Effect of Flexi-Posts on Stress Distribution of Restored Tooth

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Abstract—**The study is focused on the stress distribution of a post and core restored maxillary incisor tooth with different post materials. Metallic posts which are rigid are compared with the fiber posts which offer better flexibility. Finite element analysis is carried out on the tooth assembly model with cast metal post, titanium post, glass fiber post and carbon fiber post. The research concludes that the material of post should have lower flexural rigidity to undergo desired deformation with minimum stress.**

Keywords-maxillary incisor; glass fiber; FEM; flexibility; stiffness.

1. INTRODUCTION

The deformation and stress induced in different layers of tooth and the surrounding region differ with the variation in the material of post. Present research has been carried out with four different materials of the post namely 1) glass fiber post and composite core, 2) carbon fiber post and composite core, 3) titanium post and composite core and 4) cast metal post and core. It is observed that the material of the post have influence on the maximum stress level and it also affects deformation pattern.

2. MODELING OF TOOTH

Maxillary central incisor which is highly prone to accidents has been selected for the study. Post and core treatment is recommended for the incisors when there is sufficient loss in the tooth structure. The restored tooth model is prepared using CAD Software Solid Edge version 15 (PLM solutions, Electronic data Systems, Plano, TX, USA). The data is collected from various sources (Boschian, Guidotti, Pietrabissa & Gagliani, 2006) and (Uddanwadiker, Padole, & Harshwardhan, 2009). Each layer is modeled separately so that the deformation and stress induced in them could be studied in details accurately. Layers are finally assembled in assembly environment. Figure 1 shows 3D solid model of tooth.

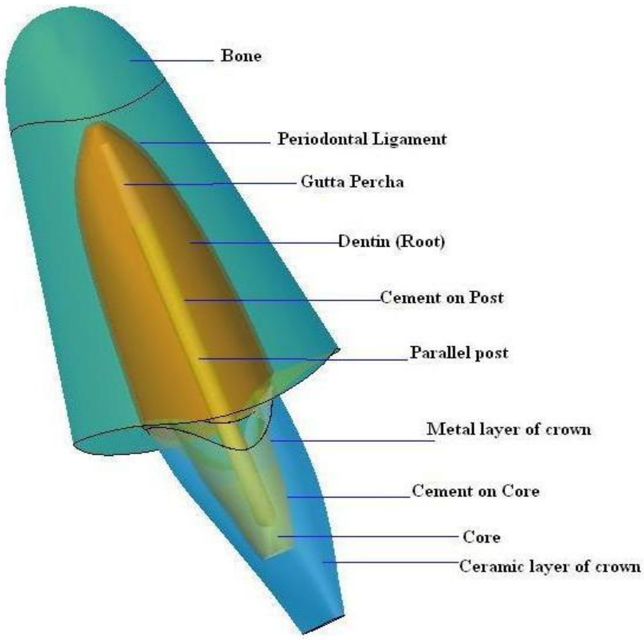

Figure 1. Solid model of Restored tooth

3. FINITE ELEMENT ANALYSIS

The tooth model thus prepared is imported in ANSYS version 11.0 (SAS IP, Canonsburg, PA, USA) software. Each layer is assigned with the corresponding material property (Uddanwadiker, Padole, & Harshwardhan, 2009). The complete model is meshed with SOLID 187, CONTACT 174 and TARGET 170 element types to create nodes and elements.

A tangential force is applied on selected nodes of the crown. This inclined load is analogous to the load resulting from the mandibular jaw central incisor to the maxillary jaw central incisor. The force is inclined at 130° to the long axis at the incisal edge of the tooth (Yaman, Karacaer & Sahin, 2004). The load is applied by specifying its horizontal and vertical components on all the four nodes selected. The surface constraint is applied on the outer surface of the bone. Figure 2 shows the restored tooth model with components of inclined load and the nodes that are constrained to zero displacement. The finite element model thus created is solved for given load and constraints for various materials of post and core. The results obtained are discussed in the following section.

Figure 2. Restored tooth loaded and constrained

4. RESULTS AND DISCUSSION

For a given boundary and loading condition, stresses are generally independent of material. However, deformations and strains are highly sensitive to material properties. Here, for a specific shape of the post, results are analyzed for different materials of the post. The stress and deformation for different parts like bone, PDL, root, post, core and crown are analyzed. The stress distribution and variation in deformation pattern are discussed under separate heads.

