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An In-Vitro Study of Crowned Endodontically Treated Immature Permanent Central Incisor Reinforced with Different Types of Aesthetic Posts Using FEA

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Abstract: *The purpose of this research is to study the stresses fallen on three different points on the palatal surface of crowned endodontically treated immature anterior tooth reinforced with esthetic post using FEA.This finite element study simulated a clinical situation where stresses are applied from occlusion of teeth against each other in three different points (Inner curvature of incisal edge, junction between middle and cervical thirds, and cingulum area) which represents three different types of occlusion (edge to edge bite, normal bite and deep bite). Three different types ofestheticpostswere used: 1 type ready-made post, direct custom made ceramic post and indirect custom made ceramic post (Both are IPS E-max press) are used with the same type of resin cement (RelyX™ U200 automix, 3M ESPE, Germany), one core material (Filtek™ Z250 XT, 3M ESPE, Germany) and one crown material (IPS E-max Press, IvoclarVivadent, USA). Properties of these materials are taken in the FE software to build the model to be studied.This finite element analysis resulted in huge graphical representations (screen shots/pictures), each one present a type of deflection, strain, or stress. Commonly when Von Mises stress reach critical values all other types of stresses and deflections would be discussed to indicate the dominant effect from loading or system materials.The studied model consists of ten components; crown, core, post, cement, MTA, mucosa, cortical bone, PDL, root, and cancellousbone.There is no significant difference between the ready-made glass fiber post (Exacto glass fiber post, ANGELUS, BRAZIL) and the custom made post (IPS E-max press) used in the study due to close modulus of elasticity of both posts which is also close to that of the dentine of the root of the tooth.*

Keywords: *FEA, Stress Analysis, IPS E-max, MTA, Immature tooth, Esthetic post, Finite element study, Von Mises stress, Different types of occlusion.*

I. Introduction

Clinical management of trauma or carious lesion is an integral part of general dental practice (1, 2). The general role for carious or fractured, non-vital anterior teeth involves root canal treatment followed by protective permanent restorations for the coronal structure (3, 4, 5). Special situations arise in young patients when the pulps of anterior teeth lose vitality with resultant arrested development of the roots. Open and sometimes divergent apical morphology and weak root dentine wall makes endodontic procedures challenging, and presents restorative problems. It is important to preserve these weakened teeth in young patients. Utilization of post and core systems has facilitated the aesthetic restoration of endodontically treated teeth. Light transmission and biocompatibility have been enhanced by the introduction of metal-free post systems.Several new esthetic post systems are available for the restoration of endodontically treated teeth, but little is known about how effectively these dowels seal the restored teeth (6). These post and core restorations are subjected to repeated tension, compression and torqueing forces. In the last decade, the use of prefabricated fiber posts has gained a lot of popularity. These new systems have demonstrated a modulus of elasticity that closely matches dentin, a reduction of stresses concentrated within the root canal, and reduced incidence of fracture (7, 8).Finite Element analysis (FEA) is a numerical method of analyzing stresses and deformations in structures which originated from the need for solving complex structural problems. In order to achieve this goal, the structures are broken down into many small simple segments or elements, each with specific physical properties. Then, an operator uses a computer program in order to obtain a model of stresses produced by various loads. (4)

II. Materials And Methods

The following materials were used in this study:

1. Three types of esthetic posts:
   A) Prefabricated or ready-made post (Exacto Glass Fiber Post, Angelus, Brazil).
   B) Direct custom made post (IPS e-max press, IvoclarVivadent, USA).
   C) Indirect custom made post (IPS e-max press, IvoclarVivadent, USA).
2. One type of composite resin as a core (Filtek™ Z250 XT, 3M ESPE, Germany).
3. One adhesive resin luting agent (Rely X™ U200 Automix, 3M ESPE, Germany).
4. One type of ceramic crown (IPS e-max press, IvoclarVivadent, USA).

Where, all materials except the post material were assumed to be homogenous, isotropic, and linearly elastic. Table 1 listed all materials used in this study and its mechanical properties fed to the finite element package.

