ORIGINAL RESEARCH

Stress Distribution in Teeth Restored with Different Posts Using Single or Multi-post Technique: A Three-dimensional Finite Element Analysis

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Abstract

Background: The reconstruction of endodontically treated teeth (ETT) is frequently required before the accomplishment of a definitive restoration, especially when the remaining coronal tooth structure is inadequate to provide retention and resistance form for the restoration.

Aim: The aim of this study is to compare the stress distribution in premolar teeth restored with different posts using a single or multi-post technique with the help of three-dimensional (3D) finite element analysis (FEA).

Materials and methods: The FEA was used in the investigation. Cone-beam computed tomography (CBCT) scan of mandibular 1st premolar was used to create a geometric model. With the help of HyperMesh software version 13.0, four finite element models were created. Model-1, endodontically treated mandibular premolar with single conventional fiber post (0.8 GC Fiber Post, GC Europe, Leuven, Belgium), Model-2, endodontically treated mandibular premolar with single everStick post (0.9 everStick POST, GC Europe, Belgium), Model-3, endodontically treated mandibular premolar with multiple conventional fiber posts, and Model-4, endodontically treated mandibular premolar with multiple everStick posts. ANSYS software version 12.1 was used for FEA.

Results: Following the analysis, von Mises stress (VMS) and principal stress values were obtained. Maximum VMS values were obtained on the buccal cusp of the crown. Between conventional fiber-reinforced composite (FRC) post and everStick post, everStick post showed less stress, whereas between single and multiple post models, multiple post models showed more stress. The Principal stress values showed that the stress distribution within the crown, dentin, and posts was not significant to cause fracture of these materials.

Conclusion: Within the limitation of the study, and from the simulation results and summary table following conclusions were made:

- Stresses are less in everStick post compared to conventional FRC post.
- Single post showed lesser stress compared to multi-post method.

Clinical significance: Strengthening ETT with the use of single or multiple smaller diameter posts applying a minimally invasive approach for post space preparation. The study of stress distribution will help us in determining the failure criterion that leads to ETT fracture. It is significant because fracture is one of the most common causes of failure of ETT.

Keywords: Endodontically treated tooth, EverStick post, Fiber-reinforced composite post, Multiple-post, Single-post.

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Introduction

Endodontically treated teeth are often found to be severely mutilated by caries, failure of previous restorations, dentin loss during de-roofing, and weakening of pericervical dentin during access preparation.[1] In cases where there is evident loss of clinical crown, teeth are not able to withstand the final restoration and additional support is required.

Mishra et al.[2] have described several posts in the literature, ranging from wooden posts in the 18th century to metal and carbon fiber posts, and more recently glass fiber, ceramic, and elastic posts. Studies have shown that stiffer metal posts may not be ideal for more even distribution of stresses across the root. The survival of ETT has been assessed in various retrospective and prospective clinical studies. Failure rates have been recorded to be 8% for carbon fiber posts over a period of 8 years[3] and 12% for glass fiber in a 2-year prospective investigation.[4]

In 1990, fiber posts with mechanical properties similar to dentin were introduced to address the shortcomings of stainless steel and titanium alloys. They have an ideal modulus of elasticity. Some of the advantages of using of fiber post include high stiffness and tensile strength, lower toxicity, and superior esthetics.[5] Akkayan and Gülmez[6] in their study calculated the fracture resistance of ETT that

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was restored with different posts systems. Teeth restored with fiber post showed a much favorable and repairable fractures, whereas teeth restored with metal posts showed unfavorable fractures.

A novel elastic FRC post has recently been introduced in the market—everStick post (0.9 everStick POST, GC Europe). It is a soft, flexible, and adaptable unpolymerized glass fiber post.[7] Along with being individually adaptable, they have favorable mechanical properties (flexural strength—1145 MPa and Young's modulus—15 GPa) making them better than conventional FRC posts.

