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Study Of Using The Ni-Cr Alloy Post And Increasing Cement Strength(Zinc Polycarboxylate) On The Stress Distribution Of Restored Human Tooth

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Abstract

The effects of stress on dental restoration and upon teeth themselves have been a topic of interest to dental researchers for the past twenty years. A model of a maxillary central incisor (front tooth) restored with titanium alloy post and another post nickel alloy in combination with different cements, are established. The stress in dentin, posts, cores and crowns have been evaluated and compared with two different post materials and two different cements. The research is performed theoretically , numerically and experimentally, A composite beam formula is derived for analysis and the stress at sections through the tooth. The numerical analysis is achieved by use of ANSYS/ver.11 software. The material of tooth is assumed to be isotropic, homogeneous and elastic. A load of 100 N is applied at an angle of 45° to the longitudinal axis at the palatal surface of the crown. The mechanical properties and chemical composition of nickel alloy and Zinc polycarboxylate are measured experimentally. In this study , There are three model type (I,II and III) , model I including the standards restoring tooth (Titanium post tooth), model II including new post (Ni-Cr) alloys and third model by using the high strength cement(Zinc polycarboxylate) . The Von Mises stress value in cement layer and post core increases with the increase of the elastic modulus of post and cement but decrease the stress in dentin.

Keyword : restoration , finite element , Post , Cement , Stress distribution , Human tooth

الخلاصة

تأثير الاجهادات في السن المعاد ترميمه كان محط اهتمام الباحثين في السنوات العشرين الماضية . تم دراسة نموذج لسن القواطع الامامية العليا للانسان معاد ترميمه بعمود تيتانيوم و تبديلة بعمود مصنوع من سبيكة النيكل-الكروم و تم استخدام نوعين مختلفين من الملاطات .الاجهاد في العاج و الاعمدة و الحشوات و التاج تم دراسته و تم كذلك اجراء مقارنة بين الاجهادات في المواد القياسية و المواد المقترحة في الاعمدة و الملاط . تم انجاز البحث نظرياً و عددياً. وقد استخدمت نظرية العتبة المركبة لتحليل السن نظرياً. أما التحليل العددي فتم انجازه بواسطة برنامج العناصر المحددة ANSYS/ver.11 أفترض السن متجانس وذو خصائص مرنة. تم تسليط قوة 100نيوتن بزاوية °45 عن المحور الطولي للسطح الفكي(من جانب الجهة الشفية) لتاج السن. الخواص الميكانيكية و التركيب الكيمائي تم قياسه عمليا لسبيكة النيكل - كروم و لمادة الملاط عالي المقاومة (زنك بولي كاربوكسيليت) . في هذه الدراسة تم دراسة ثلاث نماذج مختلفة (I,II,III) النموذج الاول يتضمن عمود من مادة التيتانيوم , النموذج الثاني المقترح هو باستخدام عمود من سبيكة النيكل – كروم اما النموذج الثالث فكان باستخدام ملاط عالي المقاومة من مادة (زنك بولي كاربوكسيليت) . لوحظ ان أجهادات فون ميسز ستزداد عند العمود مع زيادة معاملات المرونة كما انها ستزداد كذلك بزيادة معامل المرونة للملاط لكنها تنخفض عند منطقة العاج .

Notation :

Symbol	Definition	Unit
A:	Cross-sectional area	mm^2
E:	Young's modulus	N/mm^2
I:	Moment of inertia	mm^4
k:	The rate at which the slope varies over the beam axis; that is, *d(dv/dx)*	
M:	Moment	N.m
n:	Modular ratio	
N.A.:	Neutral axis	
P:	Applied force	N
σ :	stress	MPa
ε :	Strain	
y:	Distance of fiber from N.A.	mm

1- Introduction

The restoration of endodontically treated teeth is a complex procedure as it involves teeth that are weakened due to a significant loss of tooth structure. To add confusion to complexity, there remains a lack of consensus on two key issues that confront the different techniques that have been established for endodontic treatment: do they provide an efficient rehabilitation of the tooth and do they maximize the preservation and protection of the remaining tooth structure.[1]

Dental restores, as metal anchors, are surgically placed into the jawbone. For most patients, the placement of dental restores involves two stage treatment. First, restores are placed within the jawbone. For the first three to six months following surgery, the restores are beneath the surface of the gums gradually bonding with the jawbone.[2] Several investigators have cautioned that posts with inadequate resistance to rotational forces on the posts can weaken the teeth . To prevent root fractures, a post should have an elastic modulus similar to that of dentin —a property which enables a more uniform distribution of stress by distributing the occlusal load [3].

