

## Tensile stress distribution in maxillary central incisors restored with cast-made and prefabricated dental posts.

Ahmed A. Madfa,<sup>1,2</sup> Elham M. Senan<sup>2</sup> & Xiao-Guang Yue.<sup>3</sup>

**Affiliations:**<sup>1</sup>Department of Conservative Dentistry, Faculty of Dentistry, Thamar University, Yemen. <sup>2</sup>Restorative and Prosthodontic Department, Collage of Dentistry, University of Science and Technology, Yemen. <sup>3</sup>Department of Safety Science and Engineering, Wuhan University, China.

**Corresponding author:** Ahmed Madfa, Department of Conservative Dentistry, Faculty of Dentistry, Thamar University, Dhamar, Yemen. Phone: (00967) 6503255. Ext: (00967) 6501278. E-mail: ahmed\_um\_2011@yahoo.com

**Receipt:** 07/21/2017 **Revised:** 08/16/2017  
**Acceptance:** 09/22/2017 **Online:** 09/22/2017

**Conflict of interests:** None.

**Ethics approval:** None.

**Funding:** None.

**Authors' contributions:** This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

**Acknowledgements:** None.

**Cite as:** Madfa AA, Senan EM & Yue XG. Tensile stress distribution in maxillary central incisors restored with cast-made and prefabricated dental posts. *J Oral Res* 2017; 6(9):237-244.  
[doi:10.17126/joralres.2017.068](https://doi.org/10.17126/joralres.2017.068)

**Abstract:** Aim: To analyze and compare the tensile stress distribution in endodontically treated teeth restored with cast-made (Ni-Cr and gold) and prefabricated (titanium and glass fibre) dental posts. Methodology: Four three-dimensional finite element (FE) models of a maxillary central incisor restored with Ni-Cr cast-made (Model Ni-Cr), gold cast-made (Model GO), prefabricated titanium (Model TI) and prefabricated glass fibre (Model FP) posts were constructed. An oblique loading of 100N was applied to each three-dimensional model. Tensile stress distribution within the root dentine and at the post and surrounding structure interfaces were analysed. Results: In all the FE models studied, a higher magnitude of tensile stresses was observed on the palatal aspect of the cervical dentin as compared to the labial aspect and progressively decreases from the outer to the inner part of the root. The gold cast-made and glass fibre post models showed significantly less tensile stress concentration in the post-core component than the other experimental models. The maximum tensile stress was seen on the palatal aspect of the Ni-Cr compared to other posts. The higher magnitude interfacial tensile stress concentration was observed in a pulpless tooth restored with a Ni-Cr cast-made post, followed by titanium and gold cast-made posts, respectively. However, the minimum interfacial tensile stress was noticed in a pulpless tooth restored with a glass fibre post. Conclusion: Glass fibre posts tend to transfer tensile stress more homogenously within the tooth and at interfaces than the other types of investigated posts.

**Keywords:** Finite element analysis; post materials; biomechanics; tensile stress.

### INTRODUCTION.

The preservation of tooth structure is considered as a crucial factor for the successful management of structurally compromised endodontically treated teeth.<sup>1,2</sup> However, endodontically treated teeth have been shown to exhibit a significantly shorter service life compared to vital teeth.<sup>3</sup> This is because endodontically treated teeth are unlike vital teeth due to the effects of endodontic treatment. It is thought that endodontic treatment leads to weakening of the remaining tooth structure because of changes in tooth architecture, changes in the properties of dentin and changes in proprioception. The changes in tooth architecture are often attributed to the access cavity preparation and removal of the vital tissues, supposedly rendering the tooth weaker and more susceptible to fracture. Therefore, it is necessary to provide a protectively restorative treatment for essential retention and resistance and to prevent from later decay of such teeth.<sup>4</sup>

