Original Article

# Stress Distribution on Root Dentin Analogous to Natural Teeth with Various Retentive Channels Design on the Face of the Root with Minimal or No Coronal Tooth Structure: A Finite Element Analysis

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## Abstract

**Aim:** the aim of this study was to evaluate post-core design on Stress distribution in maxillary central incisor with various designs retentive channels placed on the face of the root with no remaining coronal tooth structure.**Materials and Methods:** 3 dimensional finite element model of a maxillary central incisor was developed and seven other study modes were developed. Tooth was scanned using CBCT unit, with reverse engineering software. 3D wire mesh, with ten node tetrahedral element, developed was transferred to ANASYS software. Composite was used for post-core-crown as post endodontic restoration. Mechanical properties were assigned to each component for FEA. All the materials were assumed to be isotropic, linearly elastic, homogenous and tightly bonded. A load of 100N were applied from vertical, horizontal and lateral oblique from incisal and palatal surface respectively. **Results:** Analysis revealed that stresses were concentrated at the point of load application on crown(vertical(V) 14.35MPa, horizontal(H) 27.04 MPa and lateral oblique(L)13.75MPa) and depending on the post core design the stresses were homogenous evenly distributed over the root dentin, core and least over the post. There was variation in stress distribution under vertical horizontal and lateral oblique load. **Conclusion:** Teeth with no remaining coronal structure and by placing retentive channels on the face of the root will enable homogenous stress distribution, promote mechanical retention and stability to the post core crown post endodontic restoration.

**Keywords:** *Finite element analysis, postcore crown, retentive channels on face of the root*

## Introduction

The success of endodontically treated teeth depends on hermetic apical seal, an effective coronal seal, the protection of the remaining tooth structure and restoring the form, function, and esthetic. When the remaining coronal structure is lost a postcore crown (PCC) is recommended to fulfill and achieve these requirements; therefore, the preparation design features for PCC that minimizes the chances of debonding and catastrophic root fracture will be advantages.[1-7]

A cast metal band encircling around the coronal surface of a tooth is called ferrule. The proposed function of the ferrule is to benefit in reinforcing the root canal-treated tooth. With significant loss of coronal tooth structure, the metal post without ferrule acts as a wedge and hence has high chances of root fracture.[8] Therefore, a need to assess an alternative design to the ferrule is required. This topic was investigated in many laboratory experimental studies in the past decade and still, controversies as well as interest for core and crown ferrule remain high in the field of dental research.[9,10]

Postcore and crown restorations are more frequently used for badly destructed root canal-treated teeth.[11] Newer composites with highly improved mechanical properties added with improved high bond strength of adhesive resin-bonding agents, these materials now are commonly used for core buildup over glass-fiber post, carbon-fiber post, quartz-fiber post, stainless steel, and titanium post instead of the conventional cast postcore. Two factors, that will influence the fracture resistance of postcore restored root canal-treated tooth, are the

**How to cite this article:** Shaikh SY, Mulani S, Shaikh SS. Stress distribution on root dentin analogous to natural teeth with various retentive channels design on the face of the root with minimal or no coronal tooth structure: A finite element analysis. Contemp Clin Dent 2018;9:630-6.

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**Access this article online**

**Website:**
www.contempclindent.org

**DOI:** 10.4103/ccd.ccd_536_18

**Quick Response Code:**

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ferrule and the remaining tooth structure thickness,[12,13] innovation, and improvement in the esthetic materials, as well as the clinical techniques and awareness with high demand from patients, treatment for preserving badly destructed teeth previously deemed for extraction has changed drastically.[14]

The direct adhesive bonding technique for the restoration of root canal-treated teeth is now being widely used. The foundation for postcore direct composite crowns can withstand load required for PCC complex and should be considered as an alternative treatment technique modality for restoring damaged teeth.[15] Furthermore, it is important that the mechanical properties of PCC material should have elastic properties similar to the dentin for equal stress distribution. Thus, the composite can be used for reinforcing badly destructed teeth to avoid extraction as suggested by two-dimensional and three-dimensional (3D) finite element analysis (FEA).[16-18]

