Original Article

Stress Distribution in Four Restorative Methods in Endodontically Treated Maxillary Premolar: A 3D Finite Element Analysis

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Abstract

Introduction: the Restoration of endodontically treated teeth is critical, and the Awareness of stresses developed by oblique and vertical forces in restorative methods take a great role in treatment plans. Due to the anatomical shape and inherent form of the stress distribution premolars, could be lost by fractures. Some fractures such as vertical fracture which is probable in endodontically treated teeth, makes the teeth a candidate for extraction and other surgical procedures. According to this fact that the dental restorations should be conservative, the aim of this study was to determine stress distribution using four composite restorative methods. **Methods**: Endodontically treated maxillary second premolars were restored with composite resin using four methods. For restoration, the models representing standard Mesio-occlusal-distal (MOD) restoration, cusps capping with thickness of 1 and 2mm, and the use of woven fiber in occlusal part, were prepared. The effects of the different restorative approaches on stress distribution were analyzed using three-dimensional finite element stress analysis. **Results**: the highest stress rate was observed in MOD tooth restoration and the amount of stress in natural parts of the tooth in woven fiber was found the lowest. **Conclusion**: The simulation results show that in all models, oblique forces caused more stress than vertical forces. Moreover, there was a slight difference between different types of restorations regarding the magnitude of stress; however, the results obtained from this study showed that woven fiber could partly reduce stresses.

Keywords: Endodontically Treated, Finite Element Analysis, Restorative Dentistry, Resin Composites, Woven Fibers

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Introduction

The Restoration the endodontically treated teeth is a critical step in successful treatments. Sometimes, endodontically treated teeth may fracture because of normal functional forces. The best predictor for this type of treatment’s success is the amount of remaining tooth structure (1).the preparation of endodontic access cavities and removal of the marginal ridges negatively affect the fracture resistance of endodontically treated teeth. Moreover, other changes, such as dehydration and collagen cross- linking alterations can affect the fracture resistance (1, 2).

Posterior teeth, particularly maxillary premolars, are more susceptible to cusp fracture under occlusal loads due to their anatomic form (3).

In recent years, the patient's demand for tooth colored restorations has increased; and the advances in resin based composite technology have indicated them as a good candidate for large restorations (4).

Composite restorations are somtimes preferred to cast restorations, due to simpler procedures and lower cost (5).

One study reported that composite resin restorations can strengthen the remaining structure of endodontically treated tooth about 65% of the intact tooth (6). In another study, this strengthening was reported at about 50% for premolars (7).

Different approaches have been recommended using this method to decrease the functional stresses and increase the fracture resistance of endodontically treated teeth.

One technique is cusp capping, which is performed by slightly reducing cusp height and covering the remaining structure with composite resin. This procedure could be applied only on functional or all of the tooth cusps. According to other studies, cusp capping can distribute the functional stresses on the remaining tooth structures and protect them against catastrophic tooth fractures (4, 8-10).

Another method to increase the stiffness and fracture resistance of these restorations is to use woven fibers as a part of a composite restoration to enhance its mechanical properties (11, 12). A number of previous studies suggested that fiber can splint the tooth cusps and increase the fracture resistance, whereas others revealed no significant positive effects (4, 11-17).

The aim of this study was to investigate the effect of four restorative methods on the stress distribution of endodontically treated maxillary second premolar under various occlusal loading conditions, using a three dimensional Finite Element analysis.

Materials and Methods

Modeling

Stress analysis in a tooth by a finite element method in an engineering analysis software, needs two or three-dimensional model of the object requiring appropriate numerical and dimensional information of the structural shape of the software. Simulation accuracy varies depending on the type and method of modeling,. It is obvious that a three-dimensional model of an object has more accurate and better results in analysis.

A) *Master Model Preparation.* In this study, a human maxillary second premolar was selected to obtain a three-dimensional model of the tooth, (figure 1(a)).Subsequently a three-dimensional scanner with an accuracy of 0.08 mm was used this study. In the next stage, the point cloud of tooth surfaces was created by importing this point cloud data to CAD software (CATIA V5 R21) (figure 1(b)) and progress performing, Moreover a 3D model of the intact tooth was made, (cited in this article as “primary model”) (Figure 1(c)), Then, the model dimensions close to standard sizes were acquired considering Wheeler atlas (Fig. 1(d)).

