

THE EXAMINATION OF THE STRESS DISTRIBUTION MODEL OF THE ENDODONTICALLY TREATED MAXILLARY SECOND PREMOLARS RESTORED WITH DIFFERENT METHODS BY FINITE ELEMENT ANALYSIS METHOD

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ABSTRACT

Aim: The aim of this study was the evaluation of the effect of the type of restoration (ceramic or composite with and without post inside the canal) on the stress distribution and the most fracture prone area in the maxillary second premolar.

Materials & Method: Three groups in this study include endodontically treated and restored second premolars: 1) Composite build up with buccal and palatal cusp coverage (composite onlay), 2) Composite build up with buccal and palatal cusp coverage and intra canal stainless steel post 3) Endo-Crown Ceramic. 18 roughly equally dimension maxillary second premolar, single rooted and sound were mounted in an acrylic block after root canal treatment. MOD cavities with 2 mm reduction were prepared. Finally, all three models were studied by finite element method in ABAQUS software.

Results: In finite element analysis, the highest stress was observed in group 3 (Endo- Crown) in the point of applied force in the restorative material at the crown (80.55 Mpa), in the middle third of tooth at the dentin (4.8 Mpa) and at the contact level of the restorative material and dentin (4.5 Mpa) respectively. In group 2: the highest stress was registered in root apex (1.88 Mpa). The presence of post improved the stress in the middle third of dentin compared to the non-post group, although it causes the focus of the stress in the apex and interface of the restoration and dentin of core region. Ceramic restoration produced more stress at the interface of restoration and tooth compare to composite one because of its more elastic modulus.

Conclusion: Intracanal post is used to retain restorative material. In terms of resistance to lateral forces, it is superior to other methods of restoration. Intra canal post insertion significantly reduces the stress of the cervical area, but the concentration of stress is transferred closer to the apex of the root so in the case of fracture, the catastrophic damage will be created in tooth.

Introduction

Maxillary premolar teeth after molar ones are the most commonly teeth need restoration,¹ and due to small dimensions and the anatomy of canal and crown usually require root treatment in a short time.²

Following root treatment, the teeth needs that the crown to be protected against fracture, especially in the cervical area that is the most prone area to the fracture.^{3,4}

It has been proven that the dentin of endodontically treated teeth is affected by the change in the physiological properties and physical properties associated with decreasing collagen level (reduction of hardness and fracture resistance), decreasing the elastic modulus caused by dehydration and loss of tooth tissue and, consequently, is prone to be fractured.^{5,6}

Many studies have investigated the necessity of placing post, its material, and the type of corono-radicular restoration.⁷ Regardless of the type of selective corono-radicular restoration, the following conditions for choosing treatment plan are necessary to be considered:

It is necessary to protect the restoration of the tooth against the forces through the proper distribution of force. (The necessity of choosing the type of restoration). All studies conducted agree that the forces (seen in clenching) create more stress from the forces parallel to the longitudinal axis of teeth.^{9,7}

It is necessary that the restoration have enough stability. The use of post inside the canal should not be used as a routine treatment, although the role of the post has been proven to strengthen the restoration regardless of the amount of remaining coronal tissue.^{11,10}

It is necessary that the used restoration minimizes the needed level for shaving and removing the tissue.

It is necessary that the selective retention considers the prosthetic role of the tooth. For example, if the intended tooth to be the base of the fixed partial Denture, which will be subjected to direct and indirect prosthetic forces, it will ultimately be a threatening factor to the durability of the tooth.

Aggressive treatment that includes post and core and all ceramic or PFM coating^{12,14} requires more cost and time compared to Endo- Crown treatments, or composite restorations, as well as the preparation of healthy tissue even, if not damage the resistance of tooth is not acceptable for the patient.

Since the examination of fracture resistance is costly and time-consuming by practical destructive tests and requires a large number of samples, the present study seeks to identify the most resistant type of restoration among three groups of endodontically treated and restored tooth with composite buildup, composite buildup with the post inside the canal

and Endo- Crown by finite element analysis method, and paves the way for subsequent studies in this field.

Therefore, in this study, the effect of the type of restoration (ceramic or composite with and without post inside the canal) is examined on the way of stress distribution and the most susceptible areas to fracture in the maxillary second premolar tooth.