4.1. Variation in Stress Distribution

When a post is inserted within the root and covered with core and crown, as shown in Figure 2, behavior of the assembly resembles that of a cantilever beam. Since the outer surface of the bone is completely constrained for zero degrees of freedom, the upper part of the post which is cemented to the root behaves like a fixed end.

The lower part of the post is inserted in the core which is covered by crown. The inclined load is acting on the crown; hence the lower part of the assembly behaves like the free end of the cantilever. The load is applied from lingual surface and the deformation takes place towards labial surface i.e. in the direction of load as shown in Figure 3. Under the action of load, the fibers towards the labial surface are subjected to compressive stresses whereas fibers towards the lingual surface are subjected to tensile stresses. The inclined load of 200 N (Yaman, Karacaer & Sahin, 2004) at an angle of 130° to the axis of the tooth is resolved into z (along the long axis) and y (perpendicular to the long axis) components with magnitudes of 128.55 N and 153.2 N respectively.

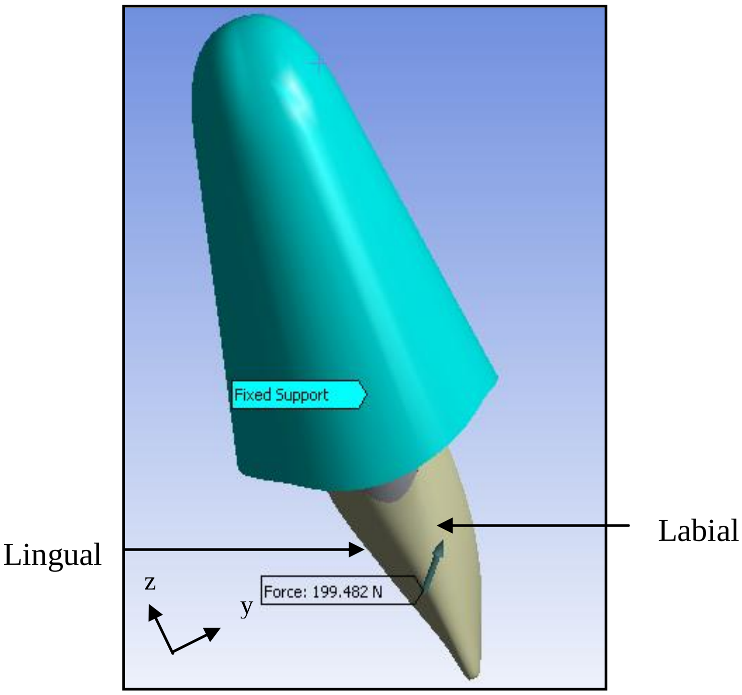

Figure 3. Inclined load in y-z plane

The z-component of load is responsible for pure compression where as y-component is responsible for bending of post. Considering the dimensions of root at the cervix level (junction of crown and root), the magnitude of compressive stress is in the range of 9-12 MPa and bending stress in the range 100 - 110 MPa on the root. The magnitudes of resultant compressive stresses (direct compression + bending compression) are therefore higher compared to tensile stress (bending tension – direct compression). Researchers (Vasconcellos, Cimini, & Albuquerque, 2006) have concluded that post and root are the critical parts of any restoration, hence effect of different parameters on these two layers are analyzed in greater depth. However, magnitudes of stresses on remaining layers are also presented.

4.1.1. Glass fiber post restoration

In the finite element analysis of the glass fiber post restoration, the load is applied at crown and a maximum stress of 125.4 MPa is observed at the point of application. This may be localized stress concentration due to point load acting on the palatal surface of the crown. The stresses developed in the root are 104 MPa tensile and -121 MPa compressive. These results are as expected since the compressive stress is higher than the tensile stress. The root is covered by PDL and bone on the outer part of the root. Since these two layers behave like a fixed support of the cantilever, stresses induced in these two layers are negligibly small of the order of 3.7 MPa and 5.8 MPa on PDL and bone respectively. Outer surface of the bone is completely constrained; hence the stress on the bone is minimum.

4.1.2. Carbon fibre post restoration

The restoration with carbon fiber post has a compressive stress of magnitude 131 MPa on the crown where load is applied. The maximum tensile stress and maximum compressive stress at the root layer are -103.84 MPa and 100 MPa respectively.

4.1.3. Titanium post restoration

For the titanium post restoration, crown has 140 MPa stress at the point of application of load. The maximum stress in the root layer is of the order of 111.4 MPa compressive and 98 MPa tensile.

