Original research:

Comparative evaluation and influence of different post on stress distribution in deciduous central incisor: A finite element analysis

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Abstract
This study aims to determine how different pressures influence stress distribution in endodontically treated deciduous maxillary central incisors fixed with various post systems. As well as a control model, 3D models of a brief post in the primary right central incisor reconstructed with glass fiber, composite, and omega steel wire were examined. In 148º, the palatoincisal section of the crown model was chewed with forces of 100, 150, and 200 N. Using Von Mises' stress criteria, the data were analyzed, and the highest principal stress was used to compare the stress values. The neck of the tooth structure was revealed to have the greatest stress. The highest Von Mises tension was exhibited by glass fiber, followed by composite, Omega steel wire, and regular tooth (control). The normal tooth (control), composite, omega steel wire, and glass fiber were found to have the lowest von Mises pressures. To increase the likelihood of the post enduring, it should be short and over-restored with an appropriate elasticity module capable of balancing the stress concentrations. Because it and the tooth were subjected to the same amount of tension, the composite post most closely resembled the structure of a healthy baby tooth. Clinically, glass fiber and composite posts are regarded as the most superior aesthetic restorations because they are less likely to fracture and distribute stress more uniformly.

Keywords: Primary incisor, FEA analysis, Fibre Post, Composite, Glass fiber post

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It is hard to fix primary teeth that are badly damaged or broken because of caries or an accident. When you don't know enough about the biomechanical features of restorative materials, bad things can happen, like the repair coming loose or breaking\textsuperscript{[1]} After endodontic treatment, intracanal retention may be needed because the remaining structure has been damaged. Instead of taking out these main teeth with good roots, a short post, and a core can be used to fix them \textsuperscript{[2]} A lot of bad dental products have come out lately, only to be taken off the market. The shape and material of the post and core have a big effect on how stress is spread across the dentin. Using materials with the same mechanical properties as dentine and enamel can help keep restorations in place when you bite down. \textsuperscript{[3]} When done on live people, biomedical research can take a long time and be morally questionable. Live tests can now be done at a fraction of the cost and risk because virtual models and stimulation methods are used more and more. Some of the ways to check the accuracy of stress readings are strain gauge testing, loading experiments, and photoelastic analysis. \textsuperscript{[4]} But the new method of finite element analysis gives a valid index for stress distribution that can be used to solve problems based on testing and clinical observation. \textsuperscript{[5]} Finite Element Analysis (FEA) is a study method used to learn more about how different materials behave, especially in dentistry.

FEA is useful because it can be used to study objects with different shapes and materials. Failures from theoretical pressures can be expected, and trouble spots in materials can be pointed out so that designers can fix them before they do any real damage. Finite Element Analysis includes building the geometric model, turning it into a finite element model, representing the properties of the materials and designing the assembly, defining the boundary conditions, setting up the loads, running the analysis, and cleaning up after the analysis. The goal of this study is to use the finite element method to figure out how stress is spread in deciduous maxillary central incisors that have been treated endodontically and fixed with different post systems.