Materials & Method

1. The introduction of the studied groups in this study:

Group 1: endodontically treated and restored treatment in the form of composite build up with the coverage of buccal and palatal cusps (composite onlay) (9 teeth)

Group 2: endodontically treated and restored treatment in the form of composite build up with the coverage of buccal and palatal cusps with the post inside the canal made of stainless steel (Nordin Gold plated screw post) (9 teeth)

Group 3: endodontically treated and restored maxillary second premolar tooth with Ceramic Endo-Crown. (9 teeth)

A strain measurement test was performed on these samples.

2. Practical test of strain measurement:

The practical strain test of the teeth with similar restoration of finite element analysis model under the same conditions is performed to verify the accuracy of the results of the finite element study/analysis test.

27 maxillary second premolar teeth, single root and single canal, healthy and without fracture, decay or crack in the same dimensions (with a crown dimension difference up to 10%) that less than 4 months is passed of pulling them for periodontal or orthodontic reasons were selected for this study.

We used polarized light radiation using the 1200LED-lumens light source and the Berno Pro 67 mm Polarizing Filter to detect the crack in the tooth.

Ultrasonic scaler was used to clean the debris from the root surface, and then the teeth were kept in 0.2% thymol solution.

Diamond Grinders (with water cooler) were used to prepare the access cavity.

The canal spaces were prepared by the Pro Taper system up to F3 number and filled with Gutta percha with a 6% convergence and AH Plus sealer. (Dentsply)

The teeth were shaved by Diamond Grinders(with water cooler) for the restoration and restorative cavities were prepared in then with the following relative dimensions:

Isthmus width : 1/2 * intercuspal width ;

Dimensions of proximal cavities:

Depth: 2/3 * vertical crown length (CEJ to Cusp's Tip)

buccolingual : 2/3 * tooth's buccolingual width;

Reduction of cusp height: minimum of 2 mm;

Then these teeth were placed in an acrylic cold cure block with the same dimensions 18 * 12* 23mm from the apical side to the 3 mm distance from the CEJ.

This set was placed in cold water to prevent thermal damage to the teeth during acrylic chemical reaction. Prefabricated metal posts were used with number M2 with a total length of 9 mm, and a root extension of 6.5 mm and a diameter of 1 mm.

We connected a strain gauge using a resin cyanoacrylate adhesive to the buccal surface of crown of 18 teeth from both groups after washing /rinsing and acid etching with 35% phosphoric acid for 20 seconds, water rinsing and air drying.

A strain gauge with a resistance of 120 ohms and a gauge factor of 2.08 was used in this study. Fixed resistances of 120 ohms and 1% accuracy were used in circuit. The strength of all components with digital multimeter was confirmed with accuracy of 3 digits. Then all the gauges were placed in the Wheatston Bridge circuit, and then this circuit was connected to the computer using a HX711 unit and Arduino Uno unit equipped with the hx711 library, and the strain value was compared with the number obtained from the UTM (Universal Testing Machine) device.

The single point bending method of metal beam was used on a piece made of steel (with st14 code) in the dimensions of 20 x 420 x 200 mm, and on a one-way cantilever to calibrate the system. A strain gauge was connected at a distance of 50 mm from its support/ cantilever.

Weights with different values were added to a point at the free end of the beam and the metal beam strain was calculated based on the mathematical phrase No. 1 obtained from the Euler-Bernoulli beam theory. The circuit voltage was recorded and the strain diagram to voltage was obtained for this system. This diagram has been shown along with the theoretical and tested values of the strain to the voltage (Diagram 1).

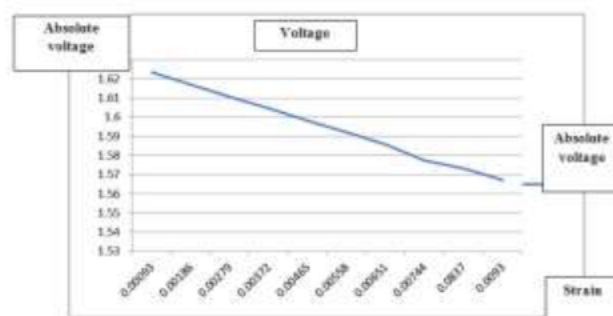


Diagram 1: Voltage to strain in calibration of strain gauge

The values of the voltage to strain were compared with the theoretical values.