4.1.4. Cast metal post and core restoration

When the tooth is restored with cast metal post and core, the stress on the crown is 230 MPa and 128.8 MPa compressive and 107 MPa tensile at the root. The post and core is fabricated as a single entity hence the maximum stress is induced in the junction of post and core where sudden reduction in the area takes place.

The value of the axial compressive and tensile stresses in a various parts of the restoration are listed in Table 1.

Table 1. Axial Stresses on different layers of restoration in MPa

Type of restoration	**Layers of tooth**					
	Crown		Root		Bone	
	Tensile	Compressive	Tensile	Compressive	Tensile	Compressive
Glass Fiber post	52.8	-125.8	104	-121	3.07	-1.7
Carbon Fiber post	59.2	-131.4	100	-103.843	3.15	-1.72
Titanium post	68.5	-140	98	-111.4	3.22	-1.4
Cast Metal post	84.1	-230	107	-128.8	3.17	-1.4

From Table 1, it is observed that for the first three restorations, i.e. glass fibre, carbon fibre and titanium post restorations, the stress induced are almost comparable. This is of course expected as stresses in general are independent of material. However, for the cast metal post restoration, the magnitude is comparatively higher because unlike other three restorations, where post is inserted in the core, cast metal post and core are fabricated as a single assembly. The higher values of stresses in cast metal post and core may be due to stress concentration at post and core junction. Stress distribution along z- axis and compressive and tensile stresses are shown in Figure 4 for cast metal post and core. Table 1 show that when an incisor is restored with cast metal posts, it presented the largest levels of stress concentration compared to the remaining three restorations. Also the compressive stresses are observed on labial surface and the tensile stresses are observed on palatal surface. In the past, Cailleteau and collaborators (Cailleteau, Rieger, & Akin, 1992) also performed a similar study and their results are also in close agreement with the results observed in the present work.

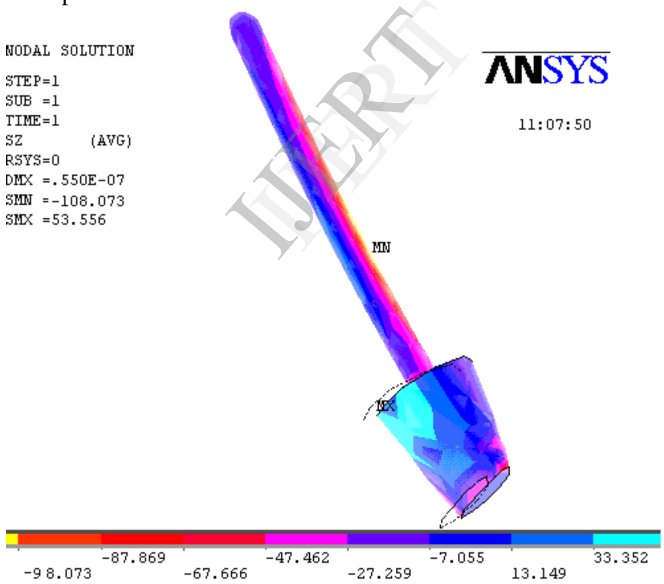

Figure 4. Stress distribution in cast metal post and core

The magnitude of stresses for different layers of the four restorations for the parallel shape of the post is presented with the help of bar chart in the Figure 5. The graph indicates that the root is the most critical part in a restoration. The stresses are higher for cast metal post restoration compared to other restorations. The results obtained by other researchers (Vasconcellos, Cimini, and Albuquerque, 2006 and Boschian, Guidotti, Pietrabissa, & Gagliani, 2006) are also in accordance with the results of the present research. The possibility of failure is decided by the assumption that, higher stress levels are indicative of chances of failure at that region. Results presented in Table 1 indicate that high stress levels are observed in the cervical region (crown-root interface) on the lingual side within the restoration. The maximum stresses are located in this region as shown in Figure 6. These observations are also supported by the result of studies carried out by earlier researchers (Topbasi, Mahir, Mustafa & Cafer, 2001). They have confirmed the same region of high stress level by using two-dimensional photo-elastic stress analysis of traumatized incisor.