Endodontic treatment can never be considered complete until the tooth has been restored to provide proper function and esthetics that

meet patient satisfaction.<sup>4</sup> The post-and-core systems are one of the earliest approaches employed for restoration of endodontically treated teeth. They are often used after root canal treatment when restoring a damaged tooth with extensive loss of coronal tooth structure to compensate for the lack of tooth structure.<sup>5,6</sup>

In general, the post-and-core systems are utilized to maintain a crown prosthesis that replaces the lost coronal part of the tooth structure. In these systems, a dental post is placed into the root canal in order to act as an anchor for maintaining the core compartment, which in turn provides retention of crown prosthesis.<sup>5,6</sup> However, it alters the stress distribution pattern within the remaining tooth structure and does not reinforce the remaining tooth structure.<sup>7</sup> In addition, the interfaces between materials with different degrees of elasticity represent areas of weakness as local discrepancies influence stress-strain distribution.<sup>8</sup> Furthermore, the difference in the thermo-physical properties (*e.g.* volumetric thermal expansion) of these constituents could generate interfacial thermal stresses during imbibing of hot and cold liquids.<sup>9</sup> These unfavorable stresses that act on remaining tissues and tooth/restoration interfaces are subsequently superimposed by the mechanical load applied during mastication.

The selection of post material is based on its biocompatibility, mechanical properties, ease of fabrication, and availability in the market and cost factor. Structurally compromised roots have conventionally been restored with casting posts and cores with the advantages of post stiffness, optimum adaptation, and high retention.<sup>10</sup> Metallic posts include titanium and nickel-chromium (Ni-Cr) gold, and stainless-steel posts. These posts can undergo a corrosion reaction, cause a metallic taste, oral burning, oral pain, sensitization allergic reaction and also resisted lateral forces without distortion that can result in stress transfer to dentin causing potential root cracking and fracture. Besides they can cause greyish discoloration of all ceramic crowns and gingiva.<sup>11</sup> Newer materials include ceramics and fiber reinforced resin used for their unique esthetic properties and other positive features.<sup>12,13</sup>

To understand the mechanisms responsible for tooth failure, the stress distribution within restored and unrestored teeth that results from mastication force has been studied extensively. The fracture resistance of post-

restored teeth has been the subject of numerous *in vitro* and *in vivo* studies with a theoretical approach. *In vivo* studies often cannot control the many variables that are present clinically. Another reason is that *in vitro* studies on fracture resistance are encumbered with standard deviations that are relatively very high. Because of the large variability of the results obtained from *in vitro* and *in vivo* studies, an increasing number of investigations of post-restored teeth are based on finite element analysis (FEA).<sup>11-21</sup>

The finite element method (FEM) is a highly approved method to simulate biophysical phenomena in computerized models of teeth and their periodontium. FEM is considered to be an extremely useful tool to simulate the mechanical effects of chewing forces acting on the periodontal ligament and on the dental hard tissues. This method is based on a mathematical model, which approximates the geometry, loading and constraint conditions of a structure to be analyzed. Deformations and stresses at any point within the model can be evaluated and highly stressed regions can be analyzed. The elastic modulus and the Poisson's ratio for the modeled materials are specified for each element. However, the result of FEM depends on its modeling methods and the values assigned to the material properties.<sup>17</sup> Thus, the FEM has become a reliable method for dental applications that enables the calculation of load distributions and the influence of model parameter variations once an accurate three-dimensional model is created.<sup>18</sup>

Most of the previously published studies have analyzed the results from Von Mises maximal stress.<sup>11-20</sup> This is probably associated to the fact that this is the normal criterion for most engineering analyses, which usually deal with ductile materials such as steel and aluminum.<sup>22</sup> It is known that the Von Mises criterion is only valid for the ductile materials with equal compressive or tensile strength, but materials exhibiting brittle behavior such as dentin, ceramics, cements or resin composites present reported values of compressive strength significantly greater than tensile strength. Since compressive strength of dentin is considerably higher than tensile strength, calculated tensile stress may be compared with the tensile strength of dentin to predict and assess the risk of failure of restored non-vital teeth.