Table (1): Material properties

Material	Young's Modulus [MPa]	Poisson's ratio
Cortical bone	13,700	0.3
Cancellous bone	1,370	0.3
PDL	0.0689	0.45
Root (Enamel)	84,100	0.31
MTA	15,700	0.23
Cement	8,130	0.3
Post 1: IPS e-max press	97,500	0.24
Post 2: Exacto glass fiber post (Angelus, Brazil)	E_x = 9,500 E_y = 37,000 E_z = 9,500 G_{xy} = 3,544.8 G_{yz} = 3,544.8 G_{xz} = 1,456.7	υ_{xy} = 0.34 υ_{yz} = 0.34 υ_{xz} = 0.27
Core	15,800	0.24
Mucosa	680	0.45
Crown: IPS e-max press	97,500	0.24

III. Methods

Geometric modeling:

Solid modeling of the model components were created on "Autodesk Inventor" Version 8 (Autodesk Inc., San Rafael, CA, USA) as post and core [9]. While the immature (incomplete formed root) central incisor model (two components crown and root) were scanned by laser scanner (Geomagic Capture, 3D Systems, Cary, NC, USA). These components were exported as SAT file in order to be assembled in finite element package. The other components as bone (cortical and spongy), mucosa, cement, PDL, and MTA were modeled in the finite element package by using set of Boolean operations between the modeled components were performed before obtaining the complete model(s) assembled. Bone geometry was simplified and simulated as two co-axial cylinders [10, 11]. The inner one represents the spongy bone (14 mm diameter x 22 mm high) filling the internal space of the outer cylinder (1 mm thick shell) that represents cortical bone (16 mm diameter x 24 mm high).

Finally these components were assembled in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). Figure (1) and complete Osseo-integration was assumed.

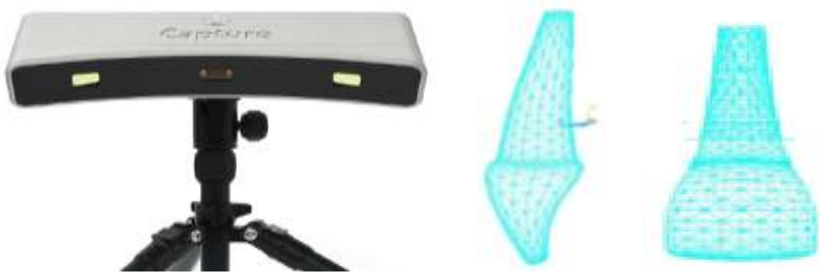

Figure (1): Geomagic Capture and central incisor after laser scanning

Element selection and meshing

These components of the model were imported and assembled in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). In this study element "SOLID 95" was selected for meshing the model volumes. Solid

95 is a solid element (with three degrees of freedom: translations in main axes directions) resulted in huge number of nodes and elements listed in Table 2.

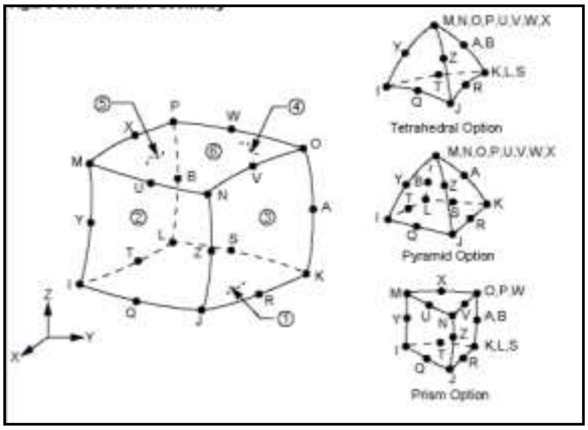

Figure (2): Element SOLID 95 shape

Table (2): Mesh density

Volume	Number of Nodes	Number of Elements
Cortical bone	15,438	17,295
Cancellous bone	51,812	48,843
PDL	148,678	147,012
Root (Enamel)	197,658	168,368
MTA	834	848
Cement	1,099	1,682
Post 1: IPS e-max press	2,643	2,540
Core	1,131	1,185
Mucosa	48,353	45,438
Crown: IPS e-max press	107,550	93,859

Loading and boundary conditions:

The top area of the cortical bone cylinder was set to be fixed in place as a boundary condition [12, 13]. While the applied load was set to be 50N, directed with 135º oblique angle from the vertical plane, to the following points;

1- Lingual slope of incisal edge
2- The junction between incisal and middle thirds
3- The beginning of cingulum

Finite Element Analyses:

Linear static analysis was performed on a personal computer (Intel Core I7 processor, 3.2 GHz, 8.0 GB RAM), using commercial multipurpose finite element software package (ANSYS version 15.0).[14]The resultant stresses of the applied loading were collected from the output of ANSYS® program, and they were collected according to maximum values of Von Mesis stress (Stress equivalent) which indicate the resultant stresses in Mega Pascal (MPa) at each specified element in the specified volume. Six runs (analysis) were performed as follows;

1- Run #1: E-max Press post material, and load at lingual slope of incisal edge
2- Run #2: E-max Press post material, and load at the junction between incisal and middle thirds
3- Run #3: E-max Press post material, and load at the beginning of cingulum
4- Run #4: Exacto glass fiber post material, and load at lingual slope of incisal edge
5- Run #5: Exacto glass fiber post material, and load at the junction between incisal and middle thirds
6- Run #6: Exacto glass fiber post material, and load at beginning of cingulum.

