Comparison of stress distribution in teeth restored with fiber post and dentin post by applying orthotropic properties: A three-dimensional finite element analysis

Sravanthi Tammineedi, Sudha Kakollu1, Murali Mohan Thota2, Ram Chowdary Basam, Lakshman Chowdary Basam3, Sayesh Vemuri

Departments of Conservative Dentistry and Endodontics and 3Orthodontics and Dentofacial Orthopedics, Sibar Institute of Dental Sciences, Guntur, 1Department of Conservative Dentistry and Endodontics, Government Dental College and Hospital, Vijayawada, 2Department of Conservative Dentistry and Endodontics, Government Dental College and Hospital, RIMS, Kadapa, Andhra Pradesh, India

Abstract:
Aim of the Study: We aimed to compare stress distribution in a tooth restored with fiber post and dentin post after applying the orthotropic properties using three-dimensional finite element analysis (3D-FEA).

Materials and Methods: Two 3D-FEA models were constructed. The material properties were assigned, and a load of 100 N was applied at 45° to the long axis of the model onto the lingual surface incisal to the cingulum. The FEA was done by applying orthotropic properties of dentin and fiber post. The maximum stresses produced in the tooth and post referred to as von Mises stress were recorded. The Ansys software was used which depicts the stress concentrations.

Results: Von Mises values showed that glass fiber post (331 MPa) and dentin post (338 MPa)-restored tooth models presented similar stress values.

Conclusion: Although both fiber post and dentin post presented similar von Mises stress values, the pattern of stress distribution is more favorable in dentin post. More favorable fracture could be expected in case of dentin post. Thus, the dentin post is a promising alternative post material for rehabilitating endodontically treated teeth.

Keywords: Dentin post; fiber post; finite element analysis; stress pattern evaluation; von Mises stress

Clinical Significance: Ascribing the orthotropic properties in a FEA study means that the computational simulation was similar to that of clinical scenario, and hence simulates the dynamic intraoral conditions, thereby giving the accurate results.

INTRODUCTION

The longevity of endodontically treated teeth predominantly relies on the amount of residual tooth structure and the type of postendodontic restoration.

Address for correspondence:
Dr. Sravanthi Tammineedi,
Department of Conservative Dentistry and Endodontics, Sibar Institute of Dental Sciences, Guntur, Andhra Pradesh, India.
E-mail: tammineedisravanthi@gmail.com

Teeth with inadequate coronal tooth structure are to be restored with posts for better retention of a core.[1] In the modern era, the focus of interest has shifted from metal post systems to fiber posts because of the quest for esthetic materials and also simple chairside technique.[2] Naumann et al. conducted a prospective observational clinical study on glass fiber-reinforced postendodontic restorations for 10 years and stated that the yearly failure rate was high in relation to the anterior teeth.[3] Hence, there is a need for...
a material that has better mechanical properties as well as esthetics.

Factors like the post material, and its mechanical properties such as Young’s modulus, compression strength, and coefficient of thermal expansion, play a critical part in the biomechanical behavior of root canal-treated tooth. Ideally, the post material should have these properties analogous to dentin, and a good bonding is anticipated between post and the root canal dentin. To date, human dentin is the only structure that essentially satisfies all these biomechanical requirements. Various authors reported dentin posts that were prepared from extracted human teeth,[4,5] However, the studies evaluating the stress distribution of the dentin posts are limited. Hence, the current study aims to assess and compare the distribution of stress in teeth that were restored with dentin post and the fiber posts.

Finite element analysis (FEA) is a modus operandi to analyze stress distribution. In this technique, the actual structure is visualized as an assembly of a finite number of elements. The problem domain is divided into a collection of smaller parts (elements), and an overall approximated solution to the original problem is determined. In earlier studies, fiber post and dentin were assumed to be isotropic (i.e., the material has the same physical property when measured in different directions), which may not simulate the clinical condition. According to Grzebieluch et al., the application of anisotropic properties to the dentin during FEA resulted in a reduction of the displacements and strain. They proposed that the application of anisotropy of the dentin should be considered in FEA studies.[6] Therefore, the current study was conducted to evaluate the stress concentration in a tooth restored with dentin post and fiber post using three-dimensional FEA by applying the orthotropic (subset of anisotropy) properties of fiber post and dentin.