The Zirconia ceramic post systems studied , zirconia posts have been shown to improve the esthetic quality of all ceramic crowns (Zeynep ÖZKURT , et al, 2010)[4] Post-retained crown (restored tooth crown with metal post in the center) is necessary to restore compromised tapered posts, thus reduced the risks of radicular fracture (Sorensen JA, Martinoff JT., 1984)[5].

The post core systems consist of components of different rigidity, among which different elastic modulus existed between dentin, cement and post material (Marchi GM et al, 2003, Freedman G, 1994)[6]. Therefore, many dentists have speculated that it might be a source of stress for the root structures. Some investigators concluded that thephysical characteristics of posts were important on stress distributions in post and core applications.Glass fiber post revealed more balanced stress distribution under functional forces. (Eur J Dent ,2007;2:67-71)[7] the comparing of the bond strengths of two types of fiber-reinforced posts cemented with luting cements based on two currently available adhesive approaches as well as evaluated their failure modes .

Previously, some investigators tried to use two-dimensional axisymmetric models to describe the post and core restorations mechanical behavior (Mendoza DB, 1997, Ross, 2003)[8]. Other investigators reported that the materials of the post and core affected the stress distribution of endodontically treated teeth restored with post-and-core system using three-dimensional FEA (Asmussen E et al, 1999)[9]. The goal of research is develop the ideal restorative material evaluate the effects of different post and cement materials on the stress distribution in an endodontically treated maxillary incisor. The ideal restorative material would be identical to natural tooth structure, in strength adherence and appearance . Titanium is used due to its excellent compatibility with human biology. The bone bonds with the titanim, creating a strong foundation for artificial teeth. In this paper the Nickel alloys and two type of cements are used .

2- Dental Restore Design:

Contemporary restorative dentistry has the main purpose of rehabilitating the function and esthetic of teeth which had their structure severely degraded due to caries or fracture.[10] Post and core system are commonly used for the restoration of endodontically treated when the teeth have suffered coronal damage. There are few subjects in dentistry that have been studied more than the restoration of endodontically treated teeth [11]. The resistance to fracture of endodontically treated teeth restored with esthetic post systems has not been extensively researched. [12]. A common factor between early loading and delayed loading of dental restores is the initial stability of the implant[13]. Restorations may be created from a variety of materials, including amalgam, gold, porcelain (ceramic), and composites. A dental restoration or dental filling is a dental restorative material used artificially to restore the function, integrity and morphology of missing tooth structure.

The structure loss typically results from caries (cavities) or external trauma. It is also lost intentionally during tooth preparation to improve the aesthetics or the physical integrity of the intended restorative material[14] In this study , the physical model of a post core restored endodontically treated the bone supporting the tooth , dentin , post ,core ,cement , crown and gutta percha . The geometry and dimensions of the physical model are shown in figure (1) . The replacing success of a tooth relies on the mechanical and biological capacity of the anatomical substitute to replace lost physiological functions, mainly the masticator one[15].

A standard adult central maxillary incisor is selected in compliance with the standard criterion of human tooth is shown in figure(1). The sample is 20 mm long, with crown length of 11mm, and root length of 11.8mm, respectively.

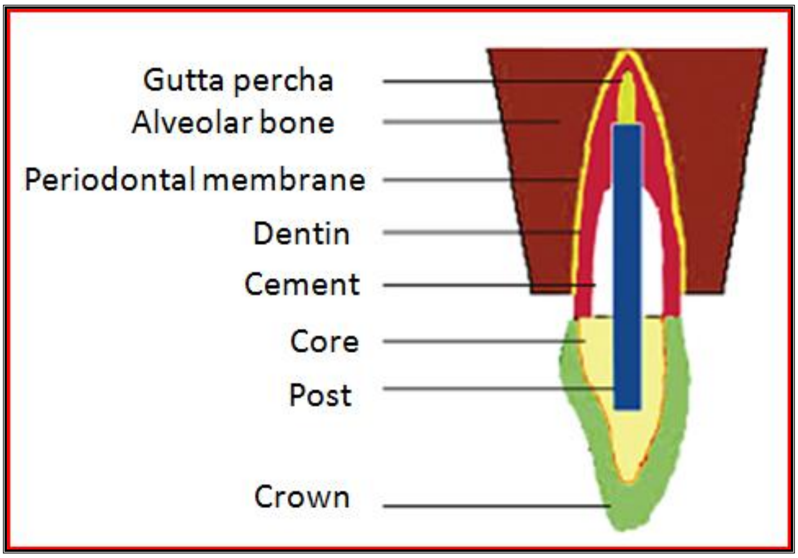


Figure (1) the restorative materials for adult central maxillary tooth

In this study , there are three model are investigate :

