FEM analysis of different dental root canal-post systems in young permanent teeth

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ABSTRACT

Aim: Aim of this work was to carry out a comparative evaluation of the structural behaviour of different root canal posts (cylindrical, conical and triple conical) fitted in a second lower bicuspid and subjected to compression and bending test. Materials and methods: This study has been carried out by numerical method of structural analysis of finite elements (FEM, Finite Element Method). Different tridimensional models were obtained by CAT images of an extracted tooth, endodontically treated, filled with gutta-percha and triple conical glass post. Images have been elaborated by a software for images (Mimics and Ansys) and CAD (Rhinoceros 3 D). In the models a II Class restoration has been virtually created. In the numerical simulation dental tissues (enamel, dentine and root cement), gutta-percha, root canal cement, different posts, different techniques of cementation and crown restoration (composites and adhesive systems) have been considered. Results: Strain distributions in dental tissues, in root canal cement and in posts have been compared. The equivalent tensions and the single components (traction, compression and cut) have been analysed. In all examined posts, the most strained part is resulted the coronal one, even if the total tension, in the different tooth-post analyzed systems, resulted uniformly distributed. A similar behaviour was shown by the root canal cement. Conclusions: According to the analyzed conditions of bond and load, varying according to the geometry of the considered posts, our results confirm that there is no substantial difference of deformation in posts, root canal cement and treated tooth.

KEYWORDS: Finite elements; Root canal posts; Strain distribution; Permanent teeth.

Introduction

During youth, dental trauma or deep decays could require endodontic treatment in young permanent teeth with apex still open and cylindrical root canal geometry rather than conical. The endodontic techniques and restorations should be fitted to the anatomical morphology of the young permanent teeth. When maturity of the root canal apex is completed, the final restoration can be performed [Villat et al., 2004; Spinas, 2003].

The aim of this study was to analyse, using the finite element method (FEM), the distribution of stresses in an endodontically treated tooth restored with a post.

Posts are necessary to guarantee stability of big coronal restorations [Toparli et al., 1999; Ausiello et al., 2004; Kamposiora et al., 2000] and optimal distribution of stresses along the root canal axis [Ho et al., 1994; Toparli et al., 2003].

Following endodontic therapy and loss of dental tissue, there are many irreversible changes in tooth anatomy and biochemical and biomechanical properties: endodontically treated teeth are therefore weaker than sound teeth [Lewgoy et al., 2003]. In fact, pulpless teeth have less humidity in the dentinal tissue and less plasticity and deformability, showing a significant decrease of hardness, an increase of brittleness and higher tendency to fractures [Pierrisnard et al., 2002].

On the market there are many types of posts, classified according to different morphological...
characteristics (anatomic shape, length, diameter, surface and materials).

The shape of the posts is very important for stress distribution along the dental roots [Ho et al., 1994].

Cylindrical posts have parallel walls and they are stronger to traction than conical shaped posts. They are used in large root canals with great loss of dentin, in particular at the third apical.

Conical posts are anatomically similar to the root canal and are usually longer than cylindrical posts but they are less retentive (therefore they are longer).

Cylindrical-conical posts are created to combine the properties of both posts: the coronal part is cylindrical (stronger to traction) while the apical part is conical (similar to the root canal shape).

Length and diameter affect the “contact area” between the post and the internal root canal surface.

The choice of the post’s length depends on anatomical, periodontal and prosthetic factors, while the diameter is less critical for retention: it’s advisable to choose a post with a small diameter to save dental tissue.

Another important factor is the post’s material. Posts are classified in metal and non-metal posts (carbon fibre post and glass fibre post).

The new materials have an elasticity modulus similar to that of the dentinal tissue in comparison to traditional metal posts: in this way, during the masticatory cycles, there is the same warping in the complex tooth-post and a lower risk of separation of the post from the tooth or from the crown restoration (there is also a lower risk of root fractures) [Genovese et al., 2005].