The long-term success of PCC in maxillary incisors is largely influenced by the magnitude as well as the direction of incisal load.[19] The stress in the postendodontic restoration is not uniform and also multiaxial. Thus, the stress distribution is nonhomogenous due to external loading as well as the geometry of postcore restored teeth and residual stresses; these are the factors of multiaxiality stress distribution.[20] One study concluded that irrespective of post material, the stress pattern was similar.[21]

The purpose of this 3D FEA study was to investigate and assess the outcome of root-filled central incisors with total loss of coronal tooth structure and the effect of (outcome of) various retentive channels design prepared on the face of the root for maximum retention-resistance-stability and stress distribution, most similar to the natural sound teeth in maxillary incisors using direct composite resin. The null hypothesis was that there is no association between various retentive channel designs on the face of the root for postcore crown (PCC) and stress distribution.

## Materials and Methods

The study was conducted using the finite element method. To validate, evaluate, and compare the mechanical reliability of the postcore crown restoration using different retentive channels on the face of the root with NO remaining coronal tooth structure for endodontically treated maxillary central incisor has been performed to calculate the stress distribution. The total length of the tooth was 23.5 mm, crown length was 10 mm, and root length was 13.5 mm (cone-beam computed tomography [CT] tooth scan → reconstruction of tooth on computer with reverse engineering technique → intact tooth model and models with PCC → boundary conditions and material properties → Ansys FEA → Mesh with 10 node tetrahedralelements → static load 100N → principal stresses in models assessed). The tooth was CT scanned (Orthophos XG-3D, Sirona, Bhensheim, Germany), the images were imported to computer for duplication with reverse engineering, Geomagic software to create the internal anatomy, and morphology for central incisor in STL format and was converted to 3D wire mesh for FEA imported to ANSYS (Ansys 14.5, Canonsburg, USA). 3D schematic model reconstruction using Solid Works 2007 software (SolidWorks corpn. Concord, USA). All the components were considered that included enamel, dentin, periodontal ligament, bone, and composite PCC, and the modeling of FEA samples requires the assignment of morphological characteristic and mechanical material properties of different components.[22] The mechanical properties of various materials simulated were identified from the available published literature [Table 1]. Based on the intact incisor tooth model, seven other models were simulated with different retentive channels on the face of the root, endodontically treated and restored with composite postcore and crown. A FEA wire mesh was generated with linear isotropic ten-node tetrahedral elements designed for stress analysis.

**Table 1: Mechanical properties of the material**

| Material | Elastic modulus (GPa) "*E*" | Poisson's ratio |
|---|---|---|
| Enamel | 84.0* | 0.33* |
| Dentin | 18.6* | 0.32* |
| Pulp | $0.98\times10^{-3}$* | 0.45* |
| Periodontal ligament | $6.9\times10^{-3}$* | 0.45* |
| Cancellous bone | $4.9\times10^{-1}$* | 0.30* |
| Cortical bone | 14.7* | 0.30* |
| Composite | 12* | 0.33* |
| Resin cement | 18.6* | 0.28* |
| Gutta-percha | 0.69* | 0.45* |

### FEA models[23]

- Model 1 [Figure 1a]: Dimensions of intact central incisor (ICI) were total tooth length –23.5 mm, crown length –10 mm, mesiodistal (MD) width at incisal region –8.5 mm, faciolingual (FL) width at incisal region –2.5 mm, MD width at cervical region –6.5 mm, FL width at cervical region –7.5 mm, and root length –13.5 mm
- Model 2: [Figure 1b]: Dimensions for plane flat root face (PF) were root length –13.5 mm, postlength –8.5 mm, core height –5.5 mm, core width –3.8 mm, gutta-percha apical plug –5 mm, and crown length –10 mm
- Model 3: [Figure 1c]: "Plus-shaped" retentive channels placed on the face of the root; in MD and FL directions, crossing each other at root canal center. Extending to the external surface of the root boundaries $(MD + FL)_x$ retentive channels as follows: MD retentive channel –6.5 mm × 1.5 mm × 2 mm (length was 6.5 mm, width was 1.5 mm and depth was 2 mm), FL retentive channel –7.5 mm × 1.5 mm × 2 mm (length was 7.5 mm, width was 1.5 mm, and depth was 2 mm), root