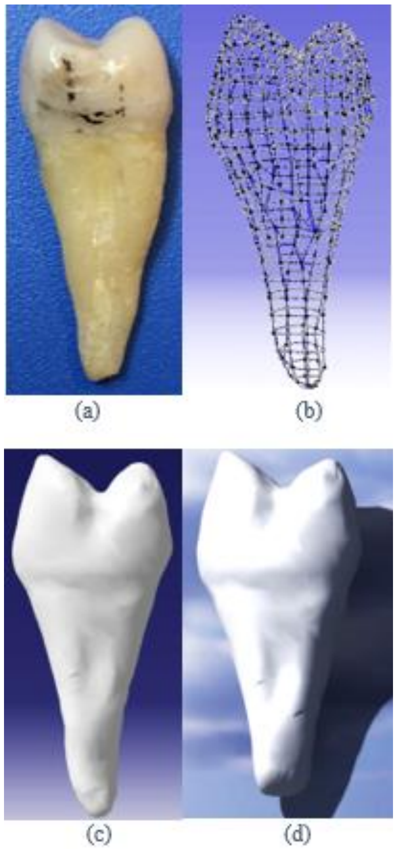


Figure 1. Model preparation, (a) Prepared natural tooth, (b) Point cloud of tooth surfaces, (c) Primary model, (d) Modified model

Enamel thickness varied between 0 and 2.3 mm on the cusp tips.

The bone model was created from two distinct parts including the cortical bone and the cancellous bone. Cortical bone thickness in this model varies between 0.20 and 0.25 mm. (Figures. 2 and 3) (18).

Gums were modeled as a layer with the thickness of 0.35 mm on the upper surface of the bone, and periodontal ligament was modeled as a layer of 0.25 mm thickness covering the root. (Figures. 2 and 3(a)). (20)

Figure 2. Model preparation, exploded view of the intact maxillary second premolar tooth model

Figure 3. Model preparation, model of intact maxillary second premolar tooth

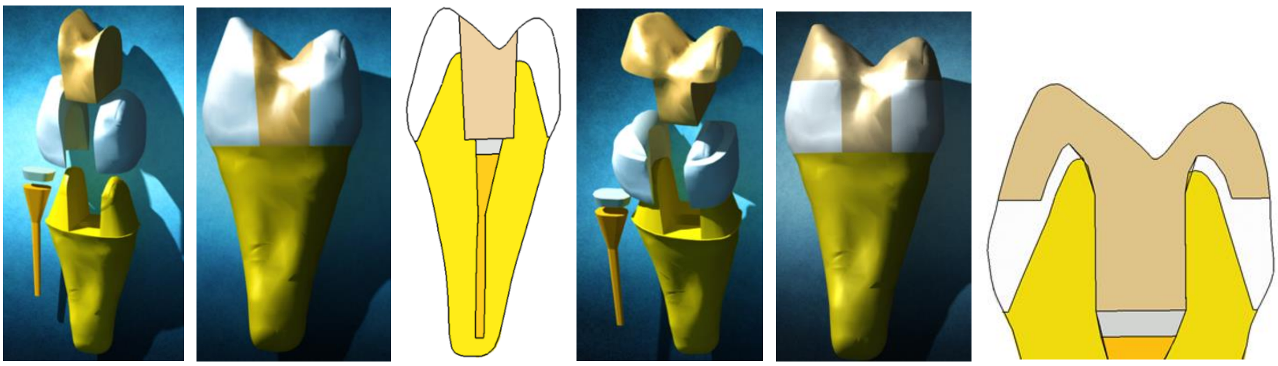
B) *Restorative Approaches*. In this study four Restorative Approaches were considered, and their 3D models were created with some changes in the intact tooth model. The root canal system was modeled based on the protaper rotary instrument properties and gutta percha was set at 1 mm short of the apex.in the next stage, the RMGI cement was used to cover the canal orifice with 1 mm thickness.The model preparation of the four restorative methods is as follows:

The first method (Mesio-occlusal restoration): Mesio-occlusal-distal (MOD) and endodontic access cavity were prepared on the tooth model. Buccopalatal dimension was obtained from the buccopalatal size of the tooth pulp chamber. A radiograph was obtained from the tooth and its magnification was measured using a metal sphere, cemented beside the tooth on a radiographic film. It was about 3.5 mm in cervical to 4.5 mm in occlusal part of the MOD preparation (Figuress. 4(a), 4(b), and 4(c))

The second method (cusps capped for 1 mm): This model is similar to the MOD model except that both cusps were 1 mm reduced and covered with composite resin materials (Figures. 4(d), 4(e), 4(f))