**MATERIALS AND METHODS**

**Three-dimensional geometrical model design of maxillary central incisor**

A human extracted maxillary central incisor with average dimensions was selected. The tooth was sectioned to a level of 3 mm coronal to dentino-enamel junction. The tooth was subjected to cone-beam computed tomography (CBCT) imaging. The CBCT images in Digital Imaging and Communications in Medicine format were imported into AutoCAD software (Catia V5R22) and outline of each layer (i.e., dentin, alveolar bone, gutta percha, post, and core) were traced. A 0.25-mm thick periodontal ligament and 0.25 mm thick lamina dura outlines were developed. In both the preliminary designs, post length, width of 1.0 mm and 1.2 mm, respectively, and apical gutta-percha of 4 mm were designed. The thin luting cement sandwiched between the dentin and post material was difficult to replicate, and it is treated as a part of dentin. No significant error was anticipated by the exclusion of this layer in the model.[7] In order to eliminate the exterior reinforcing effect on the post and core, models were not restored with any prosthesis.[8]

**Defining the simulation and loading conditions**

The preliminary designs of post and core were imported to Hypermesh software (ABAQUS 2016), and a Hypermesh assembly is formed [Figure 1]. After converting the completed model into an Ansys input file, it was then brought into Ansys software. Mechanical properties such as modulus of elasticity and Poisson’s ratio were assigned to all of the constituents [Table 1].[9-14] The models had only one variation, which was the post material, i.e., Model A as fiber post and Model B as dentin post. All materials except dentin and fiber post were assumed to be homogeneous and isotropic. Fiber post and dentin post were considered to be orthotropic [Tables 2 and 3].[6,15]

**Loading**

The models were fixed at the bottom to create a stress model. For the simulation of load conditions in the oral cavity, an arrow is used 45° at the level of the cingulum. A progressive load of 100 N was applied to both models. The greatest stresses developed in the models were referred to as von Mises stress. The Ansys software also has a color-coding system, which indicates the stress distributions.

![Figure 1: Hypermesh assembly](image)

**Table 1: Mechanical properties of materials in finite element analysis model**

| Materials            | Young’s modulus (Mpa) | Poisson’s ratio |
|----------------------|-----------------------|-----------------|
| Gutta-percha[9,10]   | 0.69                  | 0.45            |
| Periodontal ligament[11] | 6.9                  | 0.45            |
| Cortical bone[12]   | 13,700                | 0.30            |
| Spongy bone[12,14]  | 1,370                 | 0.30            |
| Composite resin[13] | 16,600                | 0.24            |
RESULTS

The results in each model were presented in terms of the von Mises stress values, which gives the failure predilection of the material analyzed. When the models were subjected to analysis, both showed maximum stresses at the cervical third and least forces at the apical third of the tooth model. Model A (331 MPa) and Model B (338 MPa) were not significantly different in performance, but the pattern of stress distribution is different in both the models. In Model A, more stresses are observed at the cervical and middle third, whereas it is at the cervical level in Model B [Figure 2]. The color-coding system indicates the stresses generated. Maximum stresses were indicated in red color, and minimum stresses were indicated in blue color. Minimal change in the color at the apical third means the complete dissipation of occlusal load, thereby decreasing the chance of vertical fractures.

DISCUSSION

FEA is the recent method to measure and analyze the stress distribution. Various other methods, such as the strain gauge method and the photoelastic method, were also used in the past for the same. Hrennikoff and Richard Courant were the first persons who used FEA in civil and aerospace engineering to resolve the difficulties in the analysis of elastic properties and structural investigations. Davy et al. used FEA to study the post and core restorations.

FEA is applied to dental biomechanics as it is a popular numerical method to precisely evaluate the intricate biomechanical performance of nonhomogeneous structures in a nondetrimental, reproducible fashion. The model is fragmented into numerous tiny parts or components, every single component with specific physical properties. Then, the operator utilizes a computer platform to attain a prototypical model of stresses made by different loads. Modulus of elasticity and Poisson’s ratio of the modeled structure are quantified for every component. Unlike other testing methods, FEM analysis can provide 100% reproducible results, even after repeating any number of times. Hence, conventional statistical analysis is not generally included in these studies. FEA permits investigators to overcome certain restrictions in terms of ethics and methodology and permits them to demonstrate the modes of stress transmission throughout the materials. FEA also permits the analysis of a single variable in a multifaceted configuration. This infers that the procedure is time saving as it does not have any standardization issues and there is no need to prepare numerous test samples.