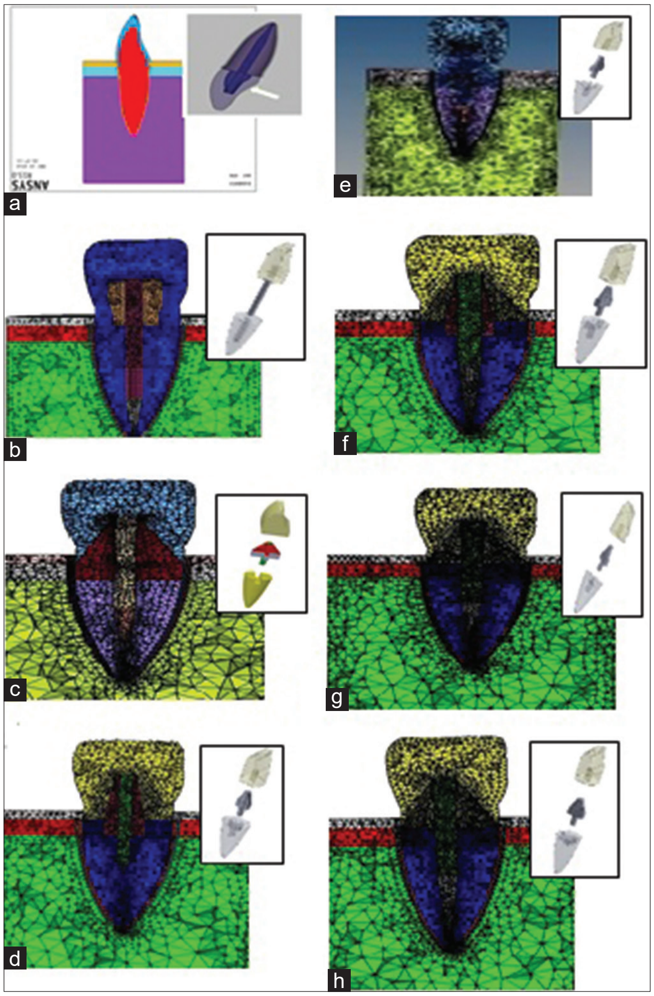

**Figure 1: (a) Model 1: Intact central incisor. (b) Model 2: Plane flat root face No retentive channel. (c) Model 3: "Plus-shaped" retentive channels on face of the root. (d) Model 4: The plus shape retentive channels 2 mm short to external surface. (e) Model5: Retentive channel only in mesiodistal direction. (f) Model 6: Retentive channel mesio-distal direction 2 mm short to external surface. (g) Model 7: Retentive channel faciolingual direction. (h) Model 8: retentive channel faciolingual direction 2 mm short to external surface. Adopted from my ongoing PhD thesis**

length –13.5 mm, totalpost length –10.5 mm (03 mm from the canal orifice into the root canal and 5.5 mm from canal orifice into the core), core height –5.5 mm, core width –3.8 mm, crown length –10 mm, and gutta-percha apical plug –8.5 mm