The third method (cusps capped for 2 mm): The model in this method is similar to the MOD model except that both cusps were capped with 2mm composite resin material. (Figure. 5(a))

The fourth method (woven fiber used): the model in this method is similar to the third model except that the space with (5 mm length and 3 mm width) was designed in the Bucco-palatal direction over the buccal and palatal cusps on the master model for the woven fiber. Finally, the upper portion of the woven fiber was covered with composite resin. The thickness of the woven fiber layer in this model varies between 0.15 mm and 0.3 mm. (figure. 5(b))



(a) (b) (c) (d) (e) (f)

Figure 4. Restorative approaches, (a), (b), (c) MOD restoration different views, (d), (e), (f) cusps capped for 1 mm different views

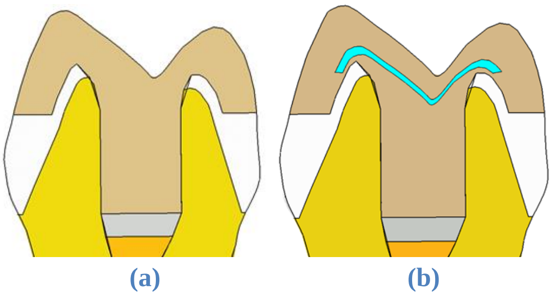


Figure 5. Restorative approaches: (a) cusps capped for 2 mm section view, (b) woven fiber used section view

Analyzing process

After assembling each model, ANSYS 16 software (ANSYS Workbench) was used to analyze the stresses in the restored tooth models. This requires some information about the mechanical properties of restorative materials.

a) *Structures and materials.* In this study, the material's structure is considered isotropic to simplify the calculation; Table I shows the mechanical properties of each part which is necessary for the static analysis.

b) *Loading and Stress Analyses.* Three different types of analysis were performed in this study. In the first type, a 100N vertical force was applied to the central fossae of restored tooth models parallel to the tooth long axis. In the second type, a 100N oblique force was applied to the palatal cusps at a 45° angle to the long axis of the tooth. In the third type, both vertical and oblique forces were applied to the model. Stress distribution in all restorative approach models was evaluated with a 3D finite element stress analysis. Additionally, Von Mises stress rates were recorded in this study.

Table I. Material properties

Material	Young's modulus	Poisson's ratio
Enamel	80	0.3
Dentin	18	0.31
Periodontal ligament	0.0007	0.49
Cortical bone	13.8	0.26
Cancellous bone	1.37	0.31
Composite resin	19	0.24
Woven fiber	12	0.3
Resin-modified glass-ionomer	10.6	0.3
Gutta percha	0.14	0.45

Results

Figures 7-10 depict the Simulation results for different models In each figure von-misses stress is shown for three different types of analysis. Maximum stress values in each analysis are shown in Table II. In all models, enamel in the cervical area and at the cementoenamel junction showed the highest stress values during force application.

The highest stress value was observed in MOD restoration model. Although, the differences between models were not statistically significant, the woven fiber method of restoration showed the lowest stress values.

Table II. Maximum stress values in different models

Model	Part	Vertical Force	Oblique Forces	Both Forces
First Method	Enamel	20.933	49.27	58.39
	Dentin	10.192	27.598	30.527
Second Method	Enamel	16.069	48.275	57.719
	Dentin	9.9427	26.398	29.974
Third Method	Enamel	15.649	47.211	56.573
	Dentin	9.6616	26.893	30.483
Fourth Method	Enamel	16.976	45.718	55.297
	Dentin	9.4156	23.42	27.907

