Original Article

Three-dimensional finite element analysis of the stress distribution in the endodontically treated maxillary central incisor by glass fiber post and dentin post

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Abstract

Introduction: From the point of dental practice, the restoration of endodontically treated teeth has become an important aspect as it involves a range of treatment options of variable complexity. Restoring teeth with insufficient coronal tooth structure, it is always indicated to use the post to retain a core for definitive restoration. Fiber post has a modulus of elasticity in analogs to dentin structure, thus reducing the stress areas at the dowel dentin interface. However, the only material that can substantiate all these properties can be none other than dentin itself.

Materials and Methodology: Three-dimensional (3D) models of the maxillary central incisor were developed incorporating all the nonlinearities. Continuum 3D elements were used in three dimensions. Maxillary central incisor was laser scanned, duplicated with the help of reverse engineering into STL format, and it was converted into 3D model for finite element analysis (FEA). For the model, fixed boundary conditions were applied at the outer bone, while 100 N static vertical occlusal loads were prescribed at 135° on the loading component of the simulated tooth. The stress distribution was evaluated using dentin and fiber post with prescribed materials, loading and boundary conditions in endontically treated teeth by 3D FEA.

Results: The analysis for von Misses stress for dentin post showed that the stress in the dentin post at the cervical area was 127 MPa. The displacement in the dentin post was <0.025 mm. Von Misses stress for the fiber post at the cervical area was approximately 182 MPa and the displacement was <0.035 mm.

Conclusion: The FEA results showed that the stress in the cervical area of the dentin was more for fiber post when compared to dentin post, and maximum displacement values were less for dentin post in comparison to fiber post.

Key Words: Dentin post, fiber post, three-dimensional finite element analysis

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INTRODUCTION

There always stay a higher risk of biomechanical failure in endodontically treated teeth than vital teeth. Restoring teeth with insufficient coronal tooth structure, it is always showed to use the post to retain a core for definitive restoration.[1] Creugers *et al.*,[2] reported that endurance rates vary largely in endodontically treated teeth restored with different post and core systems.

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Post (dowel) material plays a decisive role in the biomechanical performance of endodontically treated teeth.[1] Ideally, the post material should have a physical property such as modulus of elasticity, compressive strength, and thermal expansion, as well as esthetics similar to those of dentin, and it should bond predictably to root dentin.[3] However, the only material those can substantiate all these properties can be none other than dentin itself.

Cast metal dowel and core normally were used but recently with an increasing drift toward the use of fiber dowel systems. The advancement of materials and technology, and in accordance with lofty clinical requirements, new post restoration systems of tooth defect, the nonmetal post and core systems, including carbon fiber post system, glass fiber post system, and quartz fiber post system, have been introduced into clinical use since early 1990s.[4,5]

Fiber dowels endow with a more esthetic result than the metallic dowels. They have a modulus of elasticity in analogous to dentin structure, thus reducing the stress areas at the dowel dentin interface.[6]

However, the only material those can substantiate all these properties can be none other than dentin itself. A few reported cases using dentin as post material have shown successful outcomes.[7,8] Hence, a thorough investigation should be carried out for the probability of human dentin to serve as a post material.

Little is known about the demeanor of the dentin post. There is a minimum evidence for the dentin post as the post material. There are many case reports of having successful outcome using dentin itself as a post and a single *in vitro* study related to dentin post considering the only post for stress factor not simulating the other conditions, but as such no studies simulating the oral conditions where dentin post can be used with success is still a question.

Finite element analysis (FEA) has been of great assessment to conduct stress generated studies, and studies regarding the material behavior on dental structures during the use of root posts while these receive a certain amount of force and can be helpful to decide the type of post to be used. The technique was developed to create mathematic models, in which the behavior of a physical system can be reproduced, that is, a physical prototype can be studied through the creation of a mathematical model. In this method, a computer system is used to conjure up the physical properties of the structures in analysis, and through a great number of mathematical equations it determines the generated tension resulted from an applied force.[9]

As such there are so many studies on the post made with different materials for the stress pattern with the FEA, but no single study being evaluated for a dentin post which might change the future treatment plan. Thus, there exists a need with an aim to investigate stress distribution in endodontically treated maxillary central incisor using three-dimensional finite element analyses, with an objective to verify stress distribution by dentin post and fiber post incorporating prescribed materials, loads, and boundary conditions. Null hypothesis preassumed was there is no significant difference in the stress pattern for the dentin post and fiber post.