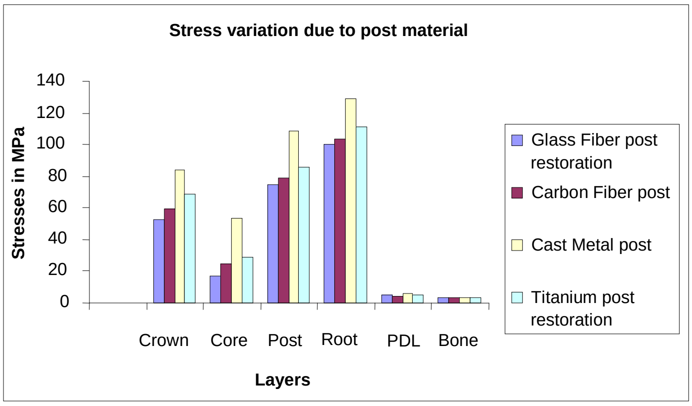

Figure 5. Effect of material of post on stress variation

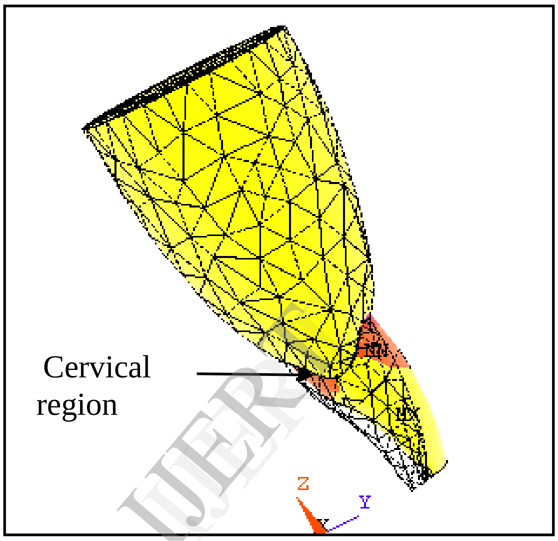

Figure 6. Stress concentrations on the cervical region

Another stress concentration region is observed in post root interface as shown in Figure 7 on coronal third (one third distance of the root measured from the crown) of the root. Since the magnitude of stress is considerably low in crown, core, PDL and the bone, study is concentrated more on post and root. The post is inserted in the cavity created inside the root. Thus the post root junction combines a foreign material cemented with the natural material. Higher values of stresses are seen in the cervical region and the parts within that region which may lead to both root and post fractures.

4.2. Variation in deformation of various parts of restoration

The effect of material for a given shape of post on deformation of the assembly is studied. The restored tooth when subjected to masticatory load undergoes deformation. It is desired that this deformation should be close to the deformation of the natural tooth when subjected to similar kind of loading conditions.

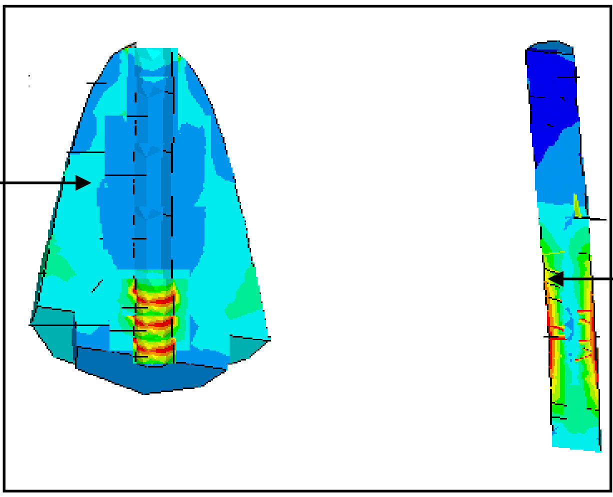

Figure 7. Post root interface

Also the deformation should not result into excessive stresses at the cervical region of the root and post which are the critical components of any restoration.

It is expected that for material of higher modulus of elasticity, the inelastic deformation would be less and vice versa. Under the action of given loading, deformation should be such that the restoration does not fracture. A flexible material can withstand higher deformation under given loading condition without failure. A system having more flexibility would result into lower stresses than a system having more stiffness. Among the four materials studied in the present research, cast metal has maximum value of modulus of elasticity as 200 GPa and glass fibre has minimum value with modulus of elasticity 54 GPa. It is expected that cast metal post and core would have highest stiffness and the restoration with glass fiber post would have highest flexibility.