IV. Results:

Fiber glass post material has lower stiffness in comparison to IPS e-max press; this may be reflected as lower stresses appeared on the post itself. As illustrated in Figure (4) about 66% lower Von Mises stress appear on fiber glass post.Up to the value of the applied load (50 N) the fiber glass post stiffness is enough to withstand the generated stresses. Thus using higher stiffness post material than the fiber glass one will not noticeably affect the model results. As the FEA was carried out at a fixed value of applied load of 50 N, and the analysis type was linear static, the applied load value can be considered as a one loading unit towards the fracture load.

The FEA showed the result of applying this unit loading as stresses, and deformations on all components of the studied model (cortical, spongy, PDL, root, etc.). Thus, as the resultant stresses are small, a larger load is needed to reach fracture (stress orload).In other words; the equivalent stress to all exerted stresses on one component of the studied model due to the applied load is called Von Mises stress. For any component of the studied model, if the applied load (50 N) produced high value of Von Mises stress (close to fracture stress of this component material) then the fracture load of this component is approximately 50 N. On the other hand, if the applied load (50 N) produced low value of Von Mises stress (very low in comparison to fracture stress of this component material) then the fracture load of this component is expected to be much higher than the applied load.

V. Results comparison

Figures (3) and (4) compare the total deformations and Von Mises stress appeared on all components. The post material had negligible effect on all components. The crown, root, and cortical bone are the most suffering components from high stress values.

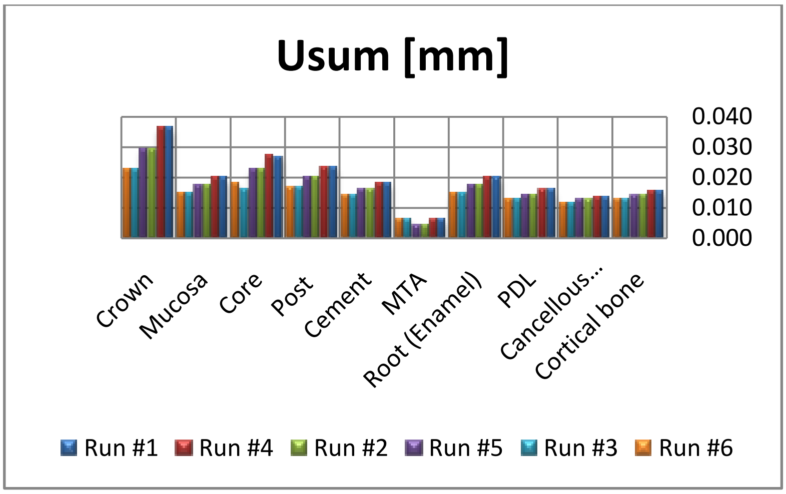

Figure (3): comparison between the total deformations on all components in the six runs

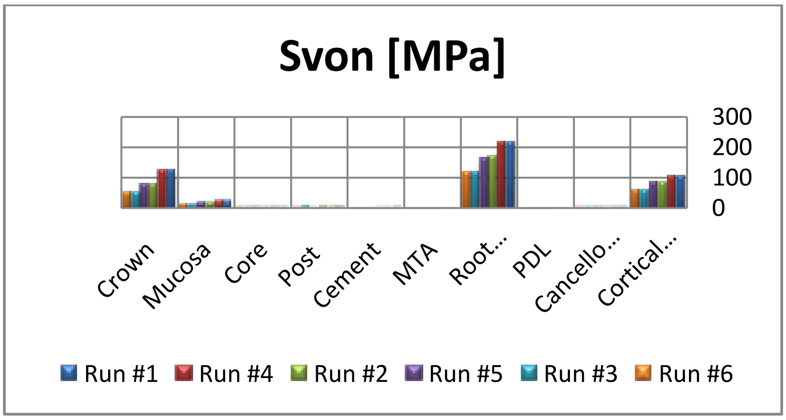

Figure (4): comparison between Von Mises stress on all components in the six runs