1. Model I is including the standards restoring materials (Ti –post).
2. Model II is including the new material post (Ni-Cr alloy post).
3. Model III is including the new cement material (Zinc polycarboxylate) is used.

The present study has the purpose of applying the finite element method to determine the stress distribution in a maxillary central incisor, with a small root-dentin thickness, restored with two different posts and cement .

3- Theoretical Analysis (Composite beam theory)

It is common practice to construct a beam of two or more materials having different moduli of elasticity to obtain a more efficient design. This is a so-called composite beam. Reinforced concrete beams, multilayered beams made by bonding together several sheets of material and the human tooth represent examples of such members. The assumptions of the technical theory of bending for a homogeneous beam are also valid for a beam of more than one material. The materials of tooth are assumed to obey Hooke's law, and their moduli of elasticity are denoted by E_1, E_2 and E_m .

$$\begin{aligned} \sigma x_1 &= E_1 \varepsilon_x = -E_1.K.y \\ \sigma x_2 &= E_2 \varepsilon_x = -E_2.K.y \\ \sigma x_m &= E_m \varepsilon_x = -E_m.K.y \end{aligned} \quad (1)$$

Let us now define

$$n_1 = \frac{E_2}{E_1}$$
$$n_2 = \frac{E_3}{E_1} \qquad (2)$$
$$n_{m-1} = \frac{E_m}{E_1}$$

In which n is termed the modular ratio.

The equilibrium equations become:

$$\int_{A1} \sigma_{x1} dA + \int_{A2} \sigma_{x2} dA + ... \int_{Am} \sigma_{xm} dA = 0 \qquad (3)$$

$$\int_{A1} -E_1.K.ydA + \int_{A2} -E_2.K.ydA + ... \int_{Am} -E_m.K.ydA = 0$$

$$\int_{A1} ydA + n_1 \int_{A2} ydA + ...n_{m-1} \int_{Am} ydA = 0$$

$$\int_{A1} (y' - \bar{y})dA + n_1 \int_{A2} (y' - \bar{y})dA + ...n_{(m-1)} \int_{Am} (y' - \bar{y})dA = 0$$

$$A_1\bar{y}_1 - A_1\bar{y} + n_1 A_2 \bar{y}_2 - n_1 A_2 \bar{y} + ...+ n_{(m-1)} A_m \bar{y}_m - n_{(m-1)} A_{(m-1)} \bar{y} = 0$$

$$\bar{y} = \frac{A_1\bar{y}_1 + n_1 A_2 \bar{y}_2 + ...+ n_{(m-1)}.A_m.\bar{y}_m}{A_1 + n_1 A_2 + ...+ n_{(m-1)} A_m} \qquad (4)$$

$$M = K.E_1 (\int_{A1} y^2 dA + n_1 \int_{A2} y^2 dA + ...n_{(m-1)} \int_{A1} y^2 dA \qquad (5)$$

$$M = K.E_1 (I_1 + n_1 I_2 + ...+ n_{(m-1)} I_m$$

where I_1 , I_2.......... and I_m represent the moment of inertia about the neutral axis of the cross – sectional area1,2,………m respectively .

$$I = I_1 + n_1 I_2 + ... + n_{(m-1)} I_m$$

$$K = \frac{1}{\rho} = \frac{M}{E_1.I}$$

$$\sigma_x = E.\varepsilon_x = -E.K.y$$

$$K = -\frac{\sigma_x}{E_1.y} = -\frac{\sigma_{xm}}{E_m.y}$$

A formula for the normal stress can now be written by combining equation :

$$\sigma_{xm} = -\frac{(\frac{E_m}{E_1})M.y}{I} \qquad (6)$$

$$\sigma_{xm} = -\frac{n_{(m-1)} M.y}{I} \qquad (7)$$

$$t_1 = t_1$$

$$t'_2 = n_{1.} t_2$$

$$t'_m = n_{(m-1).} t_m$$

In this study:

$$\sigma_{xm} = -\frac{n_{(m-1)} M.y}{I} - \frac{F}{A_{eq}} \qquad (8)$$

$$\sigma_{xm} = -\frac{n_{(m-1)}.P\cos(\theta).L.y}{I} - \frac{P\sin(\theta)}{b(t_1 + n_1 t_2 + ... + n_{(m-1)} t_m} \qquad (9)$$