Phrase No. 1 (15)

$$\varepsilon = \frac{6mgD}{Ewt^2}$$

W: beam width (cm)
 t: Thickness of the beam (mm)
 D: Distance of the strain gauge to the weight (m)
 g: gravity constant (9.816)
 m: mass (g)
 E: Elastic Modulus

Phrase No. 2 (16)

$$V_{out} = \left(\frac{R_p}{R_p + R_1} - \frac{R_x}{R_x + R_3} \right) \cdot V_{in}$$

V_{out}: Voltage measured by hx711 (volt)
 V_{IN}: Input Voltage to Circuit (Volt 3.3)
 R_p: Potentiometer resistance (Ω ohm)
 R: fixed resistance (Ω ohm)
 R_x: Strain gauge resistance (Ω ohm)

Phrase No. 3 (17) the strain relationship with strain gauge resistance change.

$$\Delta R_g = K \cdot R_g \cdot \varepsilon$$

K: Strain gauge constant coefficient
 R_g: strain gauge resistance ()
 ε: Strain, $\left(\frac{\Delta L}{L}\right)$

All teeth were fitted in the Universal Testing Machine {UTM} of the STM-200 model} and were subjected to the forces examined in this study.

The force of 400 N was entered by a 3 mm diameter cylindrical connector at a speed of 0.3 mm / min parallel to the longitudinal axis of the tooth to the palatal cusp of the teeth, and the result is reported as a strain diagram that was compared with the result of finite element analysis for confirmation.

This test was repeated 2 consecutive times for each tooth and the mean strain value was reported as the final result.

3. The preparation of three-dimensional models:

First, the anterior form of crown and root was prepared by photogrammetry method in order to perform linear structural analysis to calculate stress distribution model in different kinds of endodontically treated tooth restoration. The dimensions of the restoration and its components were recorded during the restoration and were transferred to the 3D model. Three models were set in 3 groups based on the variables studied in this study.

4. The preparation of Finite Element Model:

FE models were obtained by entering original 3D models with the ASIC SAT format to ABAQUS-Dassault System software.

The appropriate units have been used according to the following table:

Length	Force	Mass	Time	Stress	Energy	Density
mm	N	tonne	S	(MPa)Nmm ²	mJ	Tonne/mm ³

Physical behavior and mechanical properties (Poisson's Ratio(v) and Young's Modulus of Elasticity) N/mm² (of different materials are attributed to the corresponding components, that its details have been shown in Tables 1 and 2.

The solid homogeneous section is made based on the characteristics of the materials and was assigned to the relevant part.

Dentin has an orthotropic material property, which can be considered as isotropic linear elastic in these macroscopic dimensions and with force in the direction of the vertical axis.^{19,18}

Other materials are considered that include enamel, metal post, and isotropic linear elastic ceramic.^{21, 20}

Stainless steel screwed metal post with gold covering made by the Swiss company Nordin is used.

The material of endo crown was selected from Glass Ceramic Lithium-Disilicate and condensable highly filled composite (3M_Filtek_p60) was used in this study.

Material	Type
Enamel	Isotropic
Dentin	Isotropic
Resin Cement	Isotropic
Glass ionomer Cement	Isotropic
Stainless steel Post	Isotropic
Ceramic	Isotropic

Table 1: Physical behavior of the materials studied in this study

Material	Young's Modulus (N/mm ²)	Poisson's Ratio (v)	Reference
Enamel	84400	0.20	(54)
Dentin	18600	0.31	(49)
Stainless steel Post	200000	0.33	(55)
Resin Modified Glass ionomer Cement	7500	0.35	(56)
Glass ceramic(IPS Empress 2)	96000	0.22	(57)
Resin Based Composite	12500	0.35	(58)
Gutta-percha	380	0.48	(59)
Poly Methyl methacrylate	2500	0.35	(60)

Table 2: Elastic numerical values of the materials investigated in this study

Among the materials present in the study, the metal post is a part of ductile materials.²²

The force used in this study, which was selected based on the forces measured in previous studies is as follows.

