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Review of Stresses around Post Restorations – An Insight View through Finite Element Analysis

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Abstract: *Background -The finite element method is a powerful and popular method in analyzing stress in endodontically treated teeth restored with post restorations. Endodontically treated teeth are commonly reinforced with posts, but there is lack of scientific evidence to support this practice. Because of the large variability of the results obtained from in vitro studies, an increasing number of investigations of dowel-restored teeth are based on finite element (FE) analysis. Aims- This article critically analyzes the concerned topics related to the stress pattern in teeth restored with dowel retained restorations using FEA. Methods-A systematic review of PubMed/MEDLINE, databases was completed (from 2000 to 2014). Single or combined key words were used to obtain the most possible comprehensive list of articles. Checking the references of the relevant obtained sources completed the review along with a manual search to locate related articles on the topic. In vitro (computer-based finite element, and photoelastic stress analysis studies) investigations related to the topic were included. Results- Many factors influence the stress patterns around post restored teeth. Post length, diameter, ferrule and modulus of elasticity of material used in reconstruction of teeth, adhesive materials are important parameters influence the stress distribution around post restored teeth. Recognizing the significance of these factors on the stress distribution of teeth would aid in choosing the suitable treatment modality for every individual case.*

Keywords: *finite element analysis, stresses, post length and diameter, ferrule, cements.*

I. Introduction

Today the finite element method (FEM) is considered as one of the well established and convenient technique for the computer solution of complex problems in different fields. The finite element method is a powerful and popular method in stress analysis and has been applied in dental mechanics for nearly two decades.[1- 2] FEA is a technique for obtaining solution to a complex mechanical problem by dividing the problem domain into a collection of much smaller and simpler domain (elements) in which field variables can be interpolated with the use of shape function. FEA is method whereby instead of seeking a solution function for the entire domain, one formulates the solution function for each finite element and then combines them properly to obtain solution to the whole body.[3]

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis.[4] A paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures."[5] Davy et al[6] analyzed two dimensional plane strain finite element models to determine stresses in post restored central incisor models. Since post was overrepresented in plane strain models, to correct this problem, modified plane stress and axisymmetric post in pulpless teeth models were analyzed in 1992 by Ching-Chang KO et al .[7] To simplify model construction and save computational time and costs, two dimensional finite element models have been used extensively to model three dimensional objects in biomechanics. Good two dimensional models, of course, can provide valuable insights into three dimensional problems.[8] FE analysis has been performed with two- dimensional and three- dimensional models, and the consensus is that the results obtained with 3 –D models are more valid,[9-10] but also are more time consuming and costly than 2-D models.

Endodontically treated teeth are commonly reinforced with posts, but there is lack of scientific evidence to support this practice.[11] Post restored teeth demonstrated no greater rigidity than teeth with conservative root canal therapy in an in-vitro study.[12] Previous in vitro mechanical testing's indicated that posts increased the fracture loads of pulpless teeth,[13-14] but more recent studies failed to confirm this observation.[15-16]

Investigations in recent photoelastic study also questioned the capability of a post to reinforce pulpless teeth.[17] Therefore the need for post in pulpless teeth remain controversial .

II. Material And Methods

An exhaustive search was undertaken to identify published literature related to identify patterns of stress and strain around post restorations of endodontically treated teeth. Post length, diameter, ferrule and modulus of elasticity of material used in reconstruction of teeth, adhesive materials are important parameters influence the uniform stress distribution around post restored teeth. Recognizing the significance of these factors on the stress distribution of teeth would aid in choosing the suitable treatment modality for every individual case. A systematic review of PubMed/MEDLINE, databases was completed (from 2000 to 2014). Single or combined key words were used to obtain the most possible comprehensive list of articles. In vitro (computer-based finite element, and photoelastic stress analysis studies) investigations related to the topic were included. Selected articles were then obtained and reviewed.

III. Discussion

The strength and longevity of restorations depend on the post material, its length, thickness of the post, post bond to the tooth, remaining coronal tooth structure, the presence of ferrule as well as load on the tooth. Most of the important parameters are discussed below in detail.

Geometry: The first step in FEA modeling is to represent the geometry of interest in the computer. With the development of digital imaging and 3 –Dimensional reconstruction techniques, more efficient methods are available for development of anatomically accurate models. Three dimensional reconstructions created from CT scans and MRI'S is directly imported into FEA meshes after editing. This allows more precise modeling of the geometry of the bone- post and core systems. In the foreseeable future, the creation of FEA models for individual patients with different post system, based on digital technique, will become possible and perhaps even commonplace.