Therefore, the present study applies FEM to determine

the tensile stress distribution in maxillary central incisor restored with cast-made (Ni-Cr and gold) and prefabricated (titanium and glass fibre) dental posts. The results obtained with the posts are to be compared to one another, focusing on regions of stress concentration, where cracks can nucleate and eventually propagate leading to the loss of structural integrity and finally ultimate fracture of the restored tooth.

## MATERIALS AND METHODS.

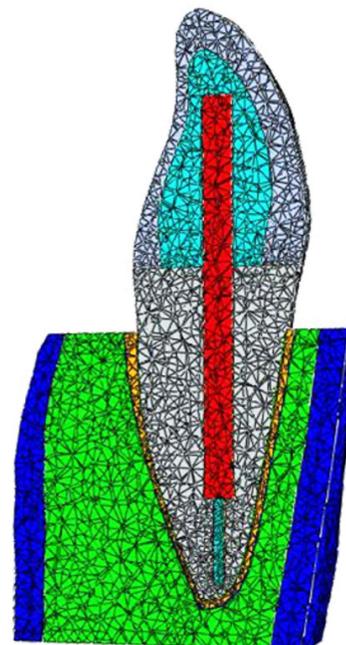
### Model Geometry

A three-dimensional (3D) model of an adult maxillary central incisor tooth with its surrounding cortical and cancellous bones was developed using Computed Tomography (CT) datasets. The CT scan images of pixels size 0.4235 and 512 resolutions were imported into the image processing software (Mimics® 13.1, Materialise, Leuven, Belgium) by using digital imaging and communication (DICOM) and 361 images were imported to Mimics®. The different hard tissues visible on the scans were then identified using Mimics® based on image density thresholding. After creating the external volume of the 3D model, which are tooth and bone components in Mimics® 13.1, the model was saved as a (.INP) file prior to importing into ABAQUS/CAE software, Professional Version (Simulia, Providence, RI, USA).

Defining the periodontal ligament from CT scan images is difficult due to its thin structure and the pixel size of 0.4235mm. Thus, a periodontal ligament 0.25mm thick was generated based on a tooth root,<sup>1,2</sup> and was subtracted from the volume of the cortical and cancellous bone. The internal volume of the 3D model was then generated by adding dentine (root) and restorative components. The restoration of the root, including the dental posts, cast and composite cores, porcelain crown, were then modelled based on the geometry of the root using 'Solid Works' software (Dassault Systèmes, Waltham, MA, USA). The dimension of each component was based on data from literature.<sup>1,2,8</sup> The size of the posts was designed at 1.5mm. Figure 1 shows a schematic illustration of the geometric model.

Four models contained various post-and-core systems of the same height and all-ceramic porcelain crowns, periodontal ligament, cortical and cancellous bone, and

**Figure 1.** Schematic illustration of the three dimensional geometric model.



approximately 4mm gutta-percha apical seal. In this study, four different post systems, including two different core materials were used as follows:

1. Model Ni-Cr used nickel-chromium cast-made post-and-core system.
2. Model GO used gold cast-made post-and-core system.
3. Model TI used prefabricated titanium post and composite core.
4. Model FP used prefabricated glass fiber post and composite core.

### Finite Element Analysis (FEA)

Mesh generation is an important procedure to subdivide the solid geometry of a FE model into smaller elements and ABAQUS provides a number of different meshing techniques. Free meshing technique was adopted and tetrahedral elements were used in this study to separate the model due to the complicated geometries of the models, thus achieving convergence. In this study, it was preferred to use four nodes first order linear tetrahedral solid elements (C3D4) for the stress analysis. The C3D4 was used with fine meshes to obtain accurate data as constant stress tetrahedral elements exhibit slow convergence.

The nodes along the bottom line of the model, referred

to as 'alveolar bone', were fixed in all degrees of freedom.