VI. Discussion

Glass fiber post material has lower stiffness in comparison to IPS e-max press; this may be reflected as lower stresses appeared on the post itself. In addition load transferred to root will be reduced as the post material stiffness increased. This finding matched Zaazou et al.[15] when the effect of different post materials on enamel root was studied. Zaazou et al. studied four different post materials, gold, nickel chromium (Ni-Cr), stainless steel (St.St.), and Reinforced Fiber Post - Glass Fiber (RFP-GF) in endodontically treated lower first premolar. The use of loading of 100 N to be applied as compressing (vertical), and oblique loading on the center node at the top of the post head. St.St. post was found to be nearly equivalent to the Ni-Cr post in behavior. Both represent stiff post materials. On the other hand Gold and RFP-GF represent soft post materials. Stiff post material, with high constraints in positioning, showed better behavior and load transfer to the other parts of the systems (less energy transfer to the other parts of the system). In terms of energy, for highly constrained parts, soft materials can absorb certain amount of energy with relatively high deformation on the other hand stiff materials can give similar result with relatively smaller deformation and this is in agreement with Bessone and Fernandez 2010 [16]. In this study it was noticed that, up to the value of the applied load (50 N) the glass fiber post stiffness is enough to withstand the generated stresses. Thus using higher stiffness post material than the glass fiber one will not noticeably affect the model results.

Similarly as Zaazou et al. [15] study, when applying the load directly on the post, the stresses generated on the root surface was correlated to the Young's modulus of the material used for the post system. Poisson's ratio was not the dominant factor for evaluation of load transformation in post systems. As the young's modulus increased from gold, to RFP-GF, to St.St., to Ni-Cr the displacement of all parts of the studied system decrease, which matched with the physics, that the stiff (rigid) the post material showed the less deformation to be obtained in the other parts of the system.Also the results of the study were in coordination with the study made by Pegoretti A. et al. [17] who studied finite element analysis of a glass fiber reinforced composite endodontic post. Three different loading conditions were separately considered: 100 N vertical load, applied on the top of the crown, to simulate bruxism load. 50 N oblique load, angled at 45 degrees, to simulate the masticatory forces over lower incisors and canines and 10 N horizontal load, to simulate external traumatic forces.

The results were compared with those obtained considering either a commercial carbon fiber post or a gold alloy cast post. A natural tooth, or better a tooth restored with ideal materials whose stiffness is equal to those of enamel and dentine, was considered as a reference model. The gold cast post-and core produces the greatest stress concentration at the post-dentin interface. On the other hand, fiber-reinforced composite posts do present quite high stresses in the cervical region due to their flexibility and also to the presence of a less stiff core material. The glass fiber composite shows the lowest peak stresses inside the root because its stiffness is much similar to dentin. Except for the force concentration at the cervical margin, the glass fiber composite post induces a stress field quite similar to that of the natural tooth. Stresses at the cervical margins could be lowered using less stiff crown materials, i.e. composite resins, thus obtaining an ''integrated'' post-core-crown system. A. Dominguez[18].

It was also in coordination with the research made by Ahmed A. et al. [19] who studied 3D FEA of cemented glass fiber and cast posts with various dental cements in a maxillary central incisor. This study aimed to analyze and compare the stability of two dental posts cemented with four different luting agents by examining their shear stress transfer through the FEM. The peak shear stress for glass fiber post models minimized approximately three to four times of those for Ni–Cr alloy cast post models.The results obtained by Öznur E. et al[20]was in agreement with the results obtained from the present study where he evaluated conservative restoration of severely damaged endodontically treated premolar teeth (a FEM study). The analysis of the von Mises stress values revealed that maximum stress concentrations were located at loading areas for all models. Root dentine tissue, lingual cortical bone, and apical bone structures were other stress concentration regions. There were stress concentration differences among the models at root dentine tissue. Highest stress values were observed at root dentine in the model restored with post-and-core. Fiber-reinforced restoration provided stress distributions similar to sound tooth.

VII. Conclusions

- Within the limitation of this study it can be concluded that stiff post materials transfer less load to the root dentine with less displacement. Therefore using rigid post materials will not endanger the root of the tooth.
- Location of applied loads is very important in determination of the type of material used because moving of the load upwards from the cingulum area to the incisal edge makes loads more concentrated which may lead to catastrophic results (un-repairable).
- There is no significant difference between the ready-made glass fiber post (Exacto glass fiber post, ANGELUS, BRAZIL) and the custom made post (IPS E-max press) used in the study due to close modulus of elasticity of both posts which is also close to that of the dentine of the root of the tooth.

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