- Model 4: [Figure 1d]: The plus-shape retentive channels placed on the face of the root; in MD and FL directions, crossing each other at root canal center. Extending 2 mm short to the external surface of the root boundaries, that is 2-mm dentin wall is present at root circumference (MD + FL) s, MD retentive channel was 3 mm × 1.5 mm × 2 mm (length was 3 mm, width was 1.5 mm, and depth was 2 mm), FL width at cervical region was 3.5 mm × 1.5 mm × 2 mm (length was 3.5 mm, width was 1.5 mm, and depth was 2 mm), root length was 13.5 mm, total postlength was 10.5 mm (03 mm from the canal orifice into the root canal and 5.5 mm from canal orifice into the core), core height was 5.5 mm, core width was 3.8 mm, crown length was 10 mm, and gutta-percha apical plug was 8.5 mm
- Model 5: [Figure 1e]: Retentive channel placed on the face of the root only in MD direction with canal orifice at the center, extending to the external surface of the root boundaries (MD), MD retentive channel –6.5 mm × 1.5 mm × 2 mm (length was 6.5 mm, width was 1.5 mm, and depth was 2 mm), root length –13.5 mm, total postlength –10.5 mm (03 mm from the canal orifice into the root canal and 5.5 mm from canal orifice into the core), core height –5.5 mm, core width –3.8 mm, crown length –10 mm, and gutta-percha apical plug – 8.5 mm
- Model 6: [Figure 1f]: Retentive channel placed on the face of the root only in MD direction with canal orifice at the center, extending 2 mm short to the external surface of the root boundaries (MD) s, MD retentive channel –3.5 mm × 1.5 mm × 2 mm (length was 3.5 mm, width was 1.5 mm, and depth was 2 mm), root length –13.5 mm, total postlength –10.5 mm (03 mm from the canal orifice into the root canal and 5.5 mm from canal orifice into the core), core height –5.5 mm, core width –3.8 mm, crown length –10 mm, and gutta-percha apical plug –8.5 mm
- Model 7: [Figure 1g]: Retentive channel placed on the face of the root only in FL direction with canal orifice at the center extending to the external surface of the root boundaries (FL) x, FL retentive channel –7.5 mm × 1.5 mm × 2 mm (length was 7.5 mm, width was 1.5 mm, and depth was 2 mm), root length –13.5 mm, total postlength –10.5 mm (03 mm from the canal orifice in the root canal and 5.5 mm from canal orifice in the core), core height –5.5 mm, core width –3.8 mm, crown length –10 mm, and gutta-percha apical plug –8.5 mm
- Model 8: [Figure 1h]: Retentive channel placed on the face of the root only in FL direction with root canal at the center, 2 mm short to the external surface of the root boundaries (FL) s, single FL retentive channel –3.5 mm × 1.5 mm × 2 mm (length was 3.5 mm, width was 1.5 mm, and depth was 2 mm), root length –13.5 mm, total postlength –10.5 mm (03 mm from the canal orifice into the root canal and 5.5 mm from canal orifice into the core), core height –5.5 mm, core width –3.8 mm, crown length –10 mm, and gutta-percha apical plug –8.5 mm.

FEA is a computer-based noninvasive stress analysis method. The model will simulate normal tooth and the bone after assigning and incorporating material properties of the tooth and bone. The stress value can be measured at any point on the model. Each model was divided into small elements interconnected at nodes with ten-node tetrahedral elements as they have the existence of automatic tetrahedral meshes, more suitable for complex geometric structure of tooth and are more accurate. Refinement and accuracy of the experimental models were checked using convergence test. Model 1 consisted of 205,243 elements and 289,422 nodes; Model 2 consisted of elements 226,489 and nodes 315,294; Model 3 consisted of elements 245,737 and nodes 362,923; Model 4 consisted of elements 289,080 and nodes 413,724; Model 5 consisted of elements 262,892 and nodes 382,496; Model 6 consisted of elements 265,290 and nodes 386,294; Model 7 consisted of elements 258,299 and nodes 375,281; and Model 8 consisted of elements 260,284 and nodes 378 293. For simplification of calculations, the materials are assumed to be homogenous, linearly elastic, and isotropic.[24]

Boundary conditions were applied on the nodal displacement constraint at the outer surface of the support cylinder. A static load of 100N was applied from vertical at incisal edge parallel to the long axis of the tooth, oblique at 45° and horizontal perpendicular to the long axis of tooth on the palatal surface at contact area, and 3 mm below the incisal edge. Stress distribution analysis was conducted with Von Mises criteria, and the results are represented in graphic with the color scale in Megapascal unit.