All components were assumed to be perfectly bonded without any gaps between them. An oblique load of 100N, angled at 45°, to simulate the masticatory force was chosen.<sup>1,8,11</sup> Any stresses that are likely to be introduced during the endodontic treatment were neglected. The elastic properties of the geometric model parts are shown in Table 1 and Table 2. The distribution of tensile stresses was evaluated within the tooth and at posts and surrounding structures interfaces using ABAQUS/CAE software, Professional Version (Simulia, Providence, RI, USA). The interfacial tensile stress was calculated along the AB path from coronal to apical regions of the dental post and surrounding structures.

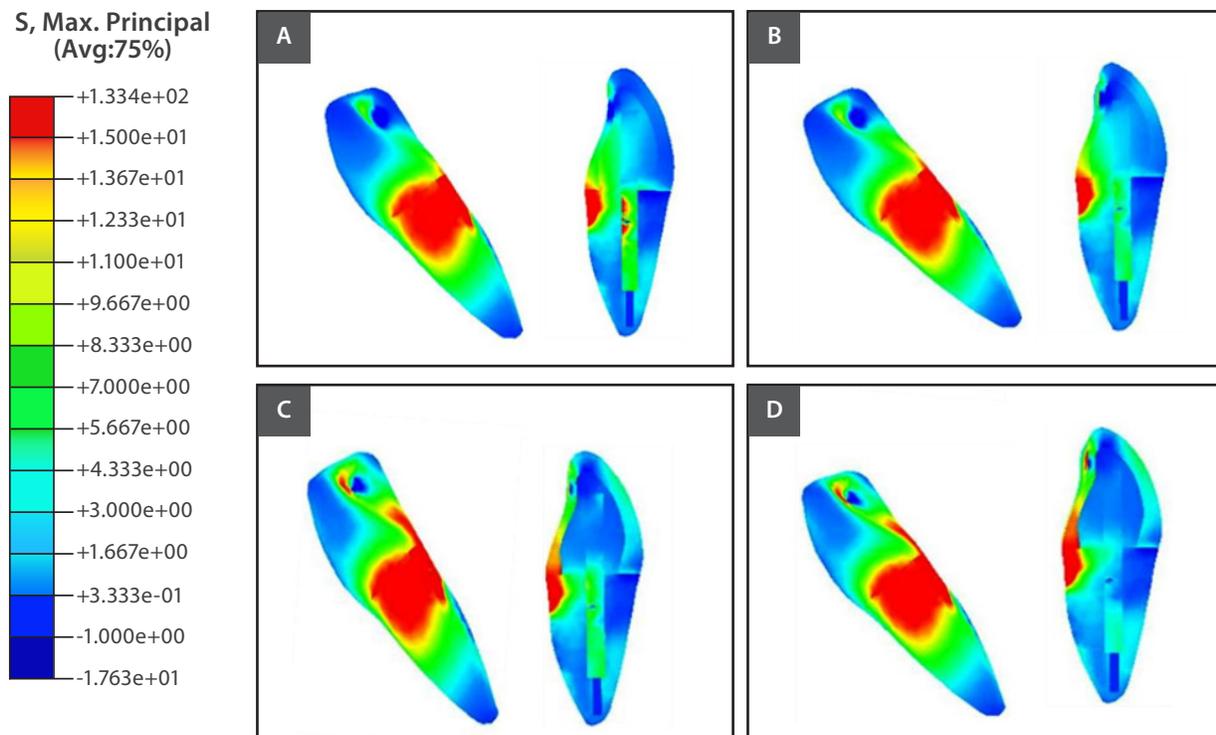
## RESULTS.