The different elastic modulus of dentin and post material may be a source of stress for the root structures: therefore the choice of materials with a physical behaviour similar to that of the biological (dental) tissue is important.

Tridimensional method analyses and numerical model allowed to evaluate the structural behaviour of a post-tooth system submitted to different stresses [Asmussen et al., 2005; Lanza et al., 2005; Eskitascioglu et al., 2002].

**Materials and methods**

We created several tridimensional models from CT of a second mandibular bicuspid, extracted for

![Fig. 1 - Distal surface of the tooth under examination.](image1)

![Fig. 2 - Fibre of glass Anatomical Post.](image2)

![Fig. 3 - CT image seen with Mimics software.](image3)
orthodontic reasons, endodontically treated, filled with guttapercha and a glass fibre post cemented in the root canal (anatomic shape: triple conicity).

CT images were examined by a software “Mimics” (Materialise’s Interactive Medical Control System) and a Cad software (Rhinocero’s 3D, Robert Mc Neel & Associates, Seattle WA) to realise three dimensional models.

Geometrical models were evaluated by 3 D-finite element analysis (every geometric model is divided into a finite number of elements, an element is a mathematical matrix of the connective interaction among degrees of freedom between a set of nodes).

In CT images, the tooth showed post and cement just underneath occlusal surface (clinically the post is cut at the top at the middle crown level and then the cavity is filled by a composite material similar to the one used to cement post in root canals). A generic Class II MOD restoration was simulated.

The system analysis considered dental tissues (enamel, cement, dentin), guttapercha, and cement used to fill root canals, different types of posts, crown restoration (composite resin material and bonding).

The numerical analysis of the structures compared three different geometrical post shapes:

1) Cylindrical post (Fiber Glass; Ideco)
2) Conically shaped post (Millenium Plus Conival, Sogeva, Varese, Italy).
3) Triple conical (anatomical post; Dentalica).

Three different posts are cemented with the same composite resin (thickness: 150 µm) and theoretically with a common axis.

In the case of the post with triple conicity shape, the thickness of cement was 150 µm except at the end of post (length: 0.35 mm) where there is a conicity of 30° (the same happened for the post with a single conicity).

In the case of cylindrical post, for 7/8 of the length the thickness of the composite resin (150 µm) was uniform but, at the end of the post, the thickness of the composite increased from 150 µm to 230 µm.

Figure 6 shows how the post axis has the same direction.

Restorative simulation shows an ideal condition where restoration is similar to sound tooth geometry (Fig. 7).
Figures 8a and 8b show a 3-D finite element model (system: tooth-post-restoration) of a mesh design in tetraedric models at 10 nodes (a node is a coordinate in space where degrees of freedoms and actions-forces of a structure under load are considered to exist).

In table 2 there is a description of three models (three kind of post) and the number of elements.

All materials (biological and restorative) are considered as elastic, isotropic and linear from a mechanical point of view.

Young’s modulus (modulus of elasticity) and Poisson’s ratio of enamel, dentin, cement and gutta-percha derive from literature.

In case of the composite used to cement post and to fill II Class MOD cavity, we referred to a Young’s modulus of a composite used in dentistry (Luxacore Dual, Zenith Dental) and Poisson’s ratio of 0.3 based on a study conducted on different composites.

The post’s Young modulus was obtained from the producer.

Poisson’s ratio was evaluated by considering an average value which characterizes the glass fibers.

The cement has the same Young and Poisson values of cortical bone.

There are external restrains (joint restrains) on all external root surface and nodes are still considered.

In fact, tooth can move in the alveolar bone but its movements are so little that they did not influence our study.

Two vertical loads were applied on the occlusal surface (principles cups) to simulate biting forces of on average of 200N while a lingual load of an average of 100N was applied.