Maceri et al.[8] advocated the multi-post technique. Fráter et al.,[9] recently conducted a study using multiple conventional FRC posts and elastic FRC posts (everStick Post) for the treatment of large, irregular endodontic cavities. According to this study, single-rooted premolars had higher fracture resistance in cases where multiple posts were used as compared to single post.

Stress distribution can be studied by multiple techniques. The most commonly used tests include brittle coating analysis, strain gauges, holography, two-dimensional (2D) and 3D photo elasticity, digital moire interferometric investigation. Finite element analysis (FEA) is a recent method used for stress analysis. Finite element analysis is an engineering method in which a numerical analysis is done based on the material properties. The most indispensable application of FEA is that it allows the calculation of physical measurements of stress within a structure.

The pattern of stress distribution within ETT's root dentine is altered following post-insertion. Many studies in the field of endodontics have used FEA to investigate the pattern of stress created following post placement. There has been a large discrepancy in the results obtained from these *in vitro* studies, hence an increasing number of studies on dowel-restored teeth are based on FEA.

However, no study has been conducted to evaluate the stress distribution in everStick post and also on the amount of stresses created in teeth restored with multiple conventional and elastic FRC posts, and its comparison with single post technique.

Aim and Objective

Aim

The aim of this study is to compare the stress distribution in premolar teeth restored with different posts using a single or multi-post technique with the help of 3D FEA.

Null Hypothesis

There is no significant difference in stress distribution among different post systems and techniques.

Methodology

Software Used:

- Ansys 12.1: For FEA
- HyperMesh 13.0: For creation of FEM
- Carestream CBCT: Model CS 9300

Methodology for Objectives

Finite element analysis is a numerical technique that can break up a complex geometrical structure into a mesh of many simple shapes known as finite elements. Because different objects have different geometric shapes, there are many ways to break a geometrical object into the finite-element mesh required for analysis.

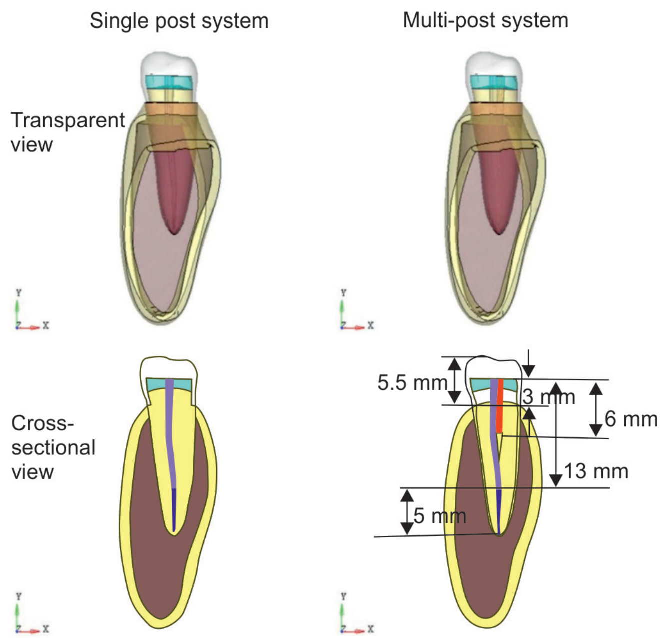

Fig. 1: Geometric models for single and multi-post technique showing both transparent view and cross-sectional view with the defined measurements for the FEA

Basic steps involved in carrying out FEA are:

Construction of the Geometric Model

A 3D model of the mandibular first premolar was created with the help of CBCT. The scanned images were obtained in the DICOM format, which was imported to Mimics software (version 8.11). It was exported to RAPID FORM (version 2004) in the stereo-lithography (STL) format. From this, the surfaces of the tooth were generated and this surface data was exported as IGES format to HyperMesh (version 13.0). This was further converted into geometric model consisting of surfaces and lines.