Where ϴ angle of applied load to the tooth (45 degree) [7]

4- Numerical Analysis

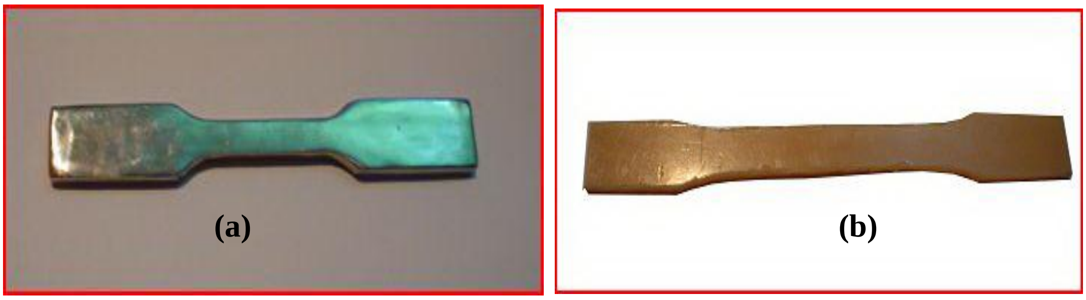
The analysis type for this study is linear static. . All the materials are linear-elastic, homogenous and isotropic. The value of modulus of elasticity for Ni-Cr and cement are obtained from experimental work (Table(1)). The values for the modulus of elasticity and Poisson’s ratio for the different layers and titanium post of a tooth are specified, this values used in this project are shown in Table2 below. In ANSYS constraints are applied to the model. The base of the model is fixed; thus all the node elements that are part of the base have zero degrees of freedom. This is to simulate the fact that the tooth is formed into the bone material of the jaw and is nearly immobile.

The combination of material in the tooth model and the magnitudes of the applied loads vary within each case study, and are further explained in the case studies section.[2] Mesh command in the ANSYS software was used to perform a smart mesh division of the FE model. There were 19347 nodes in the model. In all cases, load of 100 N was applied at the junction between upper 1/3 and middle 1/3 of the palatal surface of the crown at 45° angle with the tooth longitudinal axis. Boundary condition of the model was fixed support on the bottom of the alveolar bone[16].

5- Experimental analysis:

The theoretical and numerical analysis depend on the mechanical properties of the material; these can be found from the tensile test of standard specimens according to the recommendation of ASTM D-638[17]. To measure the mechanical properties, specimens (in Figure (2)) were prepared by casting mold and the vacuum furnace to manufacturing the Ni-Cr alloy specimenss.

Also , the Zinc polycarboxylate specimens were prepared by mixed two materials , Powder: zinc oxide & magnesium oxide and Liquid: Polyacrylic acid then casting according to the ASTM D-638 . Table 1 shows the mechanical properties of Ni-Cr post and Zinc polycarboxylate cement , also the chemical composition is measured for the Ni alloys .Table 3 shows this composition.



Figure(2) Tensile test sepecimens for : a-Ni-Cr alloy b- Zinc polycarboxylate

5- Results and discussion:

5-1 The mechanical properties results :

In table (1) the mechanical properties are shown, some results are obtained by experimental work for nickel alloys and cements properties and Table (2) shows the mechanical properties for the another materials from standards results .