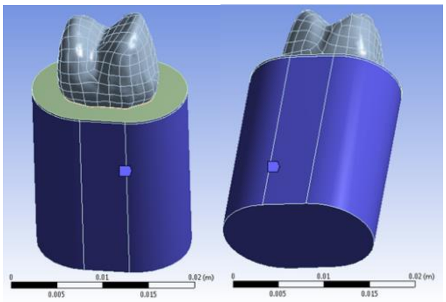
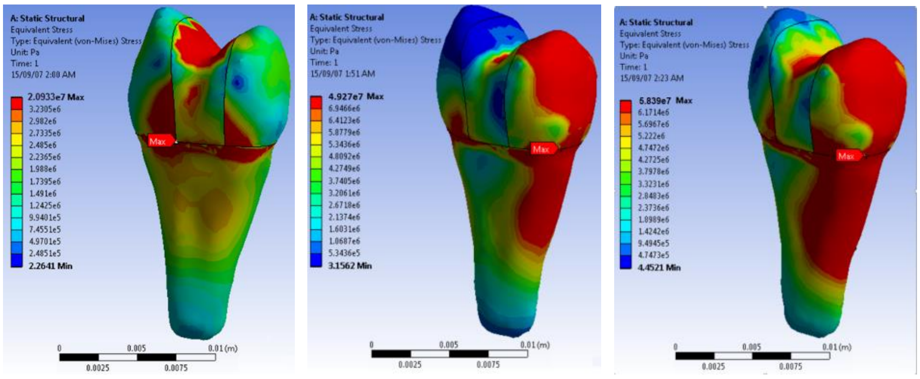
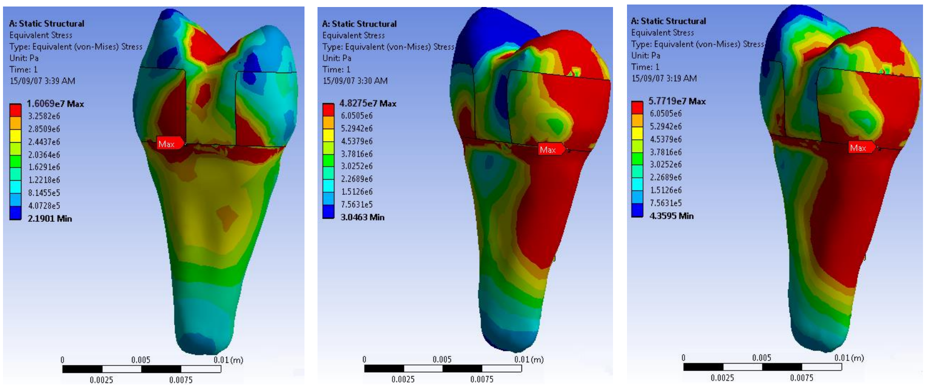


Figure 6. Fixed supports



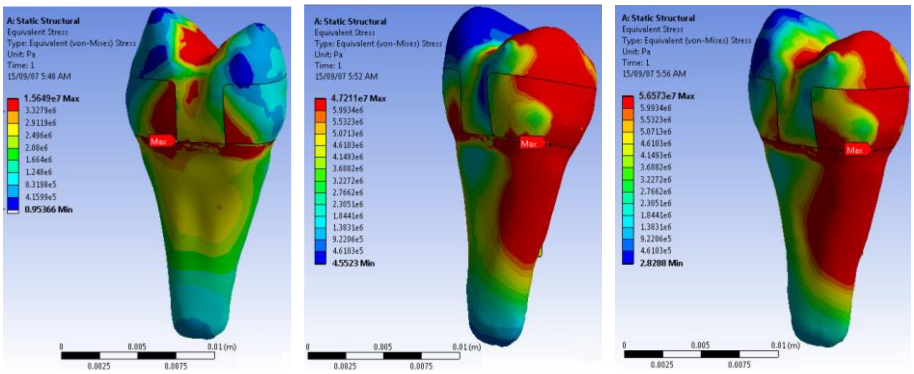
(a) (b) (c)

Figure 7. Principal stress distribution of the first method, (a) vertical force, (b) oblique force, (c) both forces



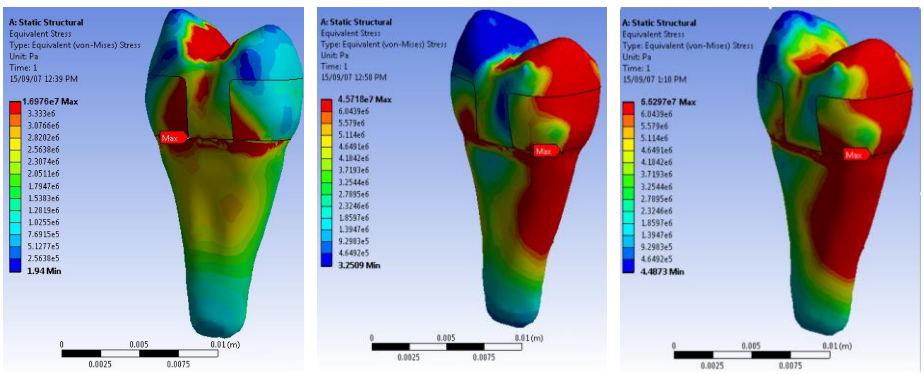
(a) (b) (c)

Figure 8. Principal stress distribution of the second method, (a) vertical force, (b) oblique force, (c) both forces



(a) (b) (c)

Figure 9. Principal stress distribution of the third method, (a) vertical force, (b) oblique force, (c) both forces



(a) (b) (c)

Figure 10. Principal stress distribution of the fourth method, (a) vertical force, (b) oblique force, (c) both forces

Discussion

Endodontically treated teeth may be at a high risk of fractures and destructions. This issue is bolded in maxillary premolars due to the high functional pressure and smaller size of molars (21-23).