**Results**

On the ground of cementation and applied load, structural analysis can give qualitative and quantitative evaluations of the tension and strain produced in the tooth-cement-post system [Cavalli and Bertani, 1999; Cavalli et al., 1996]. Our study compared three different posts in the same tooth. Analysis of finite elements represents the intensity of tension and strain and their distribution along the X, Y and Z axis, using the spectrum colours in a scale from blue to red (blue corresponds to the lowest level of tension, red corresponds to the highest level). Comparison was done on a central slice of tooth with the aim of having a global vision of tensions and strains caused by the

<table>
<thead>
<tr>
<th>Posts type of model</th>
<th>N. elements</th>
<th>N. knots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical post</td>
<td>32418</td>
<td>46303</td>
</tr>
<tr>
<td>Post 1 conicities</td>
<td>37204</td>
<td>52722</td>
</tr>
<tr>
<td>Post 3 conicities</td>
<td>33487</td>
<td>47561</td>
</tr>
</tbody>
</table>

**TABLE 2 - Number of elements forming the models.**

Fig. 7 - Ideal reconstruction of a restoration of class II effected with Rhinoceros 3D on the model of the tooth.

Fig. 8 - Model to the fem elements of tooth with inserted post and dental restoration; in 8b the restoration has been removed to allow visualization of the inserted post.

Fig. 9 - Conditions to the imposed contour: joint of the radicular surface and application of two strengths of compression (200 Ns to), and application of a strength in lingual direction (100 Ns).
post. In particular, we obtained analyses of tensions of a tooth-cement-post system, of three kinds of post, of the composite (cement) and of point of post. The analysis of finite element is used to show the mechanical behaviour in every node of the structure.

The results have been analysed considering “the equivalent tensions of Von Mises” expressed in MPa (N/mm²).

\[ \sigma_{eq} = \sqrt{\left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2\right) - \left(\sigma_x \sigma_y + \sigma_y \sigma_z + \sigma_z \sigma_x\right) + 3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)} \]

In Figure 10, distribution of equivalent tensions of Von Mises in the restored tooth with loads of compression of 200 N for each examined post is showed.

In Figure 11, distribution of equivalent tensions of Von Mises in the restored tooth with lingual-buccal loads of 50 N for each examined pin is examined.

In Figure 12, distribution of equivalent tensions of Von Mises in the restored tooth with lingual-buccal loads of 50 N for each examined pin is showed.

In Fig. 13, distribution of equivalent tensions of Von Mises in the cement with loads of compression of 200 N for each examined pin is showed.

**FIG. 10 - Distribution of Von Mises equivalent stresses [MPa] inside the restored tooth with two 200 Ns compression loads (vestibular vision): a) with cylindrical post; b) with single conicity post; c) with triple conicity post.**

**FIG. 11 - Distribution of Von Mises equivalent stresses [MPa] inside the restored tooth with 50 Ns of lingual-labial load (vestibular vision): to) with cylindrical post, b) with single conicity post, c) with triple conicity post.**

**FIG. 12 - Distribution of Von Mises equivalent stresses [MPa] in the three posts with 50 Ns of lingual-labial load (vestibular vision): to) cylindrical post; b) single conicity post; c) triple conicity post.**
From the complete analysis of the tooth-post structure, it has been pointed out that the most stressed dental side is the coronal side in case of compression load and in lingual load.

Analysis of the pressure on the posts has highlighted that the most pressed sides are the medium and cervical third. In particular, the triple conical pin is mostly loaded during compression, while the cylindrical pin is mostly deformed in case of lingual load.

From the analysis of the tensional state in the composite around the post, the triple conical post underwent the highest pressure, on the ground of compression and lingual load.

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From the analysis of the tensional state in the composite around the post, the triple conical post underwent the highest pressure, on the ground of compression and lingual load. The pressure on composite is much higher in the internal side rather than the external one, but it is not significant, because the thickness of the considered cement is very thin.

**Discussion**

Endodontically treated teeth are subjected to fracture as a result of the modifications in their natural rigidity, in particular the weakness depends on the amount of dental structure/tissue lost. In fact, it is advisable to “protect” the tooth from potential fracture caused by strains.