Most of the studies conducted using FEA modeled the tooth components as isotropic and not orthotropic. Such models denoted a static condition during mechanical loading and not representing a clinical scenario, which is dynamic and cyclic. Accurate measurements could be attained if the anisotropic material properties are used, although it demands the use of arduous mathematical calculation. Orthotropic (subset of anisotropic materials) materials have properties that vary in three orthogonal two-fold axes of rotational symmetry. Because of the orientation of dentinal tubules and glass fibers, both the post systems need to be considered as anisotropic. Ascribing these orthotropic properties meant that the computational simulation was similar to that of a clinical scenario. Hence, the present in vitro study was assumed to evaluate the distribution of stress when fiber post and dentin acts as a post material after applying orthotropic properties.

In the current study, both the fiber post and dentin post showed similar stress values. This is contrary to the study

| Table 2: Mechanical properties of fiber posts[^15] |
|-----------------------------------------------|
| Elastic moduli (E: MPa), Shear moduli (G), and Poisson’s ratio (n) | Glass fiber post |
| E11: Longitudinal modulus of elasticity (MPa) | 4000 |
| E22: Longitudinal modulus of elasticity (MPa) | 11000 |
| E33: Longitudinal modulus of elasticity (MPa) | 11000 |
| G12: Cross-sectional modulus of elasticity (MPa) | 4200 |
| G13: Cross-sectional modulus of elasticity (MPa) | 4200 |
| G23: Cross-sectional modulus of elasticity (MPa) | 4100 |
| n12: Poisson’s coefficient | 0.26 |
| n23: Poisson’s coefficient | 0.26 |
| n13: Poisson’s coefficient | 0.32 |

| Table 3: Material properties of dentin tissue used for analysis[^6] |
|-----------------------------|-------------|-------------|-------------|-------------|-----------|-------------|-------------|-------------|
| Material designation Orthotropic dentin | Exx (GPa) | Eyy (GPa) | Ez2 (GPa) | Vxy (·) | Vyz (·) | Vzx (·) | Gxy (GPa) | Gyz (GPa) | Gxz (GPa) |
| Top | 23.1 | 23.1 | 26.0 | 0.31 | 0.3 | 0.3 | 8.9 | 9.3 | 9.3 |
| Middle | 19.1 | 19.2 | 24.1 | 0.3 | 0.3 | 0.3 | 7.3 | 8.1 | 8.1 |
| Bottom | 15.7 | 15.7 | 22.0 | 0.31 | 0.3 | 0.3 | 6.0 | 7.0 | 7.0 |
conducted by Memon et al., which showed that the dentin post exhibited less stress than a fiber post.\textsuperscript{[15]} The difference in the results could be attributed to the application of orthotropic properties to dentin post and fiber post. No other FEM studies compared stress distribution in dentin and fiber post using orthotropic properties. Hence, direct comparisons could not be made. The maximum stress development was concentrated at the cervical area in the case of dentin post, whereas it is mainly concentrated at the cervical third and slightly extended into the middle third for fiber post. If the tooth restored with dentin posts were to fracture, failure probably occurs at the core/root intersection and is easily repairable compared to fiber posts. This is in agreement with the study conducted by Ambica et al. and Kathuria et al.\textsuperscript{[18,19]} Better results of the dentin post in their study could be because of the similarity in modulus of elasticity with surrounding dentin leading to homogeneous stress distribution. Clinically, adhesion between the fiber post and a luting agent is feeble.\textsuperscript{[20]} However, adhesion to a dentin post is highly anticipated. In a clinical scenario, better properties of dentin posts can be expected because of better bonding with the luting agent, as reported by Ambica et al. However, future investigations are essential to assess the safe and effective use of dentin posts for restoring endodontically treated teeth. Long-term clinical studies are also needed to evaluate the longevity of the dentin posts.

Limitations of the study

- Properties applied for the materials and structures were obtained from previously published data
- FEM study can predict stress concentration, but direct extrapolation to clinical scenario may not be precise as the mechanism of bonding, surface treatments, and residual stresses come into play. Hence, rigorous experimental validation is needed.

CONCLUSION

Although both fiber and dentin posts presented similar von Mises stress values, the pattern of stress distribution is more favorable in dentin posts. A more favorable fracture could be expected in the case of dentin post. Thus, the dentin post is a promising alternative post material for rehabilitating endodontically treated teeth.

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Conflicts of interest

There are no conflicts of interest.

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