MATERIALS AND METHODOLOGY

Three-dimensional model generation

To simulate the three-dimensional (3D) model, natural maxillary central incisor was taken. Then maxillary central incisor was laser scanned, duplicated with the help of reverse engineering (GEOMAGIC) into STL format, and it was converted into 3D model for FEA. Nonlinear FEA has been performed using the commercial software package ABAQUS® 6.13.1 with 10 node prisms quadratic meshes. The 3D model shows a nonlinear behavior because of the presence of different materials and numerous interface surfaces. 3D models of the maxillary central incisor were developed incorporating all the nonlinearities. Scanned model of maxillary central incisor was then ready to simulate for endodontically treated requiring post and core along with the crown.

Material information

Table 1 shows the material properties used in the FEA.[10] All the properties were input into the FEA program assuming an isotropic linear material model.

Finite element analysis, simulation, and loading

Continuum 3D elements were used in three dimensions. Parts in the assembly of no immediate concern in the stress analysis were modeled as discrete rigid bodies. Surface-based contact pair approach was used to model the glue among the various material components. FEA model was created and used in the analysis [Figure 1]. For the model, fixed boundary conditions were applied at the outer bone, while 100 N forces at 135° angulations at lingual surface of central incisor with bar

Table 1: Material properties used in finite element analysis

Material properties	Young's modulous (GPA)	Poisson's ratio
Porcelian crown	68.9	0.25
Nickel chrome	300	0.33
Composite core	18.6	0.26
Fibre post	45	0.25
Dentin post	18.6	0.31
Periodontal ligament	68.9	0.45
Cortical bone	13.7	0.30
Spongy bone	1.37	0.30

GPA: Gigapascal

stick attached onto it for the force application, static vertical occlusal loads were prescribed on the loading component of the simulated tooth. The color coding was there to evaluate the stress pattern with red color showing more amount of stresses and blue color showing less stress.

RESULTS

Results were presented by considering von Misses criteria and calculated numerical data were transformed into color graphics for better visualize mechanical stresses in the models. All the stress values were showed in megapascals (MPa).

The analysis for von Misses Stress for dentin post showed that the stress in the dentin post at the cervical area was 127 MPa [Figure 2]. The displacement in the dentin post was <0.025 mm. Von Misses Stress for the fiber post at the cervical area was about 182 MPa [Figure 3] and the displacement was <0.035 mm.

DISCUSSION

Nonhomogeneous material distributions will act as an interface and show higher stress concentrations. There is always a weak link of restorative systems where the interfaces of materials are with different moduli of elasticity. The risk of the root fracture is influenced by the location of stress at dentin, and stresses located at post/dentin interface may influence the risk of loss of post retention.[11] Thus, every effort should be made to reduce these stresses, by planning the treatment well and using appropriate materials and verifying the procedure by different investigations.

For the evaluation of the stress measurement and analysis, various methods are applicable, such as the strain gauge method, the loading test, and the photoelastic method.[12] These techniques being homologous, two-dimensional are difficult to reproduce at times. A valid index of stress distribution at the root structure becomes difficult to create based solely on experimental and clinical observation.[10] To resolve unworkable engineering problems, an innovative theoretic method is used named FEA.

The FEM can be called as a boon for investigating complex systems that are difficult to standardize *in vitro* and *in vivo* studies.[13] FEA enables researchers to verify how the stresses are transferred throughout the materials and allowing to overcome some ethical and methodological limitations, making the procedure more accurate. Thus, every structural and design scrutiny of the finite element models require full knowledge of the mechanical properties of the materials which are subjected to the forces applied. There is always a level of difficulty seen when treating oral rehabilitation,

