A finite element analysis on the stress induced by different post materials into dental tissues

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The purpose of this Finite Element Analysis was to evaluate the influence of post material on the stress distribution into the post and dental tissues. Two 3D models were created: one intact incisor and one reconstructed with different posts (titan, ceramic, carbon fibre and glass fibre posts). The simulated compressive load (30daN) was applied to an angle of 45 degrees on the palatal surface of the crown. The Algor software computed the stresses for each model, comparing the maximum registered intensity, localization and concentration into the post and the dental-periodontal complex. The rigid titan and ceramic posts produce the greatest stress concentration in the middle third of the root, at the post/dentin interface, which predispose to vertical irreparable root fractures. The von Mises stresses recorded in the root reconstructed with fibre posts are closer to that recorded in the root without post and are more favourable for the durability of the tooth, because they have a Young's modulus similar to the dentin and, as a result, a similar behaviour under the compressive load. This means that fibre reinforced posts are the best choice to reconstruct an endodontically treated tooth.

1. Introduction

The stresses distribution during masticatory function in endodontically treated teeth reconstructed with a post system can cause root fractures, especially in anterior teeth. Controversy exists between specialists regarding what kind of post is the best choice for the longevity of the restoration: metallic post or non-metallic post? [1,3].

The experimental studies performed in vivo and in vitro showed that fracture resistance and clinical longevity of endodontically treated teeth reconstructed with post-and-core systems are significantly influenced by the post characteristics, such as design, dimensions and material [4-6].

The purpose of this Finite Element Analysis was to evaluate the behaviour of the teeth reconstructed with different posts (titanium, ceramic, carbon fibre and glass fibre post) under a compression similar to occlusal forces.

2. Experimental

The best method for evaluating the direction, nature and intensity of stress is the Finite Element Method. This method consists of decomposing an object into as many elementary volumes as possible. Each volume takes on the mechanical properties of the part in which it is situated. At this point, it is possible to apply a load with known direction and intensity to any part of this object and to study the behaviour of each elementary volume. In the biomedical field FEM is an important method since it can avoid the necessity of traditional specimens and it is fundamental in studies that investigate stresses generated in restored teeth [7-10].

Construction of the 3D models

a. Choosing the study model

The simulation of the mechanical solicitation of post-and-core systems it has to start from the real morphological parameters of the tooth. So, it was chose a maxillary central incisor with the following dimensions: *L = 25.2 mm, M-D diameter = 8.5 mm (incisal) and 6.2 mm (cervical), V-P diameter = 1.6 mm (incisal) şi 5.1 mm (cervical).*

b. Obtaining the isocline curves

To obtain a virtual model, the tooth was sectioned transversally and every slide was photographed. The digital images were transferred in AutoCAD (AUTODESK Inc.) program, in order to construct the outlines of the morphologic elements in parallel plans and to define the isocline curves (Fig. 1).
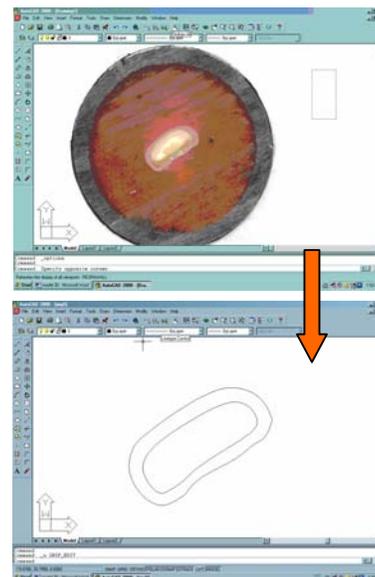

Fig. 1. Obtaining the isocline curves in AutoCAD program.

c. The discretization

The isocline curves were vertically superposed in the ALGOR program for obtaining the mesh and after that, the domain is structured in finite elements (Fig. 2).
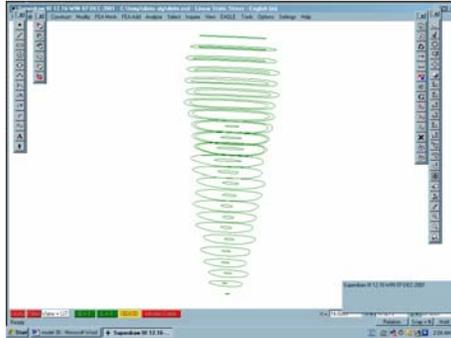

Fig. 2. The discretization of the 3D model.