In all the FE models studied, a higher magnitude of tensile stresses was observed on the palatal aspect of the cervical dentin as compared to the labial aspect and progressively decreases from the outer to the inner part of the root. Figure 2 depicts the tensile stress distributions for different post and core systems in terms of color contour

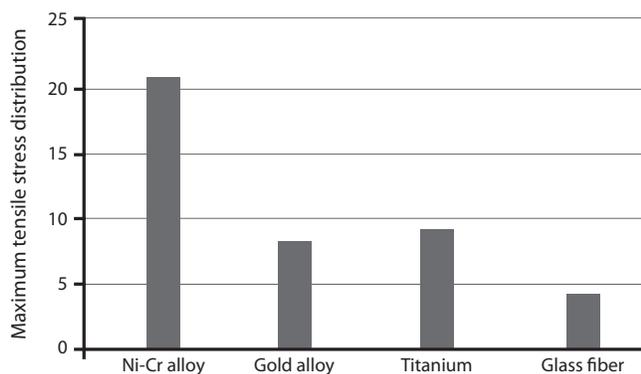
patterns. As shown in the Figure 2, the Ni-Cr cast-made and titanium post models demonstrated similar patterns of tensile stress distributions on the palatal aspect of the dentin, except for the post, in which, the maximum tensile stress was seen on the palatal aspect of the Ni-Cr cast-made compared to titanium posts. On the other hand, the gold cast-made and glass fibre post models showed more tensile stress concentration on the palatal aspect of the crown and the cervical area of dentin. However, the gold cast-made and glass fibre post models showed significantly less tensile stress concentration in the post-core component than the other experimental models.

The maximum interfacial tensile stress concentration was observed in a pulpless tooth restored with Ni-Cr cast-made post, followed by titanium and gold cast-made posts, respectively. However, the minimum interfacial stress was noticed in a pulpless tooth restored with glass fibre post (Figure 3). The reduction in the average of tensile stress values was shown in Model FP followed by Model GO and Model TI respectively, whereas the highest average of tensile stress values was noticed in Model Ni-Cr as exhibited in Figure 4.

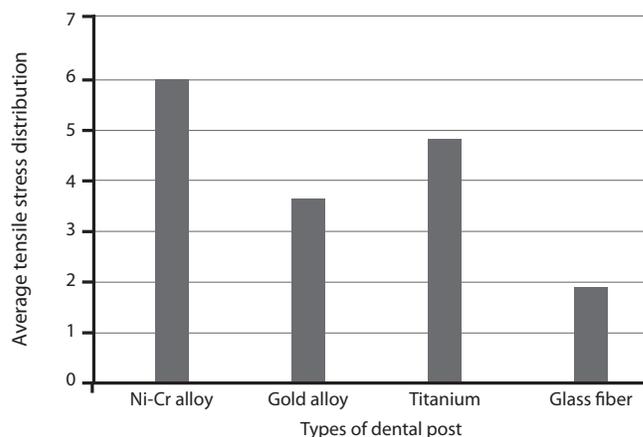
**Figure 2.** Distribution of tensile stress (MPa) following oblique loading for (A) Ni-Cr cast-made, (B) gold cast-made, (C) titanium and (D) glass fibre posts.



**Figure 3.** Maximum tensile stress at the investigated posts and surrounding structures interfaces.



**Figure 4.** Average tensile stress at the investigated posts and surrounding structures interfaces.



**Table 1.** Mechanical properties of isotropic materials.

Material	Elastic modulus (MPa)	Poisson's ratio
Cortical bone	13700	0.3
Cancellous bone	1370	0.3
Dentin	18600	0.32
PDL	0.069	0.45
Porcelain	69000	0.28
Gutta-percha	140	0.45
Composite resin	12000	0.33
Titanium post	116000	0.33
Ni-Cr alloy	200000	0.33
Gold alloy	93000	0.33

**Table 2.** Mechanical properties of orthotropic materials.

Property	Glass fiber post
Ex (MPa)	37000
Ey (MPa)	9500
Ez (MPa)	9500
Vxy	0.27
Vxz	0.34
Vyz	0.27
Gxy	3100
Gxz	3500
Gyz	3100

## DISCUSSION.

Inside the oral cavity, post and core restorations like any other restoration are subjected to masticatory forces. The stress originated by the masticatory forces in an endodontically treated tooth restored with post and core can cause root fracture. Post and core restorations are multicomponent complex systems wherein the

stress distribution within the structure is multi-axial, nonuniform, and depends on the magnitude and direction of the applied external loads. A theoretical well-known method for calculating stress distribution within such a complex structure is the FEM, which allows the investigators to evaluate the influence of model parameter variation, once the basic model has been correctly defined.