Restorative techniques play an important role in successful treatments. It is shown that a proper technique could lead to a higher fracture resistance in tooth structure (24). In this study, it was attempted to evaluate the stress distribution of endodontically treated maxillary premolars with a variety of restorative approaches.

Different methods, including –finite element analysis have been used to analyze the stresses in tooth structure. It is a precise method in assimilating clinical situations. Because of the nature of this method in simplifying the forces and other elements the researchers should focus on the quality rather than quantity (25). The study utilized vertical, oblique, and both force directions to analyze the stress distribution in designed restorative techniques.

Our results demonstrated that oblique forces may cause more stress in dental structure than vertical forces. The stress values that observed in enamel were higher than dentin. In the critical phase with both vertical and oblique forces, stress distribution in enamel and dentine parts were minimum which was similar to an intact tooth-in the fourth method (using a woven fiber). The results obtain from this technique are not in line with the findings the first method (i.e., MOD restoration - without cusp reduction) which ended to maximum stress values and it is shown that composite cusp covering applies less stress to dental structure.

Belli et al (1) studied the fracture resistance in endodontically treated molars with different restorative approaches and revealed similar results. They concluded that polyethylene fibers (Ribbond) led to a stable and resisting restoration in MOD molar cavities. According to a study conducted by

Sengun et al (13) in 2008, the effect of fiber-reinforced restorations was evaluated in endodontically treated teeth. Their results showed that there was no significant difference in fracture resistance between restorations with or without using fibers however the failure in teeth restored with fiber-reinforced composite was limited to the enamel part and was repairable. They concluded that this technique was more reliable than others.

In a similar study carried out by Oskoee et al (11) in 2009, the fracture resistance in endodontically treated teeth was evaluated with three techniques. The result showed that using fiber in occlusal part of restoration had the maximum fracture resistance and it was concluded that restorations with fibers in any of evaluated methods were more fracture resistant compared to the other groups.

Jiang et al (21) in 2010, investigated the stress distribution in endodontically treated molars with composite, ceramic and gold inlay and onlay. The found out that composite onlay had the most release in stress distribution.

In 2011 Eraslan et al (19) applied different restorative methods to study the stress distribution in endodontically treated premolars. Their results showed that the fiber-reinforced restorations had a stress distribution similar to an intact tooth.

These results are consistent with the finding in this study; however, on the contrary, researchers reported different effects. Similarly,

Fukushima et al (26) in 2004, investigated the fracture strength of endodontically treated premolars restored with different methods. Their results revealed that teeth with composite onlay had a significant lower fracture strength than intact teeth.

Soares et al (27) performed astudy on the role of cavity preparation design in endodontically treated mandibular premolars. They used four methods of cavity preparations and found out that fracture strength in bicuspal reduction was significantly lower than the simple MOD cavity preparation. These results may because of the type of selected tooth. In mandibular premolars reduction of 2/3 of cuspal height could lead to a major loss of tooth structure and as a result, the lower fracture strength.

In another study Yikilgan et al (22) investigated the stress distribution in endodontically treated maxillary premolars with four methods of restorations. They showed no difference in stress formation with the use of fiber. No explanation was found about the buccolingual size of preparation in the model in this study. However the paper's pictures, it seems that this aspect of the cavity was greater than access cavity that was used in our modeling which maybe the reason for the results.

Considering these inconsistent results, endodontically treated teeth restoration has remained a challenge so far. With the limitations of this study, it seems that cusp capping fiber-reinforced restorations could play a better role in stress distribution in endodontically treated teeth. These findings should be supported by further laboratory and clinical studies.

Conclusions

This study evaluated the stress distribution in endodontically treated maxillary premolar with four different restorative approaches. In each model three different load directions (i.e., vertical, oblique, and both) were performed. As it was predictable, oblique forces led to more stress than vertical ones in all models. Although, the amount of stress in all restorative methods was not statistically different the use of woven fiber with both cusps reduction could reduce the stress compared to the other methods.

Conflict of Interest

The authors declare no financial or other competing interest concerning this article.

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