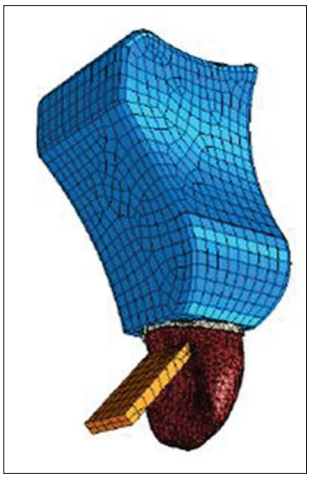

Figure 1: Three-dimensional finite element model constructed

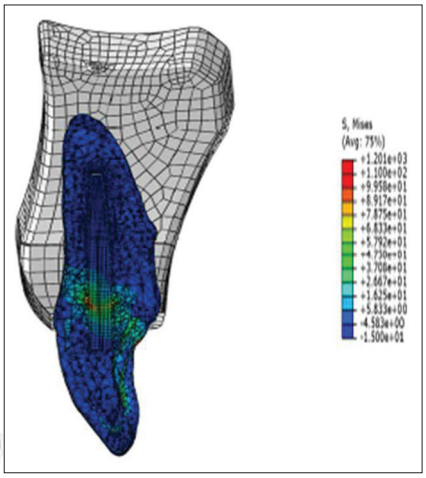

Figure 2: Finite element analysis showing stress pattern on dentin post

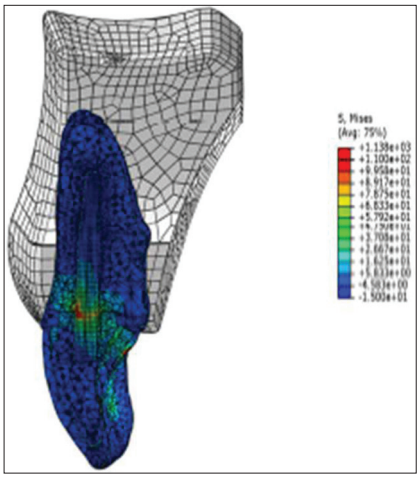

Figure 3: Finite element analysis showing stress pattern on fiber post

because of the oral tissue response along with complex loads that are produced in the oral cavity.[14] For the present study, 3D FEA was used over two-dimensional (2D) as it removes the need for conservative assumptions for 3D model problems with 2D tools.

Von Misses stress for dentin post by FEA showed that the stress at the cervical area was 127 MPa and for the fiber post at the cervical area was about 182 MPa, coming into agreement with the study conducted by Kathuria *et al*.[1] where the fracture resistance for the dentin post was higher as compared to the other groups. Henceforth, it rejects the null hypothesis as there is a significant difference in the stress pattern more for fiber post when compared to the dentin post.

Displacement for the fiber post was <0.035 mm which was found in the current study came in agreement with the study conducted by Seo *et al*.[11] which was 0.034 mm and for the dentin post value was still <0.025 mm.

Barjau-Escribano *et al*.,[15] showed that posts possessing elastic modulus similar to that of dentin and core have an enhanced biomechanical performance. In the present study, dentin itself was used as post showing that stress examined in the cervical area was less when comparing with the fiber post. Furthermore, using dentin as a post gives exact physiomechanical properties of a dentin post itself, uniform stress distribution, and shock-absorbing potential of a dentin post.

From the point of dental practice, the restoration of endodontically treated teeth has become an important aspect as it involves a range of treatment options of variable complexity along with other factors such as adhesion with the luting cement and sterilization protocol to be looked for.[16] However, the dentin post can be luted with any cement as they bond well to all cement, in particular, resin cement where they form the monobloc and increasing the adhesion.[17] There are also issues regarding sterilization protocol for the dentin post and studies does say sterilizing in autoclave at 121 lb pressure for 15 min is effective.[16]

Formalin solution has also been proven effective in sterilizing the dentin post keeping moisture content intact for dentin. Dentin post stored in formalin will maintain the moisture in the dentin just like vital dentin and increases the adhesion with the luting cement. Formalin is comprised formaldehyde, methyl alcohol, and sodium acetate in water, which acts to preserve the tissues by causing the cross-linking of proteins, glycoproteins, nucleic acids, and polysaccharides, which form insoluble methylene bridge products. The cross-linking of this macromolecule fixes the specimen and prevents the degradation of tissues after cell death occurs.[18]

It has been proved with the studies that crown involved in the endodontically treated teeth acts as a stress shielding affect on the core materials, as a consequence, deformations concentrated beneath the crown,[11] and irrespective of the post systems being used or not.

The result from the present study suggests that the mechanical properties and the nature of the material from which the posts are prepared seem to be very important to the distribution of stresses and for the success of the treatment. Finite element analysis has been proven to be a constructive technique for the analysis of stress distributions simulating the complex oral conditions.[19]

LIMITATIONS

- The structures and materials used in this study were considered to be linearly elastic, homogeneous, and isotropic
- Values such as elastic modulus and Poisson's ratio applied for the structures and materials in this study were used from a study published earlier.

Hence, there seem to be a long-term clinical trial for behavior of dentin post should be studied and future studies for the cyclic loading of dentin post should also be expected to get a better insight into its properties.

CONCLUSION

Within the limitations of the study it concludes that:

- In endodontically treated maxillary central incisor, under a static load, the stress in the cervical area of the dentin was more for fiber post when compared to dentin post. The maximum displacement values were also less for dentin post in comparison to fiber post.

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Conflicts of interest

There are no conflicts of interest.

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