The FEM can play an important role in predicting the state of stress acting in the different regions of the restored tooth under masticatory loads. This, in turn, serves as a pertinent tool to pinpoint regions within the restored structure that are susceptible to fracture initiation and crack propagation, meaning failure of the restoration process.

When FE modeling is compared with laboratory testing, it offers several advantages. The variables can be changed easily, simulation can be performed without the need for human material and it offers maximum standardization. However, the success of applying the FEM requires appropriate choice of the models that have to be compatible with the boundary and loading conditions imposed on the structure. The accuracy of the model used in this study was confirmed by convergence test where subsequent refinements of the mesh were made resulting in a mesh size of 150, 465 elements. This is comparable to other previous studies.<sup>23,24</sup> Validity is dependent upon the extent to which the model of the tooth approximates the real conditions. In this study, the model of the incisor tooth was created from a CT scan image of an adult maxillary central incisor along with its surrounding structures. It is felt this provided a realistic rendition of the clinical conditions.

The results of a FEA are expressed as stresses distributed in the structures under investigation. These stresses may be tensile, compressive, shear, or a combination known as equivalent von Mises stresses. In this study, we calculated tensile stress which is possible to compare with the tensile strength of dentin to predict and assess the risk of failure of restored non-vital teeth. Kinney *et al.*,<sup>25</sup> reported that tensile strength of dentin is in the range of 50 to 100MPa and suggested that tensile loads in the range of 150 to 300N could increase the risk of failure of restored endodontically treated teeth. An area of stress concentration, from a biomechanical perspective, indicates regions of potential failure due to the formation of cracks or fatigue.<sup>26</sup>

The mechanical risk associated with coronal-radicular reconstruction is directly related to excessive tensile stress on residual coronal and radicular dentin. Material properties greatly influence the stress distribution around reconstructed tooth structure.<sup>27</sup> Analysis of stress distribution reveals that in the absence of post intra-canal

stress intensity is insignificant. The more intense stresses appear in the cervical region with regard to the influence of root canal post.<sup>11</sup>

It was noticed in this study that tensile stresses were distributed along the posts, as expected. The tensile stress was concentrated along the palatal aspect of the posts due to the direction of loading. However, the highest tensile stresses were seen in Ni-Cr cast-made post, followed by titanium, and gold cast-made posts. Posts with higher elastic moduli were found to cause amplification of stress within the post itself but a reduced stress distribution in the root dentin. This undesirably high stress concentration in Ni-Cr cast-made, titanium and gold cast-made posts may ultimately result in de-bonding between the post and the root canal. In contrast, the tensile stress distribution of glass fibre post was concentrated mainly within the root dentin. The ability of the glass fibre to reduce the concentration of stress is likely to be due to the lower stiffness of these posts.

These results are consistent with Madfa *et al.*,<sup>2</sup> who reported that a Ni-Cr cast-made post produced a higher stress concentration than a glass fibre post. The present findings are also consistent with earlier studies using FE analysis.<sup>28,29</sup> Amarante *et al.*,<sup>28</sup> concluded that the use of a less rigid post material, that is similar to dentin, results in a more uniform stress distribution in comparison with that associated with a more rigid post. However, the less rigid post was found to promote higher equivalent stress levels mainly in the cervical region of the tooth dentin. Silva *et al.*,<sup>30</sup> compared posts of four different metals to glass fibre posts. They reported that the stress distribution within the tooth restored with a glass fibre post was more homogenous than within those restored with metal posts. Furthermore, they found that stress tended to be concentrated at the outer boundary of metal posts.

For the interface between the post and dentin, glass fibre and Ni-Cr cast-made posts exhibited the lowest and highest mean stress, respectively, compared with other types of posts. This is confirmed by the findings of Lanza *et al.*,<sup>23</sup> who stated that glass reconstruction systems produced the most benign stress conditions. Similarly, the findings of the present study revealed that glass fibre posts showed a more balanced stress distribution at the post-dentin interface, as well as at the cervical area of the tooth.