It gives real data about maximum tensile and shear stress, obtaining the Young modulus and Poisson Ratio:

Table (1) mechanical properties for Ni-Cr and Zinc polycarboxylate

Material	Yield stress [MPa]	Young modulus [GPa]
Ni-Cr alloy	346	200
Zinc polycarboxylate	9.56	5.2

Table (2) Mechanical properties for restorative materials

Material	Elastic modulus (GPa)	Poisson's ratio
dentin	18.6	0.31
Alveolar bone	13.7	0.3
Guta percha	0.00069	0.45
Cement type Superbond C&B	1.8	0.25
Porcelain layer	96	0.25
Composite resin	8.3	0.28
Titanium alloy post	120	0.31

5-2 The Chemical Composition :

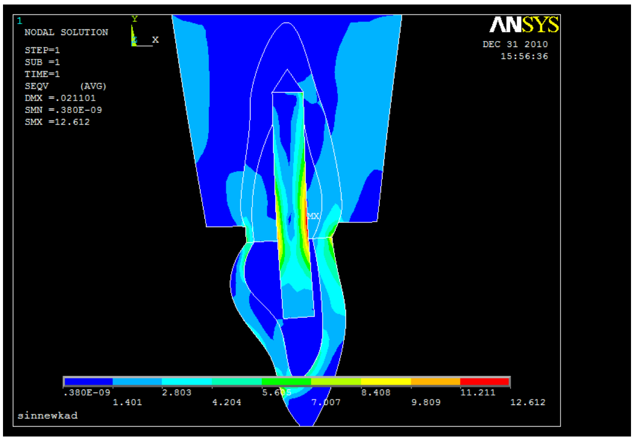
The chemical composition for the Ni-Cr post are measured as shown in table(3):

Table(3) chemical composition for Ni-Cr alloy

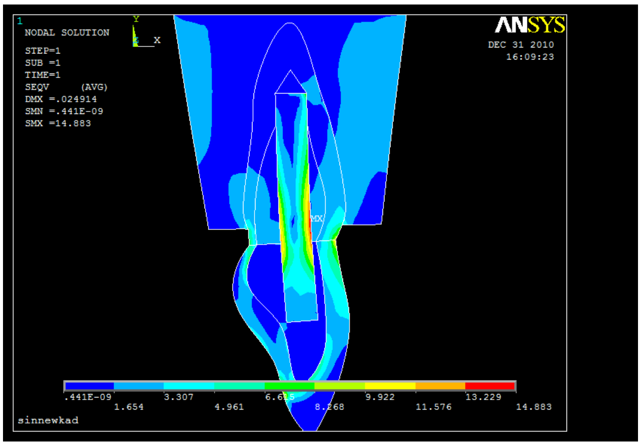
Ni %	Cr%	Si %	Fe %	Mo %
59.12	24.53	1.76	1.44	10.89

5-3 The Numerical and Theoretical Results:

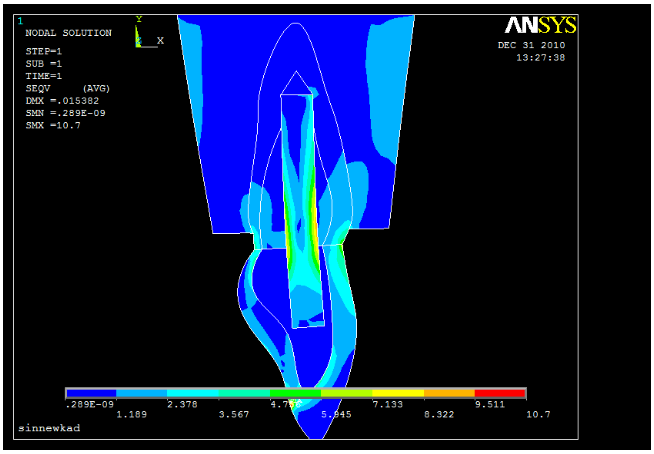
There are three model type (I,II and III) , model I including the standards restoring tooth (Titanium post tooth), model II including new post (Ni-Cr) alloys and third model by using the high strength cement . The effect of various factors on the stress distributions have been investigated using the finite element model ,developed here .The factors include post materials ,combinations of the posts and the cores, post and dentin contacts at the dentin coronal surface ,and thickness .



Figure(3) Von Mises stress distribution of the Model (I)



Figure(4) Von Mises stress distribution of the Model (II)



Figure(5) Von Mises stress distribution of the Model (III)

Figure 3 , figure 4 and figure 5 show the Von Mises stresses distribution of model(I) and model (II) and model (III) respectively at different sections for tooth.