## Results

The FEA results are presented as stresses distributed over the composite crown, root dentin, postcore, and the investigated structures for root canal-treated tooth. The stresses may occur as tensile, compressive, shear, or a stress combination known as equivalent Von Mises stresses. These stresses depend on the entire stress field and are a widely used indicator for prediction of safety and fracture of structures analyzed. Since tooth tissue exhibits brittle behavior; hence, von Mises stresses were chosen for the presentation of stress pattern that may suggest areas vulnerable to damage.

The commonly occurring phenomena with all type of postcore systems is that when the direction of the load was changed from vertical to oblique then to horizontal the stress level will be increased as the forces are oriented more oblique and finally reaches to the highest level when they were absolutely horizontal. The higher effect of leverage could be the reason for phenomena that occurs with vertical, oblique, and horizontal loads.

The results of the present study show high stress reached near the applied load for all eight FEA models [Table 2]. The stress distribution in the intact sound tooth Model1 was not relatively different from the restored tooth models. However, the load was uniformly distributed as there were minimal interfaces present, and single type of composite material was used assuming that the restored tooth with retentive channels and with no remaining coronal tooth structure has low fracture risk when subjected to the multiaxial functional load if the restored tooth mimics and its behavior tends toward to be like that of a sound tooth. Furthermore, it clearly indicates that horizontal load caused maximum stresses and the vertical load was along the long axis of the tooth with minimal stress in root dentin and restored elements; however, the diagonal-lateral-oblique load was more critical to the restored structures as well as to the remaining root dentin.

## Discussion

An engineering tool called FEA can be used for understanding and determining the stress and strain behavior of the materials used in restoration.[25]

The variables under the study can be easily altered, and the experiment simulation can be developed without the need for human material and offers maximum standardization for more accurate results.[26] With the use of computer software virtually the real problem can be analyzed, of dental materials and structures, as the software is capable of performing the numerical analysis. With geometry of the structure, mesh and with each element characterized by the mechanical properties of restoration materials complex problems can be solved.

The analysis of stress distribution in the teeth, especially root dentin and restored structure, will be difficult after the placement of posts in the clinical *in vivo* cases. Therefore, FEA provides, with certain limitations, an indirect method for analyzing the complex problems associated with surrounding structures and the teeth[27] to understand the relative susceptibility of the restored teeth complex system to the fatigue loading condition it can be successfully obtained and extrapolate this reliable information from the static linear analysis. Based on the stated assumption that there are homogeneous stress distributions for the intact and restored teeth in a static analysis conversely show low-fatigue susceptibility in clinical conditions.

It is an established fact that ferrule increases the fracture resistance of post and core restored teeth[28] and has protective effect on the stress reduction and distribution.[29] Our study was for the teeth with no remaining coronal structure. Retentive channels were placed on the face of the root in six different types and in various directions as explained in the material and method section above. It should be emphasized that bad prognosis or deemed for extraction was usually applied for such teeth. However, with improved properties of composite restorative material and other innovative techniques, complex restorations are placed in clinical practice for weakened teeth. One such attempt is our research study to design a postcore complex that will improve fracture resistance, ensure homogeneous stress distribution for long-term clinical success for these teeth.

Vertical load [Figure 2] applied, induced maximum stress at the incisal edge of the crown (13.17–13.89 MPa), and lower stress in dentin (3.008–3.96 MPa) except for Model

5. The stresses on core were (1.19–5.94 MPa) and were lowest on the post (1.53–2.33 MPa). For Model 2, PF root face with no retentive channels had stressed on root dentin similar to Models 4, 6, 7, and Model 8. For Model 3, $(MD+FL)_x$ homogeneous even distribution over the dentin and core similar to the intact natural (ICI) tooth. Model 5: stress was more on the core than dentin, $MD_x$ retentive channel placed on the face of the root was it extended to external root surface, and the postcore design caused more stress taken up by core, thereby safeguarding the underneath root dentin, a protective postcore design.