After the type of finite element was chose, the discretization can be done manually or through the program [11]. We preferred the manual method because offers the possibility to control the zones with a high risk of fracture: cervical zone of the tooth and cervical third of the root. After the 3D model of an intact tooth was made, the root was separated in order to construct the 3D model of the tooth with a post-and-core system (Fig. 3).
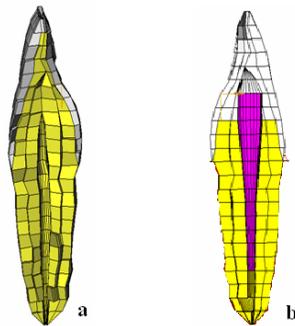

Fig. 3. a) The 3D model of an intact tooth, b) The 3D model of a tooth with post-and-core system.

The following step was to add the periodontal ligament (0.2 mm) and to establish the loading area on the palatal surface of the crown, right above the cingulum (Fig. 4). To complete the whole dental-periodontal complex, the alveolar bone representation was added and thus, the final 3D model is obtained (Fig. 5).
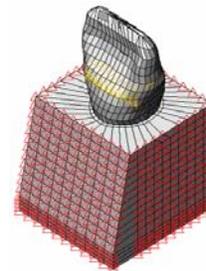

Fig. 4. Periodontal ligament.

Fig. 5. The final 3D model.

d. Establishing the analysis type and adding the material characteristics

The model consists from different components (enamel, dentin, alveolar bone, periodontal ligament, titan post, carbon fibre post, glass fibre post and ceramic post) that designate the finite element groups. Every finite element group was ascribed with the physical and mechanical characteristics of the component represented by the group (Modulus of elasticity and Poisson's ratio) (Fig. 6).
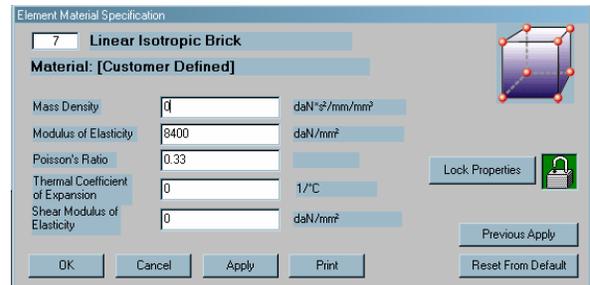

Fig. 6. Adding the material characteristics.

The biomechanical properties of materials used in this study were adopted from those available in the literature (Table 1).

Table 1. Material properties used in this study.

Constituient element	Modulus of elasticity (GPa)	Poisson's Ratio
Human dentine	18	0.31
Human enamel	41	0.33
Periodontal ligament	0.069	0.45
Alveolar bone	13.7	0.30
Carbon fibre post	21	0.31
Glass fibre post	45	0.28
Ceramic post	69	0.28
Titan alloy post	117	0.35
Gutta percha	0.186	0.45
Composite resin	16.6	0.28

e. Establishing the load and constrains

The simulated load (30daN) was applied on the palatal surface of the crown, under an angle of 45 degrees to the long axis of the tooth (Fig. 7), evenly distributed to the loading area. The deformation limits are determined to ensure the equilibrium of the structure. The conditions differ between the two 3D models (intact tooth and reconstructed tooth with different post: ceramic, titan, carbon fibre post and glass fibre post).
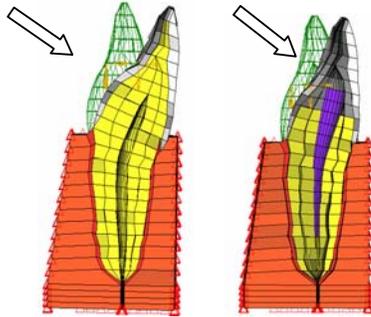

Fig. 7. The load and constrains imposed upon the models.

3. Results and discussions

The results of this Finite Element Analysis show the intensity and distribution of stresses into the post, inside the root and in the whole tooth reconstructed with different posts. The information obtained being very large, we considered opportune to present only the von Mises stresses values and distribution.

a. The von Mises stresses in the root

The root of the intact tooth showed the highest mechanical resistance from all, as was expected. The root with carbon fibre post had a lower resistance than intact root, but higher than the rest. The behaviour of the root with glass fibre post is close to that with carbon fibre post because of the similarities between mechanical properties of these two kinds of posts. In case of a rigid post, like titan and ceramic posts, the root resistance is lower than that of a root reconstructed with a fibre (carbon or glass) reinforced post.