Experimental observations [Eskitascioglu et al, 2002; Villat et al., 2004] have shown that using post in root canal gives us the possibility of endodontically “protect” the treated teeth from fracture as a result of distribution of stresses along the root axis. Other experimental observations have shown that posts too thin are unable to bear occlusal forces but at the same time too large posts require the sacrifice a higher amount of dental tissue, and this could weaken the tooth.

When an endodontically treated tooth with a post is subjected to different tensions and strains, there are different mechanical behaviours depending on different mechanical proprieties.

The advantage of Fem analysis is the possibility to simulate a biochemical behaviour in a very simple way, if compared with other methods.

Natural teeth differ from each other for many reasons (i.e. age, patient sex) and they are responsible of a large amount of standard deviations.

We analysed the biomechanical behaviour of three posts of different shape.

First, we paid attention to a central slice of the tooth and then to every single post; finally, we evaluated the cement surrounding the post.

Analyses of each type of post have been carried on every post surface (mesial, lingual, palatal and vestibular). Some different mechanical behaviour (a post with triple conicity is more susceptible to deformation if compared with a cylindrical one) have been highlighted, but we can affirm that stress distribution is quite similar in all examined posts.

Because of frequent fractures at the interface dental tissue-composite or composite-post, we have analysed the stress distribution on the interface post-composite (for every kind of post) and composite-tooth, which represents the “weakness site of the complex”.

**Table 3 - Mechanical material characteristics.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Form of Young E [MPa]</th>
<th>Coefficient of Poisson ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restoration</td>
<td>7900</td>
<td>0.3</td>
</tr>
<tr>
<td>Enamel</td>
<td>41400</td>
<td>0.3</td>
</tr>
<tr>
<td>Dentine</td>
<td>18600</td>
<td>0.31</td>
</tr>
<tr>
<td>Composite</td>
<td>7900</td>
<td>0.3</td>
</tr>
<tr>
<td>Post</td>
<td>54000</td>
<td>0.25</td>
</tr>
<tr>
<td>Guttapercha</td>
<td>0.69</td>
<td>0.45</td>
</tr>
<tr>
<td>Cement</td>
<td>20000</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Fig. 13 - Distribution of Von Mises equivalent stresses [MPa] in the cement with two 200 Ns compression loads (vestibular vision): a) with cylindrical post; b) with single conicity post; c) with triple conicity post.
According to the literature [Ausiello et al., 2004; Kamposiora et al., 2000; Ho et al., 1994], even if there are some differences on stress distribution using different shapes of posts, the choice for a cylindrical post or a single conicity post is not a priority.

Our study highlights that triple conical post and the interface composite-post are factors most susceptible to stress.

**Conclusions**

The finite elements analysis (Fem Method) allowed to evaluate the biomechanical behaviour of root canal posts and the dental system. The shape of the post (cylindrical, conical, triple conical) has been considered as the only variable, while the mechanical characteristics of tooth, crown restoration (composite, adhesive), root canal materials (gutta-percha) were constant.

Two compression loadings of 100 N on dental cuspsids and a transversal lingual load of 100 N were simulated, virtually setting some ties along the root surface in order to annul rotations or movements at the mesh knots.

Comparing the equivalent tensions of von Mises in the tooth, no significant differences between the different posts were observed.

On the basis of our results, the success of dental restoration with root canal posts is not due to the choice of a particular shape of post, but to a correct procedure of dental preparation: root cleaning, etching, use of adhesive, polymerisation of the materials.

The only condition for which we should consider the geometrical characteristics of the post is when the root canal is very large (for example in traumatised teeth in which the apexogenesis was interrupted): in this case, a cylindrical post is preferred.

We could conclude that the mechanical characteristics of the root post, and dental system with the clinical applied procedure, and not the shape of the post, are significant.

**References**