In addition, the stress values under the diagonal-lateral-oblique load [Figure 3] were more varied in distribution. For crowns, it was maximum stress (13.79–4.60 MPa), except Model 2, followed by stress on dentin, and (6.70–3.21) minimal dentin stress for Model 4.The stress on the core and dentin ( 2.12-6.17Mpa ) of model no. 3 and 7 showed equal distribution. Stresses on post were least (2.30–2.64 MPa). For Model 2 (PF), maximum stress was over the root dentin, unlike all other models making root prone for failure. For Model 3 $(MD+FL)_x$ and Model 7 $(FL)_x$, there was homogenous stress distribution evenly over the core and dentin, and the positive effect of the postcore design with retentive channels on the face of the root. For Model 4 $(MD+FL)_s$, amazingly stresses were very low and homogeneously distributed evenly over the core and dentin, and effective design for teeth with no remaining coronal tooth structure.

For the horizontal load [Figure 4], the stress values were highest when compared to the vertical and diagonal-lateral-oblique loads, maximum stress at crown (27.04–15.49 MPa) except for Model 2 Model 6, followed by stress on dentin (15.73–16.82 MPa), it was highest in dentin for Model 2 and Model 6, and stress on core (3.80–15.37 MPa) but Model 3 and Model 7 the stress was evenly distributed on dentin and core. The stress for the post was (5.03–7.46 MPa). The materials used for this study were assumed to be homogenous, linearly elastic, and isotropic.

Many studies have indicated that root canal-treated teeth need special consideration when planning postendodontic restoration as they are highly prone and susceptible to the fracture.[30,31]

Literature indicates many types and ways for postendodontic restoration but no ideal type of restoration for teeth with no remaining coronal structure. New adhesive composite restorations have modulus of elasticity similar to the dentin it can homogeneously distribute and transmit functional stresses between the composite-tooth interfaces with the potential to reinforce crippled tooth structure. Hence, the composite material was applied for restoring such teeth. When the load is applied to the restoration complex with different elastic modulus, the stresses generated will concentrate on the structure that possesses maximum stiffness resulting in peak stress localization in the less rigid component structures that will lead to crack formation and subsequently cause fracture.[32,33] Hence, the restorative material with modulus of elasticity similar to radicular dentin will be more suitable for reducing stress concentration and will also evenly distribute stress along the postcore, and root dentin for an endodontically treated teeth.[34] The maxillary central incisor can be extrapolated mechanically as to behave like an elastic beam fixed at the lower end during function and as a cantilever when loaded laterally diagonal to the long axis of the tooth[35] based on the modulus of elasticity for dentin (18GPa) postendodontic restoration of teeth with composite (12.5GPa) along with retentive