Vertical intrusive 400 N parallel to the longitudinal axis of the tooth is entered to the occlusal table of the functional cusp, which according to previous studies, is equivalent to the maximum normal chewing force in the premolar tooth^{25, 23}

A force of 400 N was entered a plate at the palatal surface of the tooth in the study of finite element.

The boundary conditions were considered in the form of displacement lock in 3 directions of space at the lower level of the acrylic block.

The results obtained from finite element test were examined by Von mises Criterion²⁶ whose value is always positive and dependent on the entire area under stress.

Von mises stress, which is commonly used as an indicator of stress in isotropic materials, is dependent on the overall energy of the stress and is always positive.

The meshing of all components was done because of the complexity of the shapes and the presence of narrow edges in the form of tetrahedral.

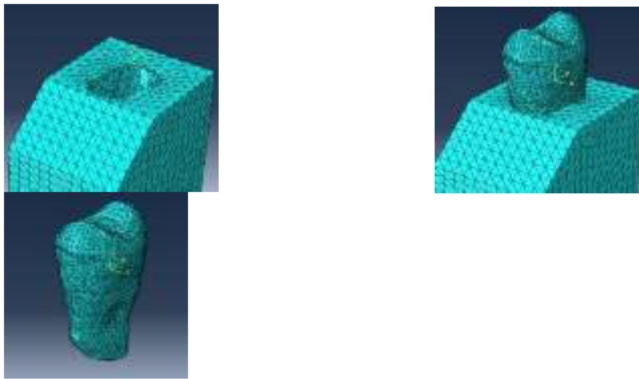


Figure 1: The meshed image of root and crown

Results

1. The results of testing the finite element analysis are as follows:

Based on the results, the highest amount of stress in the crown was calculated at 80.55 Mpa in the restored model with Endo-Crown (group 3). The highest stress amount in the middle one third of the tooth in dentin was calculated in the restored model with Endo - Crown (4.8 Mpa), and its lowest amount is related to the group of the post inside the canal. The highest amount of dental apex stress was calculated 1.88 Mpa in the restored model with the post inside the canal and composite buildup (group 2). (Figure2-5)

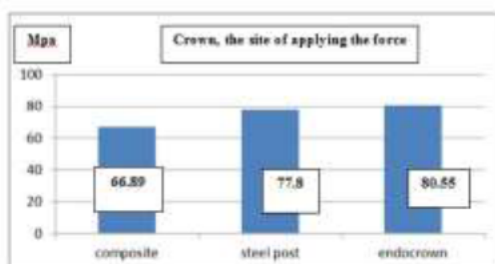


Figure 2: The comparison of the maximum stress of von mises in the crown of all three models

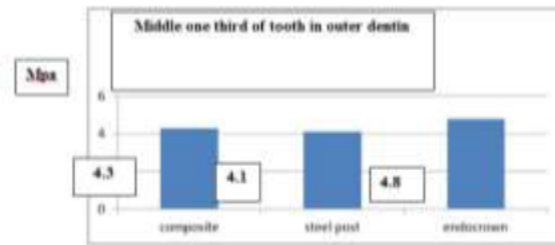


Figure 3: The comparison of the maximum stress of von mises in the crown of middle one third of all three models

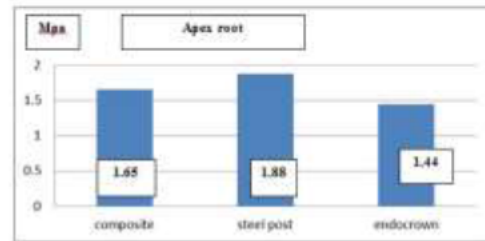


Figure 4: The comparison of the maximum stress of von mises in the apex crown of all three models

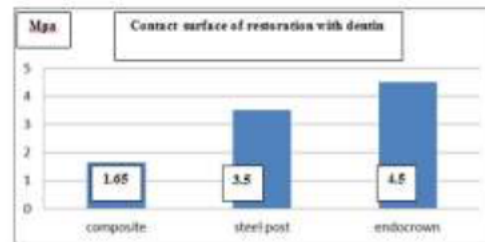
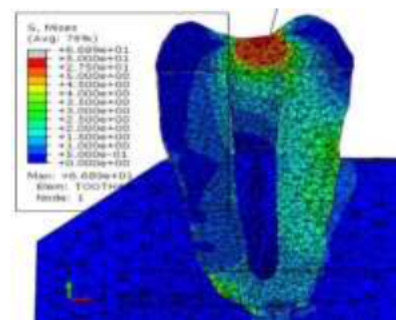


