Ferrule Designs and Stress Distribution in Endodontically Treated Upper Central Incisors: 3D Finite Element Analysis

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Abstract:
Objective: The main goal of this study was to evaluate stress distribution of endodontically treated maxillary central incisors restored with glass fiber posts, composite resin cores, and crowns with different ferrule designs.

Materials and Methods: Four three-dimensional models of a maxillary central incisor were modeled in SolidWorks 2006. Tooth with no ferrule, tooth with a 2 mm circumferential ferrule, tooth with a 2 mm beveled ferrule and tooth with a 0.5 mm circumferential ferrule. The teeth were restored with glass fiber posts, composite resin cores, and full ceramic crowns. Each model was loaded (1 N) on the palatal side at an angle of 45 degrees to tooth long axis. Von Mises stress findings along the inner surface of the root canals were assessed and compared.

Results: The Von Mises Stress at CEJ was the highest in the model without a ferrule when compared to the other models (without ferrule 0.0696, short ferrule 0.0492, cylindrical ferrule 0.0248, and beveled ferrule 0.0387 MPa).

Conclusion: Endodontically treated maxillary central incisors with a ferrule length varying between 0.5 mm and 2.0 mm exhibit lower stress distribution compared to those without a ferrule. Keeping a long ferrule is suggested to decrease the stress at the cervical area of restored teeth.

Key Words: Post and Core Technique; Tooth, Nonvital; Finite Element Analysis; Maxilla; Incisor

INTRODUCTION
Posts are used to restore compromised endodontically treated teeth with flared canals [1]. According to Fernandes and Dessai [2], posts do not reinforce an endodontically treated tooth and they should only be used when there is a need to retain the core.

There are studies advocating that materials with modulus of elasticity close to that of tooth structure will lead forces at the same direction as a normal tooth does in physiologic situation [3]. Modulus of elasticity of a fiber post is close to that of dentin. These posts are reinforced by epoxy resin matrix and fiber carbon and offer advantages such as corrosion resistance, impact strength, stiffness, lightness, excellent resistance under fatigue loads and other specific mechanical properties [4-7].

An endodontically treated tooth often has limited remaining tooth structure to provide retention for a definitive restoration, and the loss of radicular and coronal dentin makes it more...
subject to fracture [8]. It is believed that sound coronal dentin should be conserved during restorative procedures to extend the crown margin below the junction of the core and the remaining tooth structure. This may also help in core retention and allow use of a ferrule preparation designed to lessen stress transmission to the root [9]. A ferrule is defined as a vertical band of tooth structure at the gingival aspect of crown preparation. It primarily provides resistance form. A ferrule with 1-2 mm of vertical tooth structure doubles the resistance to fracture versus teeth restored with no ferrule. In some cases, especially in anterior teeth, it is necessary to perform crown lengthening or orthodontic eruption of a tooth to provide an adequate ferrule [10].

Some have reported endodontically treated teeth without a cervical ferrule to have considerably higher stress levels [11-13]. In contrast, others have found no benefits of adding a ferrule to preparation of an endodontically treated tooth [14,15]. Studies have shown that the ferrule should be a minimum of 1 to 2 mm in height, have parallel dentin walls, completely encircle the tooth, end on sound tooth structure, and avoid invasion of the attachment apparatus [16].

A ferrule has been described as a key element of tooth preparation when using a post and core [17]. The ferrule can improve resistance to dynamic occlusal loading, maintain the integrity of the cement seal of the artificial crown retainer, and reduce the potential for concentration of stress at the junction of the post and core. Besides, "the ferrule effect" reduces the wedging of tapered posts or bending forces during post-insertion and helps improve the marginal integrity of fixed partial dentures [18].

In cases where crown structure is intended to be used to function as a ferrule, a circumferential supporting structure with a uniform height may not be easily gained due to variations in

Table 1. Material Properties Used in Finite Element Models.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Poisson's Ratio</th>
<th>Modulus of Elasticity (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refor pin Fiber Glass*</td>
<td>0.30</td>
<td>30</td>
</tr>
<tr>
<td>IPS Impress2 ceramic*</td>
<td>0.19</td>
<td>6500</td>
</tr>
<tr>
<td>Panavia F2 cement*</td>
<td>0.25-0.3</td>
<td>10-15</td>
</tr>
<tr>
<td>Composite*</td>
<td>0.33</td>
<td>12000</td>
</tr>
<tr>
<td>Dentin</td>
<td>0.31</td>
<td>18600</td>
</tr>
<tr>
<td>Enamel</td>
<td>0.33</td>
<td>84.1</td>
</tr>
<tr>
<td>PDL</td>
<td>0.45</td>
<td>68.9</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>0.30</td>
<td>13700</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>0.30</td>
<td>1370</td>
</tr>
<tr>
<td>Gutta-Percha</td>
<td>0.45</td>
<td>0.0069</td>
</tr>
</tbody>
</table>

*Information given by the manufacturers.
hard tissue damage; thus, different ferrule designs may need to be incorporated. The main goal of this study was to evaluate the stress distribution in the inner dentin wall of endodontically treated maxillary central incisors restored with fiberglass posts, composite resin cores, and crowns when different ferrule designs were incorporated.

**MATERIALS AND METHODS**

Four 3D models of an upper central incisor were designed based on average tooth dimensions in SolidWorks 2006 (Concord, Massachusetts, USA). The models contained cortical bone, spongy bone, PDL, and teeth (Fig 1A). Model 1: Tooth with no ferrule; Model 2: Tooth with a 2 mm circumferential ferrule; Model 3: Tooth with a 2 mm beveled ferrule; and Model 4: Tooth with a 0.5 mm circumferential ferrule. The teeth were restored with glass fiber posts-composite resin cores and full ceramics crowns. The models were the same except for their ferrule size.

PDL was assumed to be 0.25 mm all around the root. SolidWorks 2006 (300 Baker Ave. Concord, Massachusetts 01742, USA) was selected for the modeling phase. The next stage was to transfer the models for calculation to the ANSYS Workbench version 11.0 (ANSYS Inc. Soutpointe, 275 Technology drive, Cononsburg PA 15317, USA). Material properties (Table 1) were applied based on recent researches (Fig 1B). A 45-degree-to-horizontal force of 1 N on the palatal surface of each central incisor was applied. Von Mises stress was evaluated at the cervical third of the inner wall of the dentin on the labial side.

**RESULTS**

The Von Mises Stress at CEJ was highest in the tooth without a ferrule compared to the other models (Table 2). The findings in the model without a ferrule start from 0.0696 MPa at the cervical area and decrease towards 0.0426 MPa in the middle layers (Fig 2A). The highest amount of stress recorded for the
short ferrule model was 0.0706 MPa in the sub-cervical layer and the lowest amount was 0.0492 MPa in this model (Fig 2B). The beveled cylindrical ferrule model showed 0.0387 MPa in the cervical layer and reached its highest value in its middle layer at 0.0749 MPa (Fig 2C). The cylindrical model showed the least amount of Von Mises stress in the cervical layer which was 0.0248 MPa and increased to 0.066 MPa (Fig 2D). Stress findings in the cervical area in a descending order are as follows: Cylindrical ferrule < Beveled cylindrical ferrule < short ferrule < no Ferrule.

**DISCUSSION**

In this study, Von Mises stress distribution of the root was evaluated in each of the models. According to the results, the tooth with no ferrule showed the highest amount of Von Misses stress in the cervical area among other models. It has been shown in some studies that the ferrule effect lessens the chance of fracture in non-vital teeth significantly by reinforcing the tooth at its external surface and redistributing the applied forces [18].

Maxillary central incisor was the selected tooth due to its high susceptibility to trauma that may eventually require the placement of a crown restoration. Various types of hard tissue damage may happen in the tooth structure requiring variations in ferrule design appropriate for individual fracture scenarios [18].

Stress findings in the beveled ferrule models were higher than the cylindrical ones. This can be due to a lower amount of available dentin for composite bonding, leading to increased stress.

The stress findings in a cylindrical form of ferrule were the lowest among the others, which can be explained by the highest amount of harmonious dentin available for bonding.

All findings of this study were in complete acc-

### Table 2. Von Mises stress findings in cervical third of the models

<table>
<thead>
<tr>
<th>Assessed Nodes</th>
<th>Without Ferrule</th>
<th>Short Ferrule</th>
<th>Beveled cylindrical Ferrule</th>
<th>Cylindrical Ferrule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>6.96E-02</td>
<td>4.92E-02</td>
<td>3.87E-02</td>
<td>2.48E-02</td>
</tr>
<tr>
<td>2</td>
<td>5.94E-02</td>
<td>7.06E-02</td>
<td>3.94E-02</td>
<td>3.66E-02</td>
</tr>
<tr>
<td>3</td>
<td>4.88E-02</td>
<td>6.45E-02</td>
<td>6.54E-02</td>
<td>6.01E-02</td>
</tr>
<tr>
<td>4</td>
<td>4.26E-02</td>
<td>5.85E-02</td>
<td>7.49E-02</td>
<td>6.60E-02</td>
</tr>
<tr>
<td>5</td>
<td>6.47E-02</td>
<td>5.54E-02</td>
<td>5.26E-02</td>
<td>5.60E-02</td>
</tr>
<tr>
<td>6</td>
<td>6.77E-02</td>
<td>6.45E-02</td>
<td>5.29E-02</td>
<td>5.70E-02</td>
</tr>
</tbody>
</table>
CONCLUSION

It was shown numerically that:
1-Presence of a ferrule reduced the stress findings in the cervical third of endodontically treated central incisors.
2-There was not a difference between stress findings in a tooth without a ferrule and the one with 0.5 mm of ferrule.

ACKNOWLEDGMENTS

The authors wish to thank Dental Research Center of Tehran University of Medical Sciences for their assistance and cooperation.

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