Since the entire assembly is analogous to a cantilever beam, the inelastic deformation is maximum at the free end and minimum at the fixed end. The deformation (compression) due to net compressive load is negligible compared to that of net bending load. The load acting perpendicular to the axis of the tooth is expected to cause maximum bending stress at the cervical end and also maximum bending deflection at the free end i.e. crown in the range of 0.4- 0.5 mm using the concept of deflection of beams from solid mechanics (Singh, 2002). Table 2 presents the deformation on different layers of the tooth assembly for various post material.

Table 2. Deformation (MM) on Restorations

Layer	**Type of restoration**			
	Glass Fiber post	***Carbon Fiber post***	***Titanium post***	***Cast Metal post***
Crown	0.671	0.549	0.562	0.487
Core	0.498	0.418	0.427	0.390
Post	0.469	0.409	0.417	0.384
Root	0.338	0.308	0.323	0.287
PDL	0.260	0.257	0.261	0.245
Bone	0.00385	0.00386	0.00377	0.00483

4.2.1. Glass fiber post restoration

Value of Elasticity for glass fibre is 54 GPa and is lowest among the four materials. From the finite element analysis, the resulting deformation is 0.671 mm for crown and 0.338 mm for the root. The value is minimum for bone 0.00385 mm as expected because the outer surface of the bone is constrained for zero degree of freedom.

4.2.2. Carbon fibre post restoration

The modulus of elasticity for carbon fibre is 129 GPa which is considerably higher compared to glass fibre post. Deformation value for crown is 0.549 mm and for the root is 0.308 mm. The deformation is negligibly small for bone i.e. 0.00386 mm as it is constrained.

4.2.3. Titanium post restoration

The value of modulus of elasticity for titanium post is 120 GPa which is almost similar to that of carbon fibre post. The deformation levels are also comparable with the deformation of carbon fiber post restoration. The deformations are 0.562 mm and 0.323 mm for crown and root and a marginal deformation of 0.00377 mm in the bone.

4.2.4. Cast metal post and core restoration

For cast metal the modulus of elasticity is 200 GPa, which is highest amongst the four restorations. The deformation values on crown and root are 0.487 mm and 0.287 mm. The deformation of the bone is very small of the order of 0.00483 mm.

Deformation of root which is critical from the point of failure of the restorations is studied in greater depth. The results show that deformation obtained is maximum in glass fiber post restorations in a range of 0.64 - 0.67 mm, whereas the cast metal post restoration shows minimum deformation of the order of 0.42 - 0.48 mm.

5. CONCLUSION

The flexural rigidity of the material of the post is an important criterion. Since the behavior of post is similar to that of a cantilever beam, under the action of inclined loading it is subjected to flexion. Past studies (Lanza & Raffaella, 2005) and working Prosthodontist suggest that a more stiff system works against the natural function of tooth, it is indicated that natural tooth undergoes deformation in a range of 0.5-0.6 mm in the normal working condition. Above results show that glass fiber post restoration can undergo similar deformation inducing stresses at the root and post of the order of 75 - 100 MPa. However if cast metal post and core restoration have to undergo similar deformation it would result in very high stresses (for example for 0.4 mm deformation, stresses at the root are 128 MPa) which may lead to failure of restoration. Hence it can be concluded that stress should not be the only criteria for selection of material but deformation of restoration is equally important. It is also concluded that the use of a highly rigid material, results in a non-homogeneous stress distribution, which leads to the emergence of regions of concentrated stresses. The most stable post-system is the one, which distributes the stress in a more symmetrical way and that an asymmetric stress pattern can cause the premature failure of the post. These results suggest that posts made of composite materials are capable of reducing to the minimum, the risk of root fracture.

Glass fiber post induces lesser stress and for the same value of load the deformation is higher compared to other restorations which indicate that its stiffness is lesser. However for the cast metal the deformation for the given load is very low, hence the stiffness is high. The results are also supported by Asmussen and collaborators (Asmussen , Peutzfeldt & Sahafi, 2005) who determined the stiffness of different endodontic posts experimentally. The flexibility of the post-core system presents an advantage of smaller stress on the root structure and consequently smaller risk of root fracture.

Additional advantage of flexible dental post is that it conforms to the natural curved contour of a root canal which reduces the machining of tooth thereby reducing mechanical weakening of tooth structure. Statistics based on in-vitro and in-vivo test also suggests that concerning the material of the post, a smaller incidence of extensive fracture in teeth restored using fiber posts was found by (Sidoli, King & Setchell, 1997) whereas the same kinds of fracture were observed more in case of teeth restored using metal posts.

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