The von Mises stresses recorded in the root treated with a fibre reinforced post (carbon or glass) are closer to that recorded in the root without post (intact tooth) compared with the titan and ceramic post (Fig. 8).
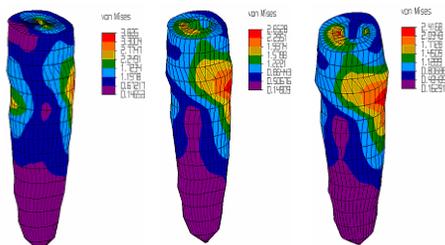

Fig. 8. The von Mises stresses recorded in a root without post (left), root with a fibre post (middle) and with a ceramic post (right).

b. The von Mises stresses in the post

Because of their material characteristics, carbon and glass fibre posts don't exhibit a great resistance to load applied, but they have an enough elastic deformation before the rupture occurs. They determine the stress concentration in the cervical third of the root, and this is an advantage for the longevity of the reconstruction. The rigid posts (ceramic and titan) are resistant to the load applied but they cause a stress concentration in the middle third of the root, at the post/dentine interface (Fig. 9).
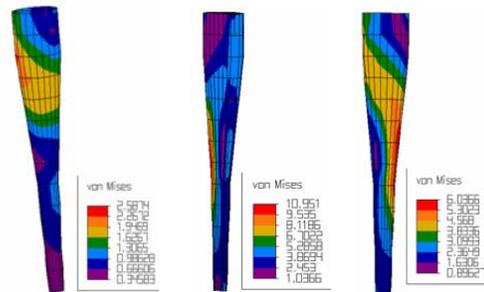

Fig. 9. The von Mises stresses inside the post: fibre post, ceramic post, titan post.

c. The von Mises stresses in the tooth

The tooth behaviour analysis began with the intact tooth, that shows, as expected, the best resistance to external load (Fig. 10).
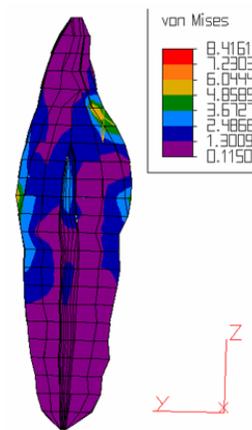

Fig. 10. The von Mises stresses in an intact tooth.

The behaviour of the tooth reconstructed with a carbon fibre post shows an excellent answer to the load. As we seen in the aspects analyzed before, the glass fibre post induces a similarly tooth behaviour like the carbon fibre post, confirming the similarities between these two posts (Fig. 11).
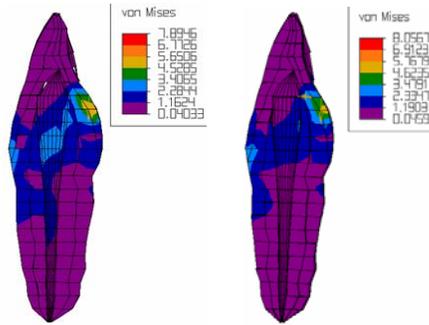
Fig. 11. The von Mises stresses in the tooth reconstructed with carbon (left) and glass(right) fibre post.

In tooth reconstructed with rigid posts (ceramic and titan) the stress distribution shows their concentration in the median third of the root (Fig. 12), that means a high risk of root fracture to occur at this level. The von Mises stresses recorded for tooth with ceramic and titan posts are very close one to each other.
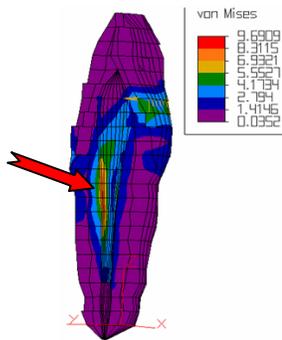

Fig. 12. The von Mises stresses in the tooth reconstructed with a rigid post.

Regarding the behaviour of the whole tooth-alveolar bone complex, we pointed out that the tooth reconstructed with carbon fibre post shows the best resistance to the external load and a stress distribution similarly with the intact tooth (Fig. 13).
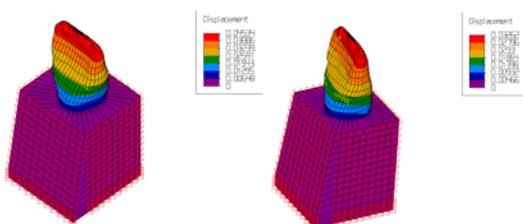

Fig. 13. Elastic deformation of dental/periodontal complex.

As we remarked along this study, the tooth reconstructed with glass fibre post behaves similarly with the tooth with carbon fibre post.

On the opposite site, the teeth reconstructed with rