The Effects of Post Diameter on Stress Distribution in Maxillary Central Incisor, A Three Dimensional Finite Element Study

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Statement of Problem: Currently there are three recognized theories about the diameter of prepared dowel space in endodontically treated teeth. Diameter of the dowel is commonly contributed to the root fracture.

Purpose: This study used a 3 dimensional (3D) finite element method to predict stress distribution in endodontically treated central maxillary tooth with cast post and core with various post diameter according to three philosophies about post diameter (Conservational, Proportional, Preservational).

Materials and Methods: In this study three 3D models of central maxillary incisors with different post diameter were created and depend on the size of post called narrow, medium and thick model with post diameter of 1.1 mm, 1.7 mm and 2.6 mm of in (CEJ) respectively. A load of 100 N was applied to cingulum fossa from lingual direction with 45-degree angle to long axis of tooth and maximum tensile, compressive and Von Misses stresses and their distribution in dentin and post was studied.

Results: The post in narrow, medium and thick models produced a similar magnitude of tensile, compressive and Von Misses stresses in dentin. Stress distribution was also similar in all models. Peak stresses in dentin were slightly decreased when post diameter increased from narrow to thick model. In all models peak tensile stresses in dentin occurred in the coronally one third of the lingual surface of the root, whereas peak compressive stresses were evident in the coronal one third of the facial surface of the root.

Conclusion: There were not significant differences stress distribution pattern and magnitude in dentin between the three theories of post diameter

Key Words: Dentistry; Finite element; Post-core; Stress analysis; Post diameter

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When coronal tooth structure is lost, the remaining structure of tooth is not sufficient to retain a restoration. In these cases, the use of either prefabricated posts or casting posts is inevitable. It has been demonstrated that the use of post and core transfer the applied loads to the root and supportive tissues and thereby strengthens the tooth.¹²³ It is, however, claimed that post and core application cause fractures in teeth.⁴⁵

The resistance of an endodontically treated tooth to fracture depends on prudent management of the residual root structure and design and preparation of the dowel space. In the design of the dowel space, length and diameter are fundamental parameters. It is the
diameter of the dowel, which is commonly contributed to the root fracture. Currently there are three recognized theories about the diameter of prepared dowel space in endodontically treated teeth.\(^6\) One group so-called “Conservationists,” advocates the narrowest diameter that allows the fabrication of a dowel to desired length with only minimal instrumentation of the canal after removal of gutta-percha.\(^7\) - \(^9\) The second group so-called, “Proportionists”\(^10\) - \(^13\) recommends a dowel space with an apical diameter equal to one third the narrowest dimension of the root diameter at the end of the dowel space. The third group, “the Preservationists”\(^14\) - \(^15\) advises that at least 1mm of sound dentin should surround the entire surface of the dowel.

Mattison\(^16\) selected the 2D Photo-elastic method used maxillary central incisor and applied two forces of 30, 60 Pounds in two directions (vertical and oblique). He found that no statistically significant difference was between the two posts (0.05, 0.07 inch) when 30 pounds oblique loads were applied, but in oblique load with magnitude of 60 P the difference was significant. Holmes et al\(^17\) used an ax-symmetric Finite Element Method (FEM) mandibular canine model and applied a force of 100N to cuspal tip from facial direction at 45-degree angle to the long axis of tooth. They mentioned that minor alterations in post dimensions had minimal effect on the stress distribution pattern and magnitude of compressive and tensile stresses in dentin. They identified the greatest stress concentration in dentin was on the coronal portion of root near the crest of bone. They also observed that compressive stresses were intensified from facial surface of root to the lingual surface and tensile stresses were intensified from lingual to facial surfaces.

Yang et al\(^18\) selected a 2D model of maxillary central incisor and applied forces at varying angles. They identified that minor changes occurred in the overall stress pattern due to variation in the diameter of the dowel and produce a similar stress pattern distribution and magnitude was. No qualitative differences were seen in the peak stress regions of PDL and dentin.

Ko et al\(^3\) selected an ax-symmetric FEM model and applied forces at varying angles to posts without any coronal restorations or ferrule reinforcement. The obliquely applied forces demonstrated that stress concentration in dentin was on the coronal and middle parts of the root.

Davy et al\(^19\) used a 2D finite element method and illustrated that minor changes in stress patterns were created by changing in post diameter, length and taper. They reported that post length has less effect than post diameter but as they mentioned, these findings should be limited to their model and load conditions.

The purpose of this study was to compare the three theories concerning the post diameter in endodontically treated teeth by evaluating the stress distribution pattern and magnitude.

**Materials and Methods**

In this investigation a 3D model of a block section of maxilla, which included central incisor and its supporting structures, was analyzed. ANSYS program (Ver. 5.4) was used if this analysis. The bottom-up method used for making 3D model. First, one acrylic model of maxillary central incisor and its supporting structures, was made 2.27 times greater than the real tooth size. Then this model was placed in a hexahedral box and transparent acryl was purred around the tooth. Therefore, a polymeric hexahedral, which has an artificial tooth in center was produced. Due to fine details in the crown, 12 cross sections in crown and 2 cross sections in the root part of the model was made. By using a scanner, the image of these 14 cross sections was transferred to an Adobe Photoshop program and 14 key points were chosen on each cross section. The position of each key point was calculated from any of three intersecting
coordinate planes of X,Y,and Z(Cartesian axes). All data about each key point transferred to ANSYS program and a three dimensional image of tooth was generated. The same method was used to create inner parts like post, cement, etc. For this investigation, three models with different post diameters were generated. The models called narrow, medium, and thick with the post diameter of 1.1mm, 1.7 mm, and 2.6 mm at CEJ respectively (Fig 1). Each model consisted of 11 components (Fig 2).

Mechanical properties of each component used in this study are summarized in table I. All models were consisted of 40000 3D tetrahedral solid elements and 60000 nodes (Fig. 3). A load of 100N was applied to cingulum from lingual, 45-degree oblique to the tooth long axis (Fig. 4).

Maximum tensile, compressive, Von Misses stresses and their distribution in dentin and post was studied.

**Results**

Figures 5 to 8 show compressive, tensile and Von Misses stress distribution pattern from facial and lingual view of root in all three models. Peak stresses for all three models are summarized in table II.

Tensile, compressive and Von Misses stress distribution patterns in dentin were approximately the same for all three models.

Compressive stresses intensified from lingual to facial surface of root. Maximum compressive stresses were the facial surface of the root near the crest of bone (between one third and cervical part of root) and the mid-facial surface of root near the crown edge in cavo-surface line (Fig. 5).

Tensile stresses intensified from facial to lingual surface of root, with the maximal tensile stresses at two regions: the lingual surface of the root near the crest of bone (between one third of middle and cervical root) and the mid lingual surface of root near the crown edge in cavo-surface line (Fig. 6).

Also peak compressive, tensile and Von Misses stresses were approximately the same for all models, however the stresses in dentin rarely decreased when post diameter increased from narrow to thick model. This decrease for tensile and compressive stresses was about 2.5% and 7.1%, respectively.

Compressive, tensile and Von Misses stresses distribution patterns from facial and lingual view of post for all three models are presented in figs. 9 to 11.

<table>
<thead>
<tr>
<th>Young's modulus (Gpa)</th>
<th>Material</th>
<th>Poisson's ration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>Enamel</td>
<td>0.31</td>
<td>3</td>
</tr>
<tr>
<td>18.6</td>
<td>Dentin</td>
<td>0.30</td>
<td>23</td>
</tr>
<tr>
<td>0.068.9</td>
<td>Periodontal Ligament</td>
<td>0.45</td>
<td>23</td>
</tr>
<tr>
<td>13.7</td>
<td>Cortical Bone</td>
<td>0.30</td>
<td>3</td>
</tr>
<tr>
<td>1.37</td>
<td>Spongy Bone</td>
<td>0.30</td>
<td>3</td>
</tr>
<tr>
<td>0.0196</td>
<td>Gingiva</td>
<td>0.30</td>
<td>23</td>
</tr>
<tr>
<td>0.00069</td>
<td>Gutta Percha</td>
<td>0.45</td>
<td>23</td>
</tr>
<tr>
<td>69</td>
<td>Porcelain</td>
<td>0.28</td>
<td>23</td>
</tr>
<tr>
<td>200</td>
<td>Steel Post</td>
<td>0.33</td>
<td>3</td>
</tr>
<tr>
<td>131</td>
<td>Silver Paladium Post</td>
<td>0.35</td>
<td>24</td>
</tr>
<tr>
<td>88</td>
<td>Gold Post</td>
<td>0.35</td>
<td>24</td>
</tr>
<tr>
<td>77</td>
<td>Gold Alloy Coping</td>
<td>0.35</td>
<td>23</td>
</tr>
<tr>
<td>22.4</td>
<td>ZPC*</td>
<td>0.25</td>
<td>25</td>
</tr>
</tbody>
</table>

*Zinc Phosphate Cement

Table I- Mechanical properties used in this study
Tensile, compressive and Von Misses stresses distribution patterns in post was approximately the same for all three models. Maximal compressive stresses were observed at the facial surface at the middle of post length and maximal tensile stresses were observed at the lingual surface at the middle of post. Peak compressive, tensile and Von Misses stresses in post were different in three models. Tensile and compressive stresses in post increased significantly as the post diameter increased from narrow to thick. This increase in tensile and compressive stresses was about 100% and 66%, respectively. Table III shows the increase of stress in dentin and post as the post diameter increased.

**Table II- Peak stresses for each case (MPa)**

<table>
<thead>
<tr>
<th></th>
<th>Max. Tensile</th>
<th>Max. Compressive*</th>
<th>Max. Von Mises</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Core</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick</td>
<td>14.2</td>
<td>-120.1</td>
<td>114.7</td>
</tr>
<tr>
<td>Medium</td>
<td>22.6</td>
<td>-117.4</td>
<td>112.7</td>
</tr>
<tr>
<td>Narrow</td>
<td>25.3</td>
<td>-116.9</td>
<td>112.3</td>
</tr>
<tr>
<td><strong>Post</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick</td>
<td>27.9</td>
<td>-36.1</td>
<td>33.4</td>
</tr>
<tr>
<td>Medium</td>
<td>19.0</td>
<td>-28.7</td>
<td>26.9</td>
</tr>
<tr>
<td>Narrow</td>
<td>13.9</td>
<td>-21.6</td>
<td>21.3</td>
</tr>
<tr>
<td><strong>Dentin</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick</td>
<td>15.6</td>
<td>-20.7</td>
<td>17.2</td>
</tr>
<tr>
<td>Medium</td>
<td>15.9</td>
<td>-22.0</td>
<td>18.8</td>
</tr>
<tr>
<td>Narrow</td>
<td>16.0</td>
<td>-22.3</td>
<td>19.8</td>
</tr>
</tbody>
</table>

* Compressive stresses were shown with negative

Fig. 1 - A: Thick model (Post and Root in above and axial cross section of complete model in below) B: Medium model (Post and Root in above and axial cross section of complete model in below). C: Narrow model (Post and Root in above and axial cross section of complete model in below).

Fig. 2 - Different part of finite element model A: Complete model B: Root-Coping-Porcelain C: Root-Core D: Root, PDL and Zinc phosphate cement E: Root, Coping-Lamina Dura.
Fig. 3- Discretization of model into about 40000 tetrahedral elements (Left) and about 60000 Nodes (Right)

Fig. 4- Load of 100N applied to cingulum fossa from lingual direction at 45-degree to long axis of tooth

Fig. 5- Compressive stresses (buccal view)
A: Narrow model
B: Medium model
C: Thick model

Fig. 6- Tensile stresses (lingual view)
A: Narrow model
B: Medium model
C: Thick model

Fig. 7- Von Misses stresses (buccal view)
A: Narrow model
B: Medium model
C: Thick model

Fig. 8- Von Misses stresses (axial cross section)
A: Narrow model
B: Medium model
C: Thick model
(Red color predicts higher stress and blue color predicts lower stress.)

Fig. 9- Tensile stress in Post at Buccal view (Left) and Lingual view (Right)
A: Narrow model
B: Medium model
C: Thick model

Fig. 10- Compressive stress in Post at Buccal view (Left) and Lingual view (Right)
A: Narrow model
B: Medium model
C: Thick model
Discussion

This study showed that the greatest principal stresses occurred in dentin at the coronally one third of the root. These results were similar to the results of Photo-elastic investigations of Assif et al and Hunter et al. (20,21). They demonstrated the greatest concentration of isochromatic fringes in dentin at the cervical region.

The results of Mattison’s study (16) showed that no statistically significant difference was found between the two posts (0.05, 0.07 inch) under 30 pounds oblique loads, but the difference in mean fringes numbers was significant under 60 pounds oblique loads.

The location and the magnitude of principal stresses in Holmes study were approximately similar to those obtained from the present study, however, slightly higher stresses were generated in dentin in their study because of different in the point of application of force. In the Holmes et al study forces were applied to the incisal edge and in the present study forces were applied to cingulum of central incisor. (17) This difference in loads point of application lead to slight different stresses magnitude in these two investigations. Also the places of compressive and tensile stresses were different due to load direction.

Magnitude and pattern of stresses distribution obtained by Yang et al (18) were also similar to the present study.

According to results obtained in this study, minor changes in the overall stress pattern resulted from variations in the diameter of the dowel. Therefore it seems that under 100N oblique forces, all three theories about post diameter will provide enough resistance against root fracture and none of them have any advantage over the others. However, this study suggests applying narrowest post diameter because of following reasons:

- Preservation of tooth structure.
- Generating less stresses in post by decreasing post diameter; the peak tensile and compressive stresses in post were increased about 100% and 67% respectively when post diameter increased from narrow to thick.
- Decreasing post diameter causes less consumption of gold in casting post and reducing patient’s cost.

Conclusion

This investigation considered a single-root tooth subjected to a load applied at 45-degree angle to the long axis of the tooth from lingual direction. Generalizing the results and conclusions to other clinical situations such as multi-root teeth or other loading circumstances may not be appropriate.

Under conditions of this study, the following conclusions were drawn regarding endodontically treated teeth restored with cast posts and cores:

- There were not significant differences stress distribution pattern and magnitude in dentinal between the three theories of post diameter (Conservational, Proportional, Preservational), and depend on root canal conditions and tooth
age, we can use different post diameters.
- Tensile and compressive stresses in dentin were decreased only 2.5% and 7.1% respectively, when the post diameter increased from 1.1mm to 2.6mm in CEJ portion.
- When the post diameter increased from 1.1mm to 2.6mm in CEJ portion tensile and compressive stresses in Post were increased 100% and 66% respectively.
- Although the stresses generated in dentin were not significantly affected by post diameter, because the amount of stresses generated in post increased by increasing the post diameter and because of preserving the tooth structure, the use of narrowest post possible is recommended.
- Peak tensile and compressive stresses in dentin in all models with different post diameters were generated at the lingual (tensile) and facial (compressive) root surface on the coronal one third of the root near the crest of bone.

References:
4- Guzy GE, Nicholls JI. In vitro comparison of intact endodontically treated teeth with or without endo-post reinforcement. J Prosthet Dent 1979; 42: 39-44.