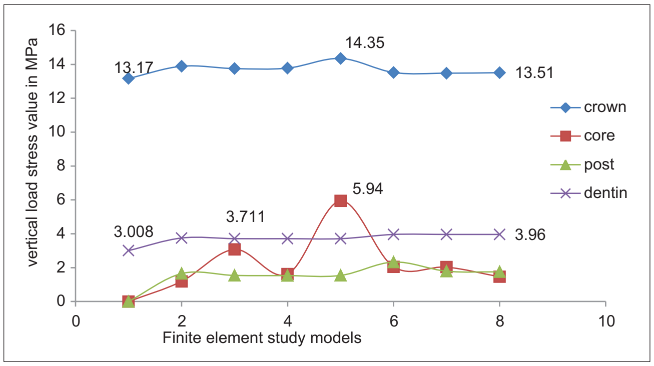

**Figure 2: Application of vertical load and stress distribution on postcore crown and root dentin**

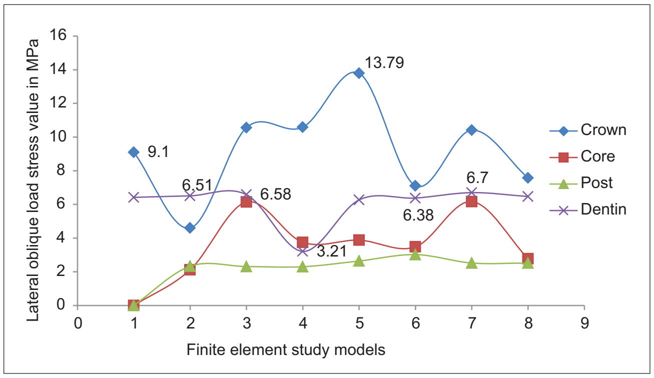

**Figure 3: Application of lateral-oblique load and stress distribution on postcore crown and root dentin**

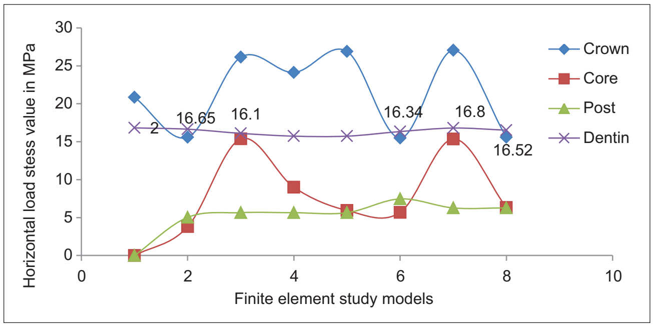

**Figure 4: Application of horizontal load and stress distribution on postcore crown and root dentin**

**Table 2: Stress distribution in crown-root dentin-post and core Megapascal unit (MPa)**

| FEA model | 100N load | Crown (MPa) | Core (MPa) | Post (MPa) | Dentin (MPa) |
|---|---|---|---|---|---|
| 1 | V* | 13.17 | NA | NA | 3.008 |
| | O* | 9.10 | NA | NA | 6.42 |
| | H* | 20.85 | NA | NA | 16.82 |
| 2 | V | 13.89 | 1.19 | 1.65 | 3.75 |
| | O | 4.60 | 2.12 | 2.33 | 6.51 |
| | H | 15.59 | 3.80 | 5.03 | 16.65 |
| 3 | V | 13.75 | 3.076 | 1.54 | 3.711 |
| | O | 10.56 | 6.147 | 2.31 | 6.58 |
| | H | 26.14 | 15.37 | 5.65 | 16.10 |
| 4 | V | 13.78 | 1.62 | 1.53 | 3.71 |
| | O | 10.59 | 3.75 | 2.30 | 3.21 |
| | H | 24.12 | 8.99 | 5.64 | 15.73 |
| 5 | V | 14.35 | 5.94 | 1.54 | 3.71 |
| | O | 13.79 | 3.88 | 2.64 | 6.27 |
| | H | 26.90 | 5.94 | 5.64 | 15.73 |
| 6 | V | 13.52 | 2.05 | 2.33 | 3.96 |
| | O | 13.79 | 3.88 | 2.64 | 6.27 |
| | H | 15.49 | 5.69 | 7.46 | 16.34 |
| 7 | V | 13.48 | 2.03 | 1.79 | 3.96 |
| | O | 10.41 | 6.17 | 2.52 | 6.70 |
| | H | 27.04 | 15.36 | 6.27 | 16.80 |
| 8 | V | 13.51 | 1.46 | 1.75 | 3.96 |
| | O | 7.57 | 2.78 | 2.52 | 6.47 |
| | H | 15.58 | 6.33 | 6.28 | 16.52 |

*Load orientation: V: Vertical, O: Lateral oblique, H: Horizontal related to the longitudinal axis of the tooth. NA: Not applicable

channels, as placed for Models 3–8, could result in more even stress dissipation within the remaining root structure and will reduce the risk of catastrophic fracture or increase the chances of restorable fracture.

## Conclusion

Based on the FEA results of this study, the following conclusions were made:

1. Under vertical load Models 3 and 5, PCC design should be incorporated for maximum benefits similar to natural maxillary central incisor teeth for stress distribution and maximum retention.
2. Under lateral oblique load, more crucial, Models 3 and 7 PCC design should be incorporated. Caution not to use Model 2, as it causes maximum stress on root dentin.
3. Under horizontal load, much similar to lateral-oblique, but have highest stress magnitude. Models 3 and 7 are favorable designs. Model 2 is a catastrophic design.

### Financial support and sponsorship

Nil.

### Conflicts of interest

There are no conflicts of interest.

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