The analytical model of mandibular premolar was created using the dimensions obtained from the data given in the literature. Following that, measurements of the dental post, core, and crown were used for the creation of the model devising final shape of an endodontically treated mandibular 1st premolar. This tooth was restored with a post-and-core retained crown. A 3D finite element model of the assembly, including dentin, post, core, crown, and surrounding periodontal ligament and alveolar bone,[1] was created. The gutta-percha length varied with the post length and ranged from 5 to 7 mm.[10] The model simulated instrumentation of the root canal and obturation with gutta-percha.[11] The composite core was 1.0 mm high and 4.5 mm wide at the cervical end. The ceramic crown was 5.5 mm high, 1.0 mm thick at the finish line, and 2.0 mm thick at the cusp tip.[12]

The models were constructed as shown in Figure 1:

Model-1, endodontically treated mandibular premolar with single conventional fiber post.

Model-2, endodontically treated mandibular premolar with single everStick post.

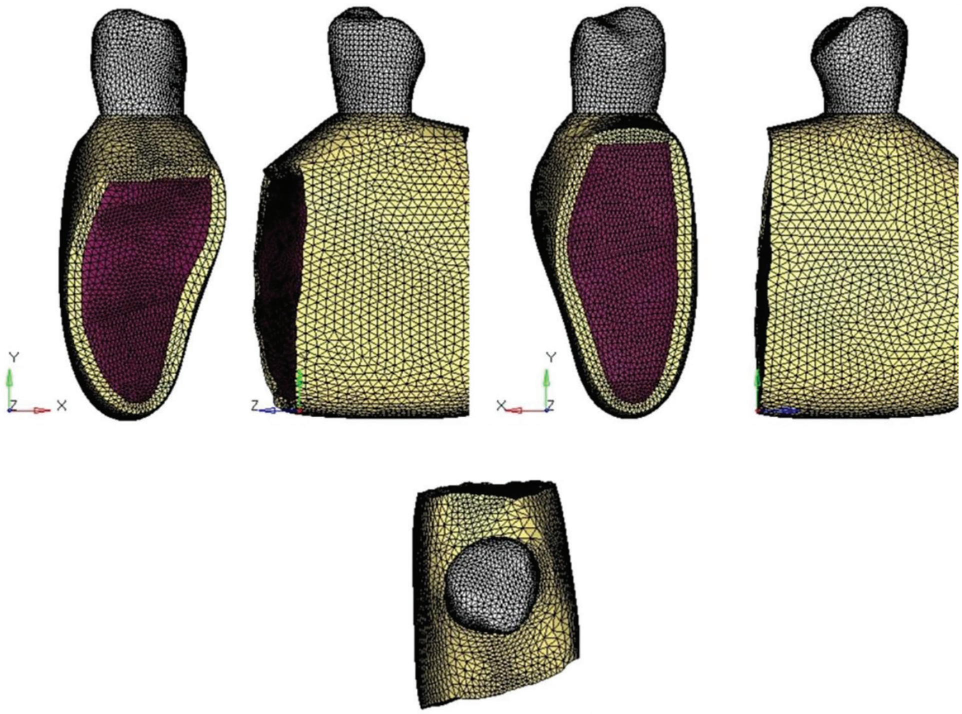

Fig. 2: FEM model of mandibular premolar shown in different views

Table 1: Elastic modulus and Poisson ratio for study materials

Young's modulus (MPa)	*Poisson's ratio*
84,100	0.33
18,600	0.31
6.8	0.45
6,900	0.45
13,700	0.26
1,370	0.31
0.69	0.45
40,000	0.25
15,000	0.18
16,600	0.24
96,000	0.26

Model-3, endodontically treated mandibular premolar with multiple conventional fiber posts.

Model-4, endodontically treated mandibular premolar with multiple everStick posts.