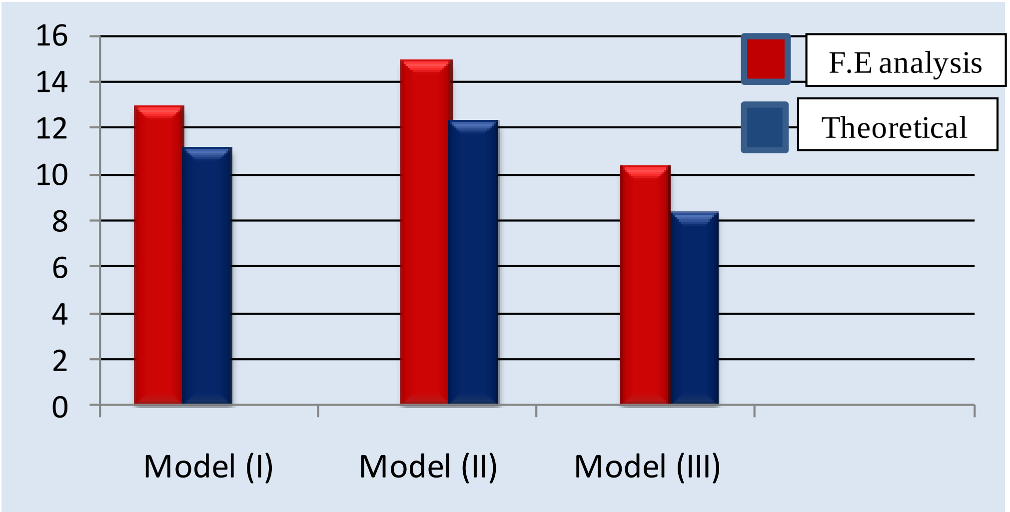


Figure (6) Von Mises stress [MPa] at the post in three models by numerical and theoretical method analysis

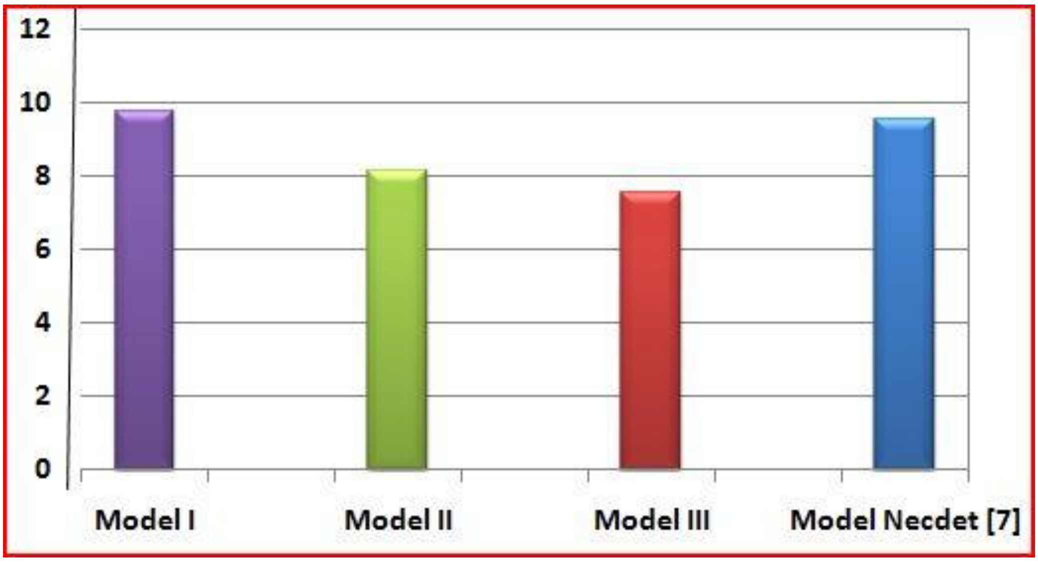


Figure (7) Maximum Von Mises stress [MPa] at the different models in dentin by ANSYS

The Von Mises stress at post was maximum value in Model II , due to the modules of elasticty was more than two another models (figure 6). Figure 7 show the Von mises stresses in dentin and cement of root respectively. Von Mises stress peak concentrates at the labial and lingual dentin of external surface of the upper part of the root, which is independent on the post and cements used. It should be seen that the load path is passed through t alloy post and some of it on the sides of alveolar bone. When elastic modulus of the post and cement are increased the maximum Von Mises values in dentin gradually decrease because the post and cement are bear the more stress due to increasing the modulus of elasticity .