Stresses: Because of the large variability of the results obtained from in-vitro studies, an increasing number of investigations of dowel-restored teeth are based on finite element (FE) analysis. The results of an FE analysis 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. Von Mises stresses depend on the entire stress field and are a widely used indicator of the possibility of damage occurrence.[18] Since compressive strength of dentin is considerably higher than tensile strength, calculated tensile and von Mises stresses may be compared with the tensile strength of dentin to assess the risk of fracture.[19] Shear stresses can result in rupture of the tooth-dowel interface.[18] Calculated shear stresses may be compared to values of adherence obtained with resin-based materials[20] or zinc-phosphate cement to assess the risk of loss of retention of the dowel.[21] When an endodontically treated teeth restored with post are subjected to the masticatory loading, dentinal equivalent stresses are concentrated on the coronal and middle thirds of the root, with slightly greater stress on the facial surface. The maximal tensile stress is concentrated on the lingual surface, and maximal compressive stress is on the facial surface. The locations of peak dentinal stresses in the two- and three-dimensional models are similar except that peak equivalent stress in the three-dimensional model during traumatic loading is located on the facial instead of lingual dentinal surface. The three-dimensional models demonstrated that peak dentinal stresses were reduced by 6.9 % to 9.6 % with gold posts and 9.9 % to 14.5% with stainless steel posts when the tooth was subjected to masticatory or traumatic loading. These reductions were slightly greater than two-dimensional plane stress (2.5% to 7.8% gold post) and axisymmetrical models (3.2% to 6.2% and 6.4% to 11% for gold and steel posts, respectively.[22]

Reconstruction of tooth: The mechanical risk associated with corono-radicular reconstruction is directly related to excessive tensile stress on residual coronal and radicular dentin. Material properties greatly influence the stress and strain distribution around reconstructed tooth structure. Analysis of stress distribution reveals that in the absence of post intracanal stress intensity is insignificant. The more intense stresses appear in the cervical region with regard to the influence of root canal post. Beta Dejak reported that use of posts caused a 21-25% decrease in stresses in dentin under oblique load whereas use of posts did not cause major changes in stresses in dentin under a vertical load. Considerable controversy exists regarding the choice of material. In a 2-D FE study of von Mises stresses, the influence of dowel modulus was investigated. The study was limited in that only peak stresses along the dentin-core interface and along the dowel were presented. It was found that the former stresses decreased, while the latter stresses increased with increasing modulus of the dowel. In 3-D FEA study, a root canal dowel of low modulus is recommended, silva et al, lanza et al, okada et al,Boschium et al[23] reported that post materials having a higher elastic modulus than dentin were capable of causing dangerous and non homogenous stresses in root dentin. Asmusse et al [24]found that increasing the elastic modulus of the post caused decreased dentin stresses in the cervical dentin. Pierrisnard L[25] observed that lower the elastic modulus of post, greater the intracanal stress at the cervical area. Still post with a modulus of elasticity close to that of dentin is preferable.[26] some manufacturers of carbon and glass fiber dowels purport that these dowels have a transverse elastic modulus that is as small as that of dentin and are, therefore, less damaging to the tooth. The FE study of Pegoretti et al[18] concluded that the investigated glass fiber dowel resulted in lower stresses ''inside the root'' than did the carbon and metal dowel. Santos-filhos et al2008, Soares et al2008 Studied that Fibre glass post has reduced stiffness in comparison to metallic post but elastic modulus of fibre glass is closer to dentine which provides more beneficial stress distribution in tooth structure . The result obtained by Isidor and Brondum[27] and Isidor et al[28] with the carbon fiber dowel in comparison with the titanium dowel may be explained, not by the low elastic modulus of the carbon fiber material, but by the relatively large diameter of the carbon fiber dowels used, conveying stiffness to the restoration, [29] and by the fact that the carbon fiber dowels were bonded, whereas the titanium dowels were not. Beeta Dejak,[30] Forberger and Gohring[31] reported that higher the elastic modulus of the core, lower the mvM stresses in the prosthetic crown and cement debonding and low contact stresses in cement –dentin interface hence higher the fracture resistance. The rigid core restorations generated less cervical stresses.