The second post was inserted next to the main post as apically as possible without producing physically and manually perceivable stress and it was kept deep enough to wedge the main post.[13]

Geometric Model Converted to Finite Element Model

The geometry in question in a FEA is represented by the mesh, which is a collection of finite elements. A mesh was created using rows and columns of numbers representing the positions of nodes and elements. In this study, the geometric model was converted into a finite element model using HyperMesh version 13.0 software. The solver used in this study was Ansys version 12.1. As shown in Figure 2, the total number of nodes used in this study is 7,011, and the total number of elements is 38,300.

Material Property Data Representation

The application of appropriate material properties into a finite element model is important to simulate the behavior of the biological entities present in the tooth and to obtain the accurate result of the study. The specific values are given in Table 1.

FEA

It is a noninvasive, *in vitro* method. After incorporating the material properties of tooth, the models simulate the natural tooth. Stress value can easily be measured in any given point of the model. Repetitive study will not alter the properties of the materials involved.[14]

Defining the Boundary Condition

The boundary conditions in the models were defined at all peripheral nodes. The bone element was assumed to be uniform, homogenous, and isotropic.

Application of Forces

The finite element mesh was imported into the Ansys software. This simulated a static occlusal loading of 180 N on the buccal surface at 45° in all models.[15]

Results

The results from FEA are expressed as stresses distributed in the structures being investigated. These stresses may be in the form of tensile, compressive, shear, or a combination known as VMS. This combination of stresses is dependent on the entire stress field and is used as an indicator of damage occurrence. In this presented study, force was applied to the buccal cusp in each finite element model, following which the VMS was analyzed. The results were calculated in terms of stress maps, with hot colors representing higher stress

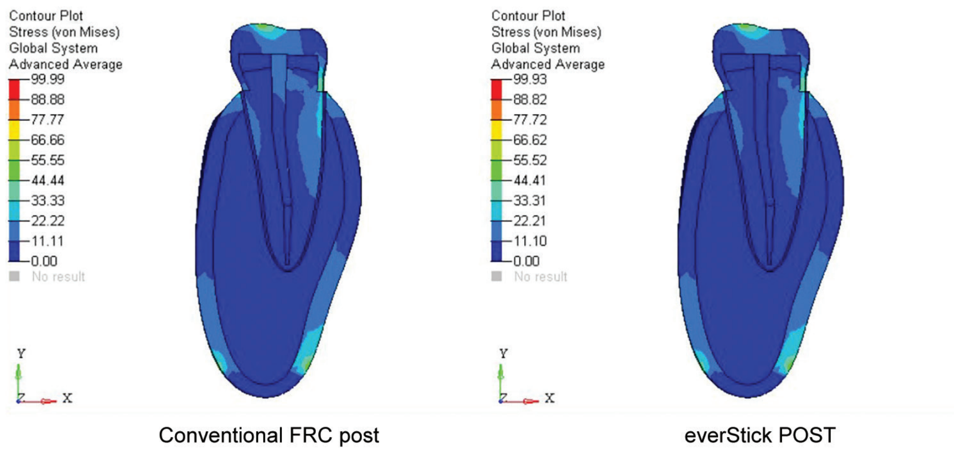

Fig. 3: Stress distribution in full models (single post) with different hot spot and cold spot. Hot spot being represented in red and cold in dark blue. Maximum value being 99.99 for conventional FRC post and 99.93 for everStick post