Pegoretti *et al.*,<sup>24</sup> reported that glass fibre posts distributed stress better than did Ni-Cr cast-made or gold cast-made posts. This is in the same line with the results of the present study, which showed that metal posts generated the highest stress values. Obviously, tensile stress tends to concentrate in the interfaces areas where the properties of the materials are varied as revealed in this study. These findings concurred with that of Madfa *et al.*,<sup>8</sup> who noticed that the stiffer post systems work against the natural function of the tooth and create zones of tension and shear both in the dentin, and at the interfaces regardless of the cement materials used for luting the post. At the interfaces, materials have different moduli of elasticity and represent the weakest link of the restorative systems.

Generally, glass fibre post showed a reduction in peak

tensile stress compared to the other investigated post systems. The reduction in tensile stress for glass fibre post is due to their modulus elasticity being less than that of the other dental posts. The reduction in the interfacial tensile stress for glass fibre post is advantageous as it is likely to be able to resist cyclic loading and reduce the probability of root failure. Therefore, posts with elastic properties similar to dentin are preferred.

## CONCLUSION.

Mechanical properties of posts were important to determine the tensile stresses distribution. Glass fibre post tends to transfer tensile stress more homogeneously within the tooth and at interfaces than other investigated post-and-core systems.

## REFERENCES.

1. Madfa AA, Kadir MR, Kashani J, Saidin S, Sulaiman E, Marhazlinda J, Rahbari R, Abdullah BJ, Abdullah H, Abu Kasim NH. Stress distributions in maxillary central incisors restored with various types of post materials and designs. *Med Eng Phys.* 2014;36(7):962–7.
2. Madfa AA, Al-Sanabani FA, Al-Qudaimi NH. Effect of Post Materials on the Biomechanical Behaviour of Endodontically Treated Tooth. *Int J Med Imaging.* 2014;2(3):54–8.
3. Kainose K, Nakajima M, Foxton R, Wakabayashi N, Tagami J. Stress distribution in root filled teeth restored with various post and core techniques: effect of post length and crown height. *Int Endod J.* 2015;48(11):1023–32.
4. Eliyas S, Jalili J, Martin N. Restoration of the root canal treated tooth. *Br Dent J.* 2015;218(2):56–62.
5. Merdji A, Bouiadjra BB, Chikh BO, Mootanah R, Aminallah L, Serier B, Muslih IM. Stress distribution in dental prosthesis under an occlusal combined dynamic loading. *Mater Des.* 2012;36:705–13.
6. Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, Polimeni A, Goracci C. A randomized controlled trial of endodontically treated and restored premolars. *J Dent Res.* 2012;91(7 Suppl):72S–78S.
7. Torbjörner A, Fransson B. Biomechanical aspects of prosthetic treatment of structurally compromised teeth. *Int J Prosthodont.* 2004;17(2):135–41.
8. Madfa AA, Al-Hamzi MA, Al-Sanabani FA, Al-Qudaimi NH, Yue XG. 3D FEA of cemented glass fiber and cast posts with various dental cements in a maxillary central incisor. *Springerplus.* 2015;4:598.
9. Morresi AL, D'Amario M, Capogreco M, Gatto R, Marzo G, D'Arcangelo C, Monaco A. Thermal cycling for restorative materials: does a standardized protocol exist in laboratory testing? A literature review. *J Mech Behav Biomed Mater.* 2014;29:295–308.
10. Sharafeddin F, Alavi AA, Zare S. Fracture resistance of structurally compromised premolar roots restored with single and accessory glass or quartz fiber posts. *Dent Res J.* 2014;11(2):264–70.
11. Shetty PP, Meshramkar R, Patil KN, Nadiger RK. A finite element analysis for a comparative evaluation of stress with two commonly used esthetic posts. *Eur J Dent.* 2013;7(4):419–22.
12. Er O, Kilic K, Esim E, Aslan T, Kilinc HI, Yildirim S. Stress distribution of oval and circular fiber posts in amandibular premolar: a three-dimensional finite element analysis. *J Adv Prosthodont.* 2013;5(4):434–9.
13. Lazari PC, Oliveira RC, Anchieta RB, Almeida EO, Freitas Junior AC, Kina S, Rocha EP. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite element analysis based on micro-CT data. *J Appl Oral Sci.* 2013;21(6):511–7.
14. Lü LW, Meng GW, Liu ZH. Finite element analysis of multi-piece post-crown restoration using different types of adhesives. *Int J Oral Sci.* 2013;5(3):162–6.
15. Romeed SA, Dunne SM. Stress analysis of different post-luting systems: a three-dimensional finite element analysis. *Aust Dent J.* 2013;58(1):82–8.
16. Ciccio M, Bramanti E, Matacena G, Guglielmino E, Risitano G. FEM evaluation of cemented-retained versus screw-retained dental implant single-tooth crown prosthesis. *Int J Clin Exp Med.* 2014;7(4):817–25.
17. Bessone L, Bodereau E, Cabanillas G, Dominguez A. Analysis of biomechanical behaviour of anterior teeth using two different methods: Finite element method and experimental tests. *Engineering.* 2014;6(3):148–58.
18. Kaur J, Verma PR, Sharma N, Kinra M. Review of Stresses around Post Restorations – An Insight View through Finite Element Analysis. *IOSR J Dent Med Sci.* 2015;14(2):75–9.
19. Kumar P, Rao RN. Three-dimensional finite element analysis of stress distribution in a tooth restored with metal and fiber posts of varying diameters: An in-vitro study. *J Conserv Dent.* 2015;18(2):100–4.
20. Kainose K, Nakajima M, Foxton R, Wakabayashi N, Tagami J. Stress distribution in root filled teeth restored with various post and core techniques: effect of post length and crown height. *Int Endod J.* 2015;48(11):1023–32.
21. Erdemir M, Guess TM, Halloran J, Tadepalli SC, Morrison TM. Considerations for reporting finite element analysis studies in biomechanics. *J Biomech.* 2012;45(4):625–33.