In figure(7) the effect of change cement (Zinc polycarboxylate cement) in the stresses at the dentin more than change the post (Ni-Cr alloy) , Also ,the von Mises stress at three models in dentin are comparing with Necdet Adanir model [7] . During stress loading, maximum Von Mises stress in cements increases with the increase of elastic modulus of cements. Superbond C&B has the smallest stress value, while Zinc polycarboxylate cement has the largest stress value. Figure 8 shows the maximum displacement on the restorative tooth, the post in model (I) , and model(III) were made from titanium alloy therefore the displacement in theses models more than in model(II) , the effect of modulus of elasticity in post more than in cement .

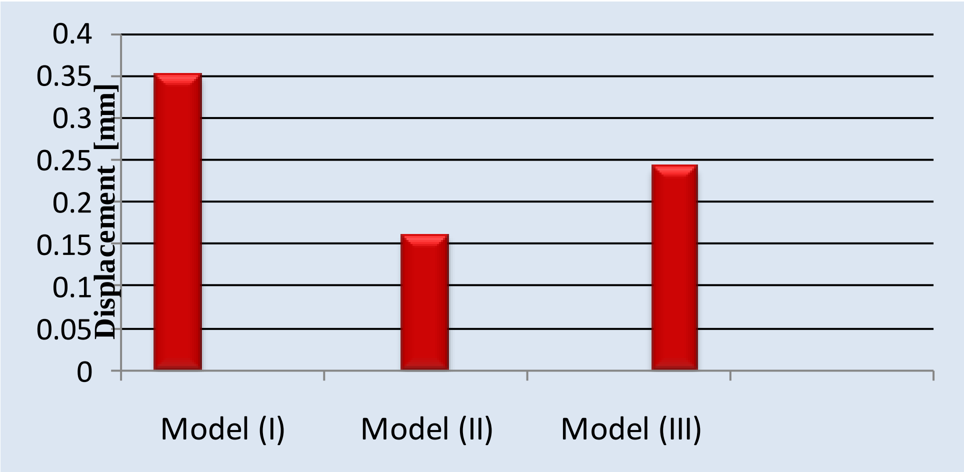


Figure (8) Maximum displacement [mm] at the different models

6- Conclusion:

A finite element model of restored root, restored with parallel titanium alloy post and Ni-Cr alloy post in combination with different cements, is established in this study. Stress distribution and the displacement pattern in dentin, and two cement layer of the root with different the elastic modulus is analyzed. two cements with different the elastic modulus . The high stress appears at the top of the crown is not realistic because of the point application of the load the force is transferred from the crown to the core and dentin .

The elastic modulus is the most important factors that affecting stress redistribution of restorations. Stress in the different posts and different cements are different ,the relation between elastic modulus and stress in root dentin: when tooth is loaded, occlusive force is passed to the root. The root dentin can bear the load together with the post and cement when elastic modulus of post or cement is closer to that of the dentin. This makes stress in root distributed more evenly, high stress region extension is reduced and Von Mises stress is also decreased. The effect of change the cements type more than change of post materials on the stress distribution on the total restoring tooth but the change of Titunum post to Ni-Cr post is increasing the stress distribution on the dentin .

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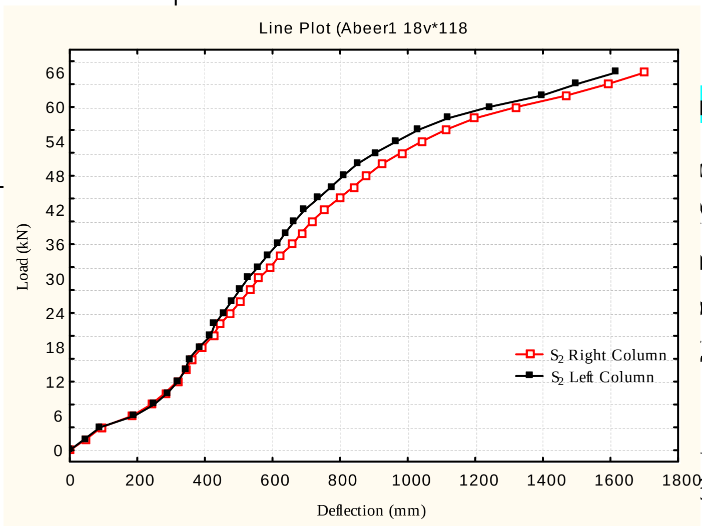

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