited capacity to clarify the stress–strain relationship in the tooth-restoration complex (25, 26). The use of nondestructive tests, such as strain gauge tests (27), and finite element analysis (FEA) (28, 29) is more suitable for understanding the failure characteristics of the restorative procedures (30, 31). Several studies have made comparative investigations using only FEA (21, 29, 30, 31), however, this methodology is more representative when associated with destructive tests (32), or with non-destructive assays such as the strain gauge test (26, 33).

Valid FE analyses have clarified how static stresses are distributed within the dental material and the tooth tissues. Restoration of endodontically treated teeth has become an important aspect of dental practice that involves a range of treatment options of variable complexity. Recently, post and core restorations are the option of choice for endodontically treated teeth, but it may makes teeth fragile and more susceptible to fracture (34). The present study compared the stress distributions of carbon and titanium post systems under thermal and mechanical loading conditions. According to the results of this study, both mechanical properties and thermal conditions of the post material affected stress distribution.

Glass and carbon posts show high fatigue and tensile strength, and they have a Young's modulus comparable to dentin (17). Under the vertical static loads, teeth restored with fiber posts showed significantly stronger than those with metallic posts. Hot and cold liquids cause thermal stress over the time. This phenomenon is very important and needs to be investigated. Hot liquid caused more thermal stresses when titanium was used. Therefore, from these results it can be concluded that carbon post shows better behaviour than titanium when hot liquid is used. Titanium post has more thermal stress than carbon posts.

According to the results of the present study, the mechanical properties and design of the of the post material, and the nature of the material from which the post and core are made are very important to the distribution of stress. Finite-element analysis (FEA) has been shown to be a useful technique the analysis of stress distributions.

Conclusion

Within the limitation of this study, it can be concluded that the thermal and physical properties of posts were important on stress distributions in post and core applications. Our study shows that the titanium post yields larger stresses than the carbon post under thermal conditions.

Acknowledgments

The authors deny any conflicts of interest related to this study.

References

1. Papa J, Wilson PR, Tyas MJ. Pins for direct restorations. Journal of Dentistry 1993;21:259–64.
2. Joshi S, Mukherjee A, Kheur M, Mehta A. Mechanical performance of endodontically treated teeth. Finite Elements in Analysis and Design 2001;37:587–601.
3. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent. 2007;35:778–786.
4. Qualtrough AJ, Mannocci F. Tooth-colored post system: a review. Oper Dent 2003; 28: 86-91
5. Purton DG, Love RM. Rigidity and retention of carbon fiber versus stainless steel root canal posts. Int Endodontic J 1996;29:262-5.
6. Malquarti G, Berruet RG, Bois D. Prosthetic use of carbon fiber-reinforced epoxy resin for esthetic crowns and fixed partial dentures. J Prosthet Dent 1990;63:251-7.
7. Lassila LVJ,Tanner J, Le-Bell AM,Narva K,Vallittu PK. Flexural properties of fiber reinforced root canal posts. Dent Mat 2004;20:29–36.
8. Cacciafesta V, Sfondrini MF, Lena A,Scribante A,Vallittu PK, Lassila LV.Flexuralstrengthsoffiber-reinforcedcomposites polymerized with conventionallight-curingandadditional postcuring. American Journal of Orthodontics and Dentofacial Orthopedics 2007;132:524–7.
9. Sahafi A, Peutzfeldt A, Ravnholt G, Asmussen E, Gotfredsen K. Resistance to cyclic loading of teeth restored with posts. Clin Oral Invest 2005;9:84–90
10. Santos AF, Meira JB, Tanaka CB, Xavier TA, Ballester RY, Lima RG, Pfeifer CS, Versluis A. Can fiber posts increase root stresses and reduce fracture? J Dent Res 2010;89:587-91.
11. Yang HS, Lang LA, Guckes AD, Felton DA. The effect of thermal change on various dowel-and-core restorative materials. J Prosthet Dent 2001;86:74-80.
12. Palmer DS, Barco MT, Billy EJ. Temperature extremes produced orally by hot and cold liquids. J Prosthet Dent 1992;67:325-7.
13. Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005;94:321–9.
14. Chen J, Xu L. A finite element analysis of the human temporomandibular joint. J Biomech Eng 1994;116:401–407.
15. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prosthet Dent 2004;91:144–150.
16. Eraslan Ö, Eraslan O, Eskitaşcıoğlu G, Belli S. Conservative restoration of severely damaged endodontically treated premolar teeth: a FEM study. Clin Oral Invest 2011;15:403-8.
17. Ko, C.C., Chu, C.S., Chung, K.H., Lee, M.C. Effects of posts on dentin stress distributions in pulpless teeth, J. Prosthet. Dent., 1992;68: 421-7.
18. Asmussen E, Peutzfeldt A, Heitmann T. Stifness, elastic limit and strength of newer types of endodontic posts. J Dent 1999;27(4):275–8.
19. Toparlı M. Aykul H, Sasakı S. Evaluation of the onset of failure under mechanical and thermal stresses on luting agent for metal-ceramic and metal crowns by finite element analysis. J Oral Reh 2003;30:99–105.
20. Holmes, D.C., Diaz-Arnold, A.M., Leary, J.M., Influence of post dimension on stress distribution in dentin, J. Prosthet. Dent., 1996;75: 140-7.
21. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon

posts in a maxillary incisor. Dent Mater 2005;21:709-5.

22. Hsu, ML., Chen, CS. Chen, BJ., Huang, H.-H. and CHANG, C.-L. Effects of post materials and length on the stress distribution of endodontically treated maxillary central incisors: a 3D finite element analysis. J Oral Reh 2009;36:821–830.
23. Geng JP, Tan Keson BC, MSD, and Liu GR. Application of finite element analysis in implant dentistry: A review of the literatüre. J Prosthet Dent 2001;85:585-98.
24. Kacan U. Oral sıcaklık degisikliklerinin farklı yapıdaki restoratif post ve kor materyaller üzerindeki termal stres etkisinin üç boyutlu sonlu elemanlar termal analiz yöntemi ile karşılaştırılması. Hacettepe Universitesi, Sağlık Bilimleri Enstitüsü, Protetik Diş Tedavisi Anabilim Dalı, 2006.
25. Soares CJ, Santana FR, Silva NR, Preira JC, Pereira CA. Influence of the endodontic treatment on mechanical properties of root dentin. J Endodon 2007;33:603–6.
26. Soares CJ, Fonseca RB, Gomide HA, Correr-Sobrinho L. Cavity preparation machine for the standardization of in vitro preparations. Braz Oral Res 2008;22, 281–7.
27. Ross RS, Nicholls JI, Harrington GW. A comparison of strains generated during placement of five endodontic posts. J Endodon 1991;17:450–6.
28. Kishen A, Kumar GV, Chen NN. Stress-strain response in human dentine: rethinking fracture predilection in postcore restored teeth. Dent Traumatology 2004;20:90–100.
29. Jacobsen PH, Wakefieldt AJ, O'Doherty DM, Rees JS. The effect of preparation height and taper on cement lute stress: a three-dimensional finite element analysis. The European Journal of Prosthodontics and Restorative Dentistry. 2006;14:151–7.
30. Lin CL, Chang CH, Ko CC (2001) Multifactorial analysis of an MOD restored human premolar using auto-mesh finite element approach. J Oral Reh 28, 576–85.
31. Magne P, Belser UC (2003) Porcelain versus composite inlays/onlays: effects of mechanical loads on stress distribution, adhesion, and crown flexure. The International Journal of Periodontics & Restorative Dentistry 23, 543–55.
32. Fennis WM, Kuijs RH, Barink M, Kreulen CM, Verdonschot N, Creugers NH (2005) Can internal stresses explain the fracture resistance of cusp-replacing composite restorations? Euro J Oral Sci 113, 443–8.
33. Palamara JE, Palamara D, Messer HH. Strains in the marginal ridge during occlusal loading. Aust Dent J 2002;47:218–22.
34. Melo MP, Valle AL, Pereira JR, Bonachela WC, Pegoraro LF, Bonfante G. Evaluation of fracture resistance of endodontically treated teeth restored with prefabricated posts and composites with varying quantities of remaining coronal tooth structure. J. Appl. Oral Sci 2005;13(2):141-6.