Post diameter and length: The biomechanical behavior of restored teeth mainly depends upon the length and diameter of post. Je Kang –DU 2011[32] observed the peak von mises stresses were at a minimum in root dentin when the diameter of post was 50% of root and peak tensile stresses was at minimum when diameter of palladium alloy post is 20% of premolar root. Rodriguez-Cervantes P.J et al,[33] (C.Gonzalez-Llunch et al 2009 [34], Nakamura T et al 2006). Reported that post diameter was more significant than post length for teeth restored with stainless steel post. However diameter and length was insignificant with the glass fiber post system. According to C.Gonzalez-Llunch et al 2009[34] use of greater thickness ratio resulted in higher stresses in junction of post with dentine, cement and core of model of stainless steel post systems. Nevertheless crown reduces the importance of the effect of the post diameter by acting as a protector (C.Gonzalez-Llunch et al 2009) for restored teeth. M.L.Hsu et al[35] reported that in metal post groups a short post length showed high stress concentration around the metal post tip so post length should be as long as possible. Cailleteau et al[36] regardless of post material as post length becomes longer total displacement becomes smaller. The location of stress concentration migrated from the coronal to apical area of root. Ferrari et al also found no difference in values and distribution of stresses around posts of various lengths. Rodriguez-Cervantes P.J et al[33] observed no correlation between post/root length ratio and fracture resistance likewise Schiavetti et al found no significant difference when testing fracture resistance of teeth restored with 5mm,7mm and 9mm long post. Chuang et al[37] discovered that mean root fracture resistance in teeth restored with 5 mm and 10 mm long FRC post had similar values. Fiber posts are less sensitive to length as form monobloc with resin cement and composite core and have benefits like conservative post space preparations, easy removal if retreatment is advised. According to M.L Hsu et al 2009 shorter fiber posts might be a superior substitute for longer metal posts. Nissan et al confirmed that post length does not affect the tooth strength when 2mm ferrule is present. Similarly Isidor found that post length did not influence the fracture resistance of crowned teeth when sufficient ferrule is present. However Mc laren et al showed a fracture resistance nearly 2 times higher in teeth with 10mm long posts as compared to 5mm post length.

Ferrule: Ferrule- the effect of a crown encircling – considerably increases the tooth resistance to fracture.[38] Most authors demonstrated the positive influence of ferrule effect on strength of teeth restored with post. It also increases the crown- root ratio and prevents the luting cement to wash away and improves post retention. According to Pereira[39] ferrule causes a significant increase in tooth resistance to fracture. Lima et al[40] showed that teeth with ferrule effect failed at load less than half a value without ferrule. The height of ferrule is of secondary significance in supragingival structures[41] however Nauman et al[42] and tan et al hold contrary opinions. Schmitter et al[43], Eraslan et al[44] and pierrisnard et al[25] obtained findings with FEA using post and core with ferrule effect increases stresses in teeth without supragingival structures. In clinical follow up of three years Mancebo 44 only 6.6% of failure is seen in teeth restored with post with 2mm ferrule instead of 26.20% failures is seen in teeth restored without ferrule. According to NG et al[45] maintaining coronal dentin on palatal aspect in upper incisors increase their resistance to fracture 2 times.

Cements: Three dimensional FEA has its unique advantages, such as repeatability, high accuracy and efficiency. Different kinds of adhesives with the same form and different loads can be applied on the same tooth. Apart from ability to measure the stress state at any point and interface, the deformation of the models can also be calculated which can provide data for the stability of the restoration solution.[46] The adhesives with larger young's modulus transmitted most of the load to the root canal; hence these adhesives cannot protect the root canal effectively.[47] In the same loading conditions adhesive with smaller young's modulus produced larger deformation that has an important role in protecting the root canal. In long term adhesives with low young's modulus had greater deformation and stress concentration is at the root canal orifice area may cause root splitting.[48] The maximum displacement of all adhesives in biting and chewing condition is 0.009mm and 0.046mm [49] thus deformation of the adhesive with low young's modulus can be recovered after removing the load. Glass ionomer and resin modified glass ionomer cements had better bonding strength than zinc phosphate and polycarboxylate owing to their low solubility and plastic deformation under cyclic loading.[50] However zinc phosphate and polycarboxylate cement are still more preferable in cementing metal posts and reducing the risk of root fracture during post removal and retreatment.[51] Resin based cements are the gold standard for the bonding fibre post due to their high bonding strength despite polymerization shrinkage which usually generates high stress concentration at dentine- post interface.[52-54] The maximum von mises stresses generated at the GFP cement interface were significantly lower than the metal post group regardless of the cement used conversely peak maximum von mises stresses were approximately 4-7 times higher in root dentin of GFP group similar findings were reported by other authors.[55-56]. However Romeed SA and Dunne SM reported that RC and RMGI showed the least stresses in both groups. Some studies cast doubt on their bonding strength and subsequently lead to microleakage over period of time[57] conversely other studies favour Resin cement in terms increasing fracture resistance and reducing microlaekage.[58]

IV. Summary And Conclusions

- Using stiff materials for post and core restorations leads to stress reduction in tooth tissues at cervical area.
- Bonded dowels resulted in less dentin stress than the nonbonded dowels.
- Post diameter was more significant than post length for teeth restored with metal post. However diameter and length was insignificant with the glass fiber post system.
- The absence of cervical ferrule is a determining factor resulting in increased stress level that could lead to failure.

Most guidelines were based mainly on ex vivo studies and hypothetical analysis. The lack of long-term controlled randomized clinical studies was the main hindrance to reaching a conclusive and undisputable opinion regarding endodontic posts in terms of tooth fracture and biomechanical behaviour.

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