**Materials and Method**

The three-dimensional (3D) tooth model was created using an avulsed, healthy, primary central incisor from the maxilla with a completely developed root and no cracks, fractures, or cavities. The literature provided the enamel, dentine pulp, encircling cementum, periodontal ligament, and bone thicknesses. Using the 3D tooth model, which was therefore constructed as a conventional geometric model, additional experimental models were created. Images of the tooth with 0.5 mm cross-sections were captured using a spiral CT scanner, and a three-dimensional mesh model was produced using the Pro/Engineer program Ansys (Figure 1). Due to their varying elastic moduli, the study's restorative materials were selected as test materials. Composite Restoration (Feltik, Z250/P60, Ireland, USA). FEA with ANSYS 14.0 (Swanson Ansys Inc., Houston, PA, USA) was used to analyze the stress distributions in several restorative materials. The following arbitrary commercially available post-geometry values were used for structural evaluations (Figure 2): The zinc oxide eugenol-simulated obturation occupies 6 mm of space at the post apex, while the glass ionomer cement occupies 1 mm. The post occupied the remaining 3 millimeters of space. The glass fiber composite post used was opaque, smooth, round, and non-serrated (1.35 mm diameter, 7 mm length), with 3 mm of the post and 4 mm of the core placed, respectively, in the intracanal post space. Crown anatomy is constructed in the same manner as the dimension of the control solid model. Composite resin simulant for cementation, core, and crown construction. To replicate optimal primary occlusion, 100N, 150N, and 200N point loads in the lingual direction at 148 degrees to the inter-incisal angle were applied to the three-dimensional model (Figure 3). Literature was utilized to modify material parameters, including Young's modulus and Poisson's ratio, of the tooth, supporting tissues, and restorative material. Table 1 contains the material parameters used to create a tooth model with surrounding soft and rigid tissue. The restorations that were modeled based on their individual material qualities are summarized in Table 2.
Comparative evaluation and influence of different post on stress distribution in deciduous central incisor: A finite element analysis

Dr. Divya Nigam, 2022

Table 1: Material properties of the tooth.

<table>
<thead>
<tr>
<th>Component</th>
<th>Elastic Modulus(MPa)</th>
<th>Poisson’s Ratio</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>80350</td>
<td>0.33</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Dentine</td>
<td>19890</td>
<td>0.31</td>
<td>Adanir15</td>
</tr>
<tr>
<td>Pulp</td>
<td>2</td>
<td>0.45</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>14700</td>
<td>0.30</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Spongiose bone</td>
<td>490</td>
<td>0.30</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Periodontal ligament</td>
<td>69</td>
<td>0.45</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Cementum</td>
<td>18600</td>
<td>0.3</td>
<td>Shikhar Desai1</td>
</tr>
<tr>
<td>Gingiva</td>
<td>0.019</td>
<td>0.3</td>
<td>Adanir15</td>
</tr>
</tbody>
</table>

Table 2: Properties of filling materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus(MPa)</th>
<th>Poisson’s Ratio</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel wire</td>
<td>200000</td>
<td>0.33</td>
<td>Adanir15</td>
</tr>
<tr>
<td>Composite</td>
<td>11570</td>
<td>0.24</td>
<td>Obici13</td>
</tr>
<tr>
<td>Glass fibre post</td>
<td>45000</td>
<td>0.28</td>
<td>Adanir15</td>
</tr>
<tr>
<td>Glassionomer cement</td>
<td>10800</td>
<td>0.30</td>
<td>Gurbuz18</td>
</tr>
<tr>
<td>Zinc oxide eugenol</td>
<td>288</td>
<td>0.40</td>
<td>Farah9</td>
</tr>
</tbody>
</table>

The study was done using four models:
Model 1: A primary tooth that doesn't need a post-core fix because it is healthy.
Model 2: Teeth that have been treated with endodontics are fixed with a composite post made of glass fibers (Glassix or NORTAN) and a composite core and cap.
Model 3: A composite post (Feltik, Z250/P60) and a composite core and crown were used to fix teeth that had been treated with endodontics.
Model 4: Teeth that have had endodontics are fixed with a round steel wire post (0.9mm, Jaypee) and a composite core and crown.
As a comparison, the model of the healthy main tooth with no post-core restorations was used. The root dentine was put under tensile stress because it was thought that tensile stress is most often what breaks a weak root. The material was thought to be the same everywhere and to have constant elasticity. At the area where the tooth was cut, it was thought that the alveolar bone that held the tooth was rigid, and the effect of the cementum was not taken into account because it was the thinnest layer.

Step 1. Step Preprocessing/ Construction of the geometric model
Step 2. Conversion of the geometric model into a finite geometric model.
Step 3. The Finite Assembly/Material Property data representation.
Step 4. Defining the boundary conditions.
Step 5. Loading Configuration.
Step 6. Processing.
Step 7. Post-processing

![Figure 2: Preparation of post space and standardization of post](image)
Comparative evaluation and influence of different post on stress distribution in deciduous central incisor: A finite element analysis

Dr. Divya Nigam, 2022

Results

Increasing pressures that represented masticatory functions were applied to models. In the post, core, dentin, and periodontal ligament, the maximal and minimum Von Misses stresses were evaluated qualitatively. The distributions of tensile and compressive stress were evaluated. The calculated stress values presented as numerical data were converted into color graphics. Warm colors (primarily red, orange, and yellow) were indicative of tensile stresses according to the interpretation of the color template, which is a representation of stress values. While frigid colors (primarily blue hues) provide areas with compressive forces after load application. Maximum principal stress increased as load application increased, as represented by the red areas at the site of load application, the middle third of the labial aspect, and the cervical margin. Figure 5 depicts the maximum tensile tension measured on a glass fiber post (94,781 N).
Figure 4: Comparative evaluation of maximum principal stress of primary maxillary central incisor labiopalatal sectional view. Maximum principal stress was increased along the point of load application and later appeared along the cervical margin and middle third labially as the load increased. In the decreasing order, maximum tensile stress was evaluated with glass fiber post > omega steel wire post > composite post > normal tooth (control).

Figure 5: Comparative evaluation of minimum principal stress of primary maxillary central incisor labiopalatal sectional view. Minimum principal stress was more homogenously distributed in the composite post, and omega steel wire post. Glass fiber post shows maximum interfacial stresses between the post and dentin among the three posts. In the decreasing order, minimum von mises stress was evaluated best with normal tooth (control) > composite post > omega steel wire post > glass fiber post.
Comparative evaluation and influence of different post on stress distribution in deciduous central incisor: A finite element analysis
Dr. Divya Nigam, 2022

![Figure 6](image.png)

**Figure 6:** Comparative evaluation of primary maxillary central incisor uncut sectional view maximum principal stress. In decreasing order, maximum von mises stress was seen with glass fiber post > composite post > omega steel wire post > normal tooth (control). Normal tooth showed maximum area covered by tensile stress in the tooth's crown from 100N to 200N load.

In all three restorations, including the control, the places with the least principal stress are shown in blue. It’s been seen that composite and omega steel wire posts spread it out more evenly. The best way to measure the minimum von Mises stress (-270.46N) was with a normal tooth. Figure 5 shows that the glass fiber post (94.781N) had the most stress at the point where the post met the dentin. In the uncut section, the greatest von Mises stress happens almost everywhere on the crown: in the palatal, labial, cervical, and proximal areas. As the load on the crown increases, restorative failures can happen. Figure 6 shows that the glass fiber posts, composite posts, Omega steel wire posts, and normal teeth (control) all had the highest tensile strains.

**Discussion**

The structure and supporting tissue of human dentition are composed of numerous materials with distinct mechanical properties. Using materials with mechanical properties similar to dentin and enamel in vitro and in vivo experiments can be studied using FEM. This verifies the stresses and circumvents some ethical and methodological limitations, enhancing the accuracy of the process. Previous research has allowed for the greatest resistance and retention of the restoration against forces that attempt to move or block it, thereby preserving the remaining tooth structure. Complex systems that are difficult to standardize demonstrated that 3D modeling is an effective method for examining the tension distribution in dentin and post. It has been used to determine how stress is distributed in teeth that have been treated with endodontics, as root fractures caused by stress are common. Therefore, in order to examine the structure and design of finite element models, you must have complete knowledge of the mechanical properties of the materials.

Patterns of stress distribution are represented as color-coded measurement bars, where each color or combination of colors corresponds to a range of stress values. Dark red indicates a high level of tension, while dark blue indicates a lower level.

In this study, a finite element analysis was done on the glass fiber post, the composite post, and the omega steel wire post on the front teeth that come in first. The von Mises criterion and maximum principal stress (MPS) were used in this study to figure out how the stress was distributed. Von Mises is a failure criterion that shows how energy moves through the building where it is most concentrated.
On the other hand, the MPS can tell the difference between positive (tensile) and negative (compressive) stress fields. Materials and structures in the mouth have high compressive strengths, but when put under tensile pressures, they break easily. So, the MPS shows that there is a place on the frame where tensile stress is more likely to cause it to break. The current study showed that the sound tooth's stress distribution changed after the clinical crown was lost and the post was put in.

Functional loading was done on the mouth, and the average maximum bite force of children ages 3 to 5.5 with normal occlusion was found to be 213.17 +/- 43.97 N. These forces that are put on the healing materials could cause them to change in length and volume. In this study, masticatory forces of 100 N, 150 N, and 200 N were gradually applied. In their study, Gujjar and Indushekar [8] used a dislodging force of 1000N, which is more than the maximum bite force, to test the strength of the crack of different posts in primary teeth. The damage could hurt the periodontal ligament and cause the surviving tooth to crack, but it does not always mean that the crown or root has broken. Casas et al. say that crack propagation is linked to long-term fatigue root fracture under functional cyclic loads, and fatigue fracture may happen at the weakest or most stressed spot. In this study, the most stress was in the cervical third of the main anterior tooth, between 80 and 94 MPa. Biting bruxism, force, masticatory forces, and injuries can all change the way horizontal, vertical, and oblique forces move. In this study, the load was put on the incisal edge of the buccal surface of the primary anterior teeth at an angle of 148° to mimic the ideal occlusion of the primary anterior teeth (the angle between the incisal edges of primary teeth is 150°, while it is only 123° between permanent teeth). This force was about the same as what Gurbuz et al. used in their one study on post-in primary teeth. [18]

The design and material of the post are subject to the distribution of the dentinal stress. The primary teeth undergo root resorption and are subject to exfoliation henceforth design of the post should be such that it does not hinder the eruption of permanent teeth. In this study, a 4mm of intracanal post space preparation was done to accommodate 3mm of the post and 1 mm of the GIC button, following the study carried out by Mortada et al. [12] and is followed in most of the clinical procedures in primary anterior teeth restored with post and core. Applying force to a healthy tooth structure causes a chain reaction that involves the dentin, enamel, and supporting components from the root's coronal section to its apical tip. Using a post and core to reconstruct a tooth alters the stress distribution patterns inside the remaining tooth structure by concentrating the stress on the structure with a higher modulus of elasticity. Glass fiber and omega wire posts, which have a high elastic modulus, can support a lot of weight. As the post takes on greater pressure, the dentine is relieved of tension at the post-dentine interface, and the stress is redistributed to the tip of the post instead. If the composite post has a low modulus of elasticity, it can only take in a certain amount of force before passing it on to the dentin. Here, researchers found that when a healthy maxillary central incisor tooth was subjected to a progressive load, the crowns' cervical and middle thirds bore the brunt of the stress. The stress distribution pattern was similar regardless of the postmaterial used, although the highest primary stress varied.

Maximal tensile stress (MPa 94.7) was observed in the cervical area of the glass fiber post, with an increased load on the periodontal ligament (Figures 4-6). The central one-third of the root is calibrated for low internal stresses since the glass fiber post absorbs the most force at the interface and transmits it apically. (Fig. 5) Dentinal tension decreased with increasing post-modulus of elasticity during masticatory stress. [14] Because of its ability to soak up and dampen pressures, glass fibre post material is incredibly sturdy. Adanir et al., [15], who studied permanent molars, found findings very similar to these. Because primary anterior teeth have posts that are only about two-thirds as long as those in permanent teeth, the present study suggests that this disparity in post depth is responsible for the observed concentration of tension in the middle and apical thirds of the tooth. The maximum primary stress (93.5 MPa) was also detected in the coronal portion of the root when the stress distribution of the omega wire post was analyzed. Memon et al. [5] found that the enhanced rigidity of the omega wire post with a modulus of elasticity (E = 2000000) caused a highly stressed region on the root surface to the level of the post-apex, which increased the chance of dentin fracture.

In this study, the composite post resulted in the lowest tension value in the cervical region of the tooth. This was likely because the composite post's Young's modulus (1,570) was closest to that of dentin (19,890) when compared to other materials. When materials with a low modulus of elasticity were utilized, the stress values in the short post and core structures decreased. 14 This result was supported by the research of Yamanet et al., [10] and Gurbuz et al. [18]. Resin-based restorative materials with elastic moduli similar to dentin or less should be recommended for short-post cores and over-restorations of endodontically treated maxillary primary incisors, according to the findings of this study. The homogeneity of the material in the post, core, and cementing media, which operate as a single unit, could also be a contributing factor. Due to the material's low stiffness, tension distribution at the interface is diminished. Pegoretti et al. hypothesized that tensions at the cervical margins could be reduced by utilizing less rigid crown materials, i.e. composite resins, thereby achieving a "integrated" post-core-crown system. [11] Similarly, Eshghi et al. [21] utilized three distinct
restorative techniques in their clinical study: 53 composite post-restorations, 54 fiber post-restorations, and 54 reversed post-restorations on 161 pulpectomized decayed primary teeth. After one year of observation, 98 percent of composite posts, 84 percent of fiber posts, and 90 percent of reversed posts were deemed acceptable. In a separate study by Baghalian et al. [2], the fracture resistance of composite posts exceeded that of glass fiber posts and gamma shaped posts. However, composite material is subject to polymerization contraction, which may result in post system failure due to a lack of cohesiveness. [16,19] Gurbuz et al. [18] and Memarpour et al. [22] used mushroom-shaped composite posts to enhance mechanical and micromechanical bonding to the tooth structure in their study. Fiber-reinforced composite material, which forms a complete monoblock, confirms the anatomy of the canal in the primary tooth and reduces interfacial tension, is one of the more recent materials introduced to the market. Therefore, additional research is required to demonstrate the clinical relevance of these products based on their material properties. Clinically, both glass fiber and composite posts are regarded as superior aesthetic restorations due to their superior fracture resistance and uniform stress distribution. The effects of glass fiber post-supported restorations on root resorption and their influence on the exfoliation of restored primary incisor teeth are poorly understood.

Limitation

Loading a restored tooth may not immediately cause failure, but over time, it may develop fissures in the tooth assembly that lead to catastrophic failure. A computer model cannot replicate the experience of an in vivo model when all occlusal forces are applied. Furthermore, the completeness of the analysis' precision is contingent on the application used, the model built, and the baseline data used. The system is susceptible to erroneous results if it is fed incorrect values or if its design is flawed. This study's findings need to be validated by further clinical investigation.

Conclusions

Within the limitation of the study, the following conclusion can be drawn:

• Normal tooth (control) / Model 1: The stress on the healthy tooth was distributed along the cervical edges, cervicoproximally, in the middle one-third of the pulp volume near the crown, and along the cervical side of the periodontal ligament. The stress got less and less from the middle third of the root to the end.

• Tooth repaired with a glass fiber post/Model 2: The periodontal ligament was stressed the most from the root to the tip, and the post-dentine interphase was also stressed.

• Tooth repaired with a composite post/Model 3: Stress distributions were almost the same as for a glass fiber post, but the stress was spread most evenly in the post and the tooth. Compared to glass fiber posts, the tensile pressures were less.

• Omega steel wire post / Model 4: The crown and root had a less even spread of stress. Compared to the glass fiber posts, the frontal side had the most compression.

References


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