22. Pérez-González A, Iserte-Vilar JL, González-Lluch C. Interpreting finite element results for brittle materials in endodontic restorations. *Biomed Eng Online*. 2011;10:44.
23. 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(8):709–15.
24. Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post. *Biomaterials*. 2002;23(13):2667–82.
25. Kinney JH, Marshall SJ, Marshall GW. The mechanical properties of human dentin: a critical review and re-evaluation of the dental literature. *Crit Rev Oral Biol Med*. 2003;14(1):13–29.
26. Upadhyaya V, Bhargava A, Parkash H, Chittaranjan B, Kumar V. A finite element study of teeth restored with post and core: Effect of design, material, and ferrule. *Dent Res J*. 2016;13(3):233–8.
27. Mahmoudi M, Saidi AR, Amini P, Hashemipour MA. Influence of inhomogeneous dental posts on stress distribution in tooth root and interfaces: Three-dimensional finite element analysis. *J Prosthet Dent*. 2017;pii:S0022–3913.
28. Amarante MV, Pereira MV, Darwish FA, Camarão AF. Virtual analysis of stresses in human teeth restored with esthetic posts. *Mat Res*. 2008;11(4):459–63.
29. Al-Omiri MK, Rayyan MR, Abu-Hammad O. Stress analysis of endodontically treated teeth restored with post-retained crowns: A finite element analysis study. *J Am Dent Assoc*. 2011;142(3):289–300.
30. Silva NR, Castro GG, Santos-Filho PC, Silva GR, Campos RE, Soares PV, Soares CJ. Influence of different post design and composition on stress distribution in maxillary central incisor: Finite element analysis. *Indian J Dent Res*. 2009;20(2):153–8.