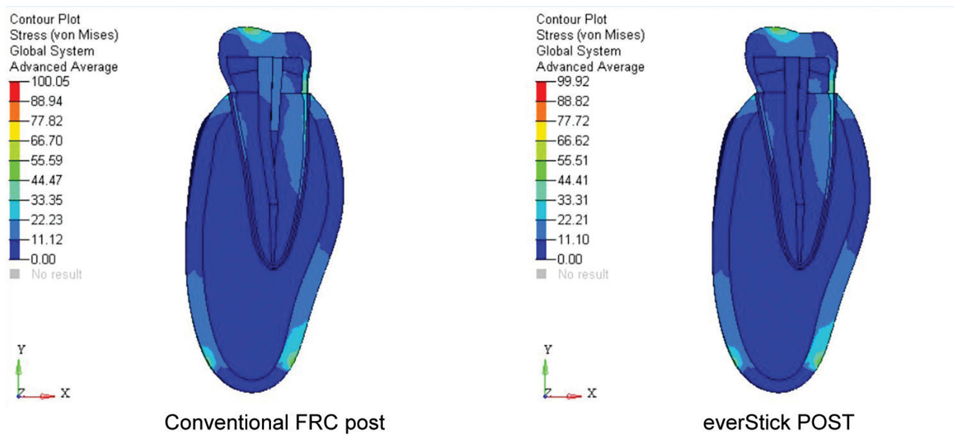

Fig. 4: Stress distribution in full models (multi-posts) with different hot spot and cold spot. Hot spot being represented in red and cold in dark blue. Maximum value being 100.05 for conventional FRC post and 99.92 for everStick post

Table 2: VMS values on each component

Single post system		*VMS*	
Case 1	*Part*	*Conventional FRC post*	*everStick post*
Single	Crown	99.99	99.93
	Dentine	29.31	29.67
	Post	9.19	4.77
	Cancellous bone	9.89	9.89
	Cortical bone	34.17	34.17
Multiple post system		*VMS*	
Case 2	*Part*	*Conventional FRC post*	*everStick post*
Multiple	Crown	100.05	99.92
	Dentine	29.16	29.88
	Post	24.14	10.53
	Cancellous bone	9.89	9.89
	Cortical bone	34.17	34.17

and cold colors representing lower stress, as shown in Figures 3 and 4. The maximum VMS value was obtained after loading and is mentioned in Table 2.

The results are usually interpreted in a pictorial manner by a colored band spectrum, each color in the bands is assigned to a particular level of stress. Maximum stress levels are shown in RED, minimum stress levels are shown in DARK BLUE.

In all the finite element models, homogeneous stress distributions and VMS values were observed along the structures, including posts, periodontal ligament, radicular dentin, core, and crown. For the single post system, stress distribution was similar in both conventional FRC post and everStick post; however, stress concentration was seen more on the conventional FRC post as compared to the everStick post. Higher stresses were observed in the crown on the buccal region as shown in Figure 3.

In multi-post technique, stresses were more as compared to the single post group. The stress distribution was similar in both the conventional FRC post and the everStick post, however stress concentration was seen more in the conventional FRC post than in the everStick post. Figure 4 shows that higher stresses were observed in the crown on the buccal region.

The graphical representation of the VMS is shown in Figure 5, comparing single and multiple post, and FRC and everStick post.

Discussion

Endodontically treated teeth as per previous studies are known to be weaker and more prone to fracture than their vital counterpart. Components of post and core create unusual stresses because the

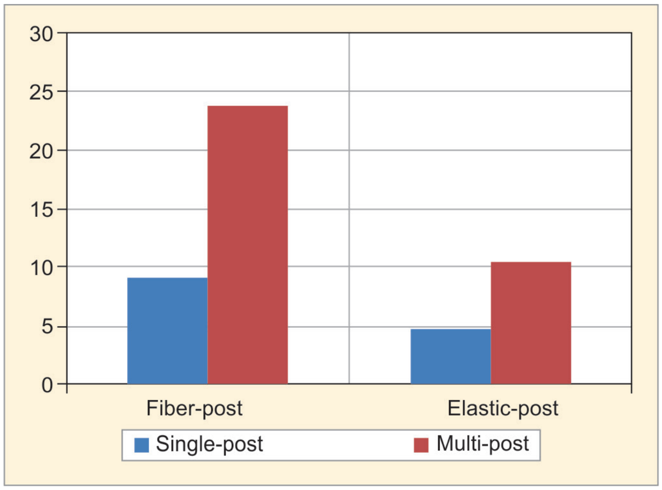

Fig. 5: Graphical representation of stress in single and multiple posts using conventional FRC and everStick, clearly shows more stress in multiple post as compared to single post

post space is occupied by materials that have a defined stiffness, which is different from natural tooth containing vital pulp, making it difficult to recreate the original stress distribution within a root-filled tooth. Additionally, the physical properties of post and core differ greatly from dentin, thus showing fundamentally different fatigue behavior.[16]