Figure 5: Comparison of the maximum stress of von mises in the contacting surface of restoration with dentin

Based on finite element analysis test, maximum stress of von mises was calculated at the contact surface of the crown range of metal post with composite 11 Mpa and the highest stress amount was calculated 16.8 Mpa in the middle one third of the tooth inside the metal post.

The model of stress distribution in 3 models has been shown as isoStress in the following figures.

Colors represent the von mises stress with MPa unit.



The following figures show the finite element analysis of the restored tooth with composite.

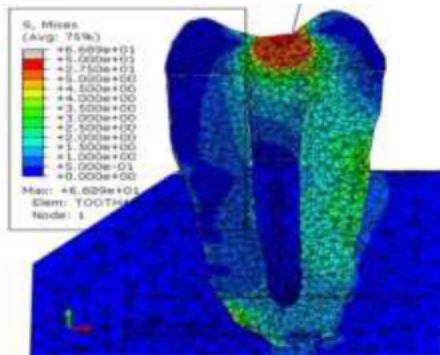


Figure 7: Stress distribution of von Mises in the anterior posterior facet of the restored tooth with composite

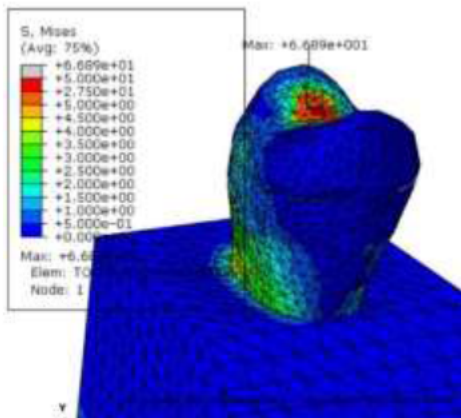


Figure 8: Stress distribution of perspective in the anterior posterior facet of the restored tooth with composite

The following figures show the model of finite element analysis of restored tooth with composite and the post inside the canal.

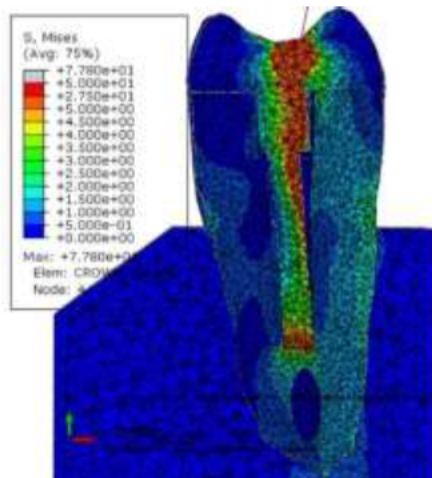


Figure 9: Stress distribution in the anterior posterior facet of the restored tooth with composite and the post inside the canal

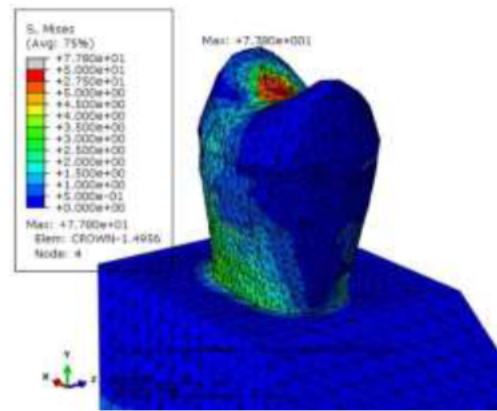


Figure 10: Stress distribution of perspective in the anterior posterior of the restored tooth with composite and the post inside the canal

The following figures show the model of finite element analysis of restored tooth with Endo -Crown.

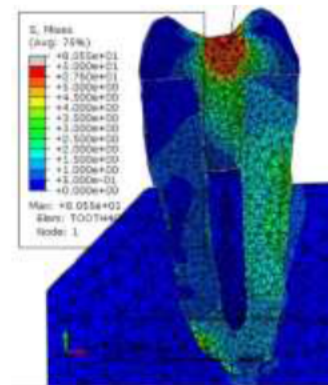


Figure 11: Stress distribution of the anterior posterior facet of the restored tooth with Endo - Crown

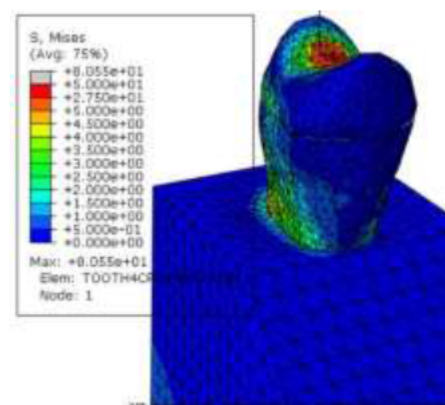


Figure 12: Stress distribution in the perspective of restored tooth with Endo -Crown

2. The result of the practical test and its comparison with the study of finite element analysis:

In the test of teeth in UTM, the amount of strain was obtained against force for different teeth.

$$\mu = \bar{x}$$

The UTM displays the displacement level of the sample against force at the contact point (palatal cusp) and records the strain gauge system at the buccal level.

Assuming the normal distribution of the data, the natural distribution range was obtained using the following phrase and the t-table. The sample size was number 9 (degree of freedom was 8) and $\alpha=0.05$ (error level).

$$\mu = \bar{x} \pm t_{\frac{\alpha}{2}} \cdot \frac{s}{\sqrt{n}}$$

Buccal strain (μ strain)	Finite element analysis	Medium value in practical test (9 sample)	SD	Range of normal distribution
Restored tooth with composite	105.95	100.22	15.4497	11.913±
Restored tooth with composite and post inside canal	106.43	110.44	0.635366	7.3135±
Group crown	105.32	109.73	0.85222	6.3256±

Table 3: Strain at Buccal level

Vertical displacement in palatal cusp (mm)	finite element analysis	Medium value in practical test (9 sample)	SD	Range of normal distribution
Restored tooth with composite	0.047	0.0481	0.0103	0.01187±
Restored tooth with composite and post inside canal	0.052	0.0473	0.0089	0.0068411±
Group crown	0.049	0.0461	0.0076	0.0086321±

Table 4: Vertical displacement of palatal cusp

As shown in Tables 3 and 4, the values obtained from the finite element analysis are in the 95% range of normal distribution of the mean values resulting from the practical test and cannot reject the accuracy assumption of data of finite element analysis.

Discuss

Premolar teeth have a function between cutting and crushing, such as the anterior and posterior teeth. Usually the stress accumulates in heterogeneous materials or at contact surfaces. The contact surfaces of the materials with different elastic modulus are the weak points of a restoration system, because the difference in toughness and stiffness affects the propagation of stress.^{27,26} Kinney *et al.*²⁸ concluded that the stress values of von mises inside the dentin are comparable to the tensile strength of dentin to evaluate the probability of tooth fracture. Also, some researchers have suggested that dentin tensile stress is the main contributing factor in tooth fracture.^{26,29}

However, von mises stresses indicate more multi-axial stress situation, because they show the areas that are subjected to highest stress that in fact, it predicts the

fracture due to fatigue. The direction of force is effective in the stress level created so that the direction of force has been considered more effective than other factors in stress concentration.^{28,29} In this study, maximum stress in the crown area at the place of entering the force was between (66.89 and 80.55 Mpa) that is close to the study conducted by Dong-Yeol *et al.*²⁰

Lower maximum stress of the crown in the other two groups compared to the restored tooth with the ceramic endocrown is probably due to the greater flexibility of the composite than the ceramic. As the modulus elastic of ceramic is 96000 Mpa and modulus elastic of composite is 12500 Mpa.

The composite has the ability to distribute stress in the core volume, while the ceramic distributes less the force due to less flexibility. This model of stress propagation in the tooth can predict the possible point of catastrophic fracture. In the dentine of the middle one third of the tooth, which is adjacent to the connection point of the acrylic block to the tooth, the highest stress has been seen in group 3 (Endo - Crown). Here, this area certainly plays a supporting role and acts as a bone crest in the normal dental system.