The most common reason for the failure of ETT may be due to the fracture of one of the components or adhesive failure at the interfaces between the components.[17] Up to 22% ETT with radicular post are known to suffer a vertical fracture. It has been supported that dentin shows a mechanism of fracture toughening, therefore reducing the possibility of crack progression.[1] For the aforementioned reasons, the protocol used for the post space preparation was minimally invasive. And thus, posts of the smallest available diameter (0.8 mm GC Fiber Post; 0.9 mm everStick POST) were selected for the study.

According to Maceri et al.,[8] a multi-post technique will lead to a closer adaptation of the post to the conforms of the prepared post space. Along with that, it will also possibly reduce the risk of a pull out. It will then help to increase the restoration's durability. Consequently, using multiple posts in the same canal or a single post is aimed at achieving a better, more homogeneous fit to the individual, preserved root canal anatomy possibly augmenting long-term clinical prognosis. With the use of a multi-post technique, the operator will be able to successfully fill large and irregularly shaped root cavities more efficiently than with a single, centrally positioned post, which will possess more voids. Fráter et al.[9] favor the use of multiple posts in the same root canal. According to their study, the multi-post technique with both conventional FRC and elastic FRC yielded significantly higher fracture resistance than the single post conventional FRC restoration.

This study was conducted using a 3D FEA method to investigate stresses in teeth restored with single and multi-post techniques. The use of a 3D model created was more precise compared to a 2D model in terms of variables like element numbers, simulation quality, and a finer representation of tooth forms. In the present study, all materials were assumed to be homogenous, isotropic, and linearly elastic. On the contrary, this postulation does not reflect the exact properties of many tissues and materials, including periodontal ligament, dentin, and glass fiber posts. For example, the periodontal ligament has nonlinear mechanical properties. Since the purpose of this study was to compare the stress distribution between models, it was believed that this assumption regarding the periodontal ligament and material properties seems appropriate.

As per investigators' recommendations in previous studies,[1] it was also assumed that different materials in this study were perfectly bonded at their interfaces, which was needed for smooth stress flow within the restoration-post-tooth assembly.

Von Mises stress was measured, which is a more appropriate representative of a multiaxial stress state as they show the most stressed areas, which are measured to be a more precise predictor of fatigue failure. The results of this study showed that maximum von Mises within the root canal were influenced significantly by the post material and the number of posts. This finding concurs with those of previous studies as shown in Figures 3 and 4.

The result of this study was also similar to Fráter et al., in which higher fracture resistance was seen in everStick post as compared to conventional FRC post. The use of multi-post technique utilizing small diameter posts helps the operator fill large and irregular canal morphology more proficiently than with a single, centrally positioned post.[8] However, according to the result of this study, more stress was generated in the multi posts group of both conventional FRC and everStick posts. This is in accordance with Trope et al., who showed that post space preparation severely weakened the root and reduced its ability to endure forces and insertion of the post further increased risk of fracture. In various other studies, it has been shown that pulpless teeth without intraradicular "strengthening" resisted occlusal forces better than teeth with various posts.

Limitations of the Study

Although the FEA method provides better control of test conditions than other methods, there are certain limitations as well. In FEA, static loading conditions do not exact the masticatory forces correctly. Furthermore, the assumption of well-bonded interfaces is not a true representative of the clinical situation (exception—adhesive bonding techniques). The assumed material properties are not the identical properties of actual structures, and we expect that this affects the stress values.

Conclusion

Within the limitation of the study, and from the simulation results and summary table following conclusions were made:

- Stresses are less in everStick post compared to conventional FRC post.
- Single post showed lesser stress compared to multi-post method.

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