In the present study, post insertion significantly reduced the stress of the cervical area, which is consistent with the results of kishen and pierrisnard.³⁰ Perhaps the metal-post due to less flexibility than the dentine as the load carrier column transfers all the stress directly to the end of post and causes the least accumulation of stress in the dentin in the middle area of the tooth so that the stress in this group has been evaluated less than the other two groups. The presence of the post significantly increases the stress levels in the radicular dentin wall, which several authors have obtained the same results.³⁰

Kishen *et al.* reported that these areas are the stress concentration of the main centers of forming the crack inside the canal below the crestal bone and actually indicate a higher occurrence of root fracture in restored teeth with the post that is due to the fact that functional stress model and strain distribution in the dentin is more effective than the mineralization rate and its spatial gradient direction.

Functional dentin adaptation leads to a more mineralization and larger elastic modulus in the external dentin of the labiolingual plate, as well as less mineralization (more collagen) and less elastic modulus in the inner dentin of core.

In addition, the results of the present study indicate that post placement increases the likelihood of root fracture. Stress in the studied teeth in static forces was obtained in the range of 1.44 and 80.55 that is much less than the ultimate tensile strength of the tooth textures (44 to 97 Mpa) and restorative materials.²⁹

According to the results of the previous studies, routine chewing forces do not seem to cause fracture of any restored teeth. Cyclic forces of chewing increases the growth of cracks in the restored teeth at the interface of restoration and tooth structure. Sudden fracture of the

dentin due to the material fatigue is seen even in non-restored teeth under excessive chewing forces.³⁰

In the examination of maximum stress in the interval of the restoration and dentin, the highest stress has been observed in the restored group with Endo- Crown and the lowest has been seen in the restored group with non-post composite. The difference of elastic modulus between the composite and the ceramic is the difference factor in the maximum amount of stress in restoring and dentin in the surface between the restoration and dentin.

In the restored tooth with metal post and composite, the post transmits forces directly to the end part, and a smaller amount of force is entered the dentin and the contact surface of the restorative material and dentin. The stress distribution model is similar in restored samples with composite and ceramic Endo crown, in such a way that the stress accumulation areas are at the place of entering the force in the crown at the contact surfaces between the restorative material and the dentin and at the contact point of the root with the alveolar bone in the middle one third of tooth on the palatal side.

Conclusion

The findings of the present study indicate that there is no significant difference in maximum stress in three methods of restoration.

Stress distribution model in restored teeth with composite and Endo crown is similar to each other, and had been in the form of propagation from the place of entering the force to the bastion, in the dentin lower than the alveolar bone height, while the model of stress distribution in the restored tooth with the post inside the canal and the composite buildup had been in the form of the propagation of the place of force entry and propagation to the support site, in the dentin lower than the height of the alveolar bone, and in the same way through the post to its end.

The post inside the canal is used to create the sang and in terms of resistance to lateral forces, it is superior to the other two methods of restoration, but transmits the concentration of stress to a site closer to the root apex, which in the case of tooth fracture due to the extension of crack under cyclic forces, or sudden intense force, an irreversible destruction will be created in the tooth.

Research Suggestions

Stress and strain propagation under forces in the range lower than tooth tolerance range were investigated in this study, as the models under the force in UTM machine were under static pressure of 400 N, and none of the models were fractured and therefore the behavior of the material did not exit from elastic phase. For a better examination of the teeth fracture path by finite element analysis, it is advisable to investigate crack propagation.

Research Limitation

The mechanical properties of dentin are different in individuals, and dentin is also more fragile with increasing

the age, which may be effective in the difference of the result of the practical test and the examination of finite elements.

In real conditions, the metal post has no chemical connection to the root canal and does not allow the same distribution of stress.

Although the finite element analysis method creates more controlled conditions for experimental conditions than other studies, static forces are not precisely regenerative chewing force.

Although the physical properties of the materials obtained from the papers may not fully be correspond to the actual properties, but the comparative nature of this study makes the findings acceptable, because the objective of the present research has not been to determine the stress level in models, but is to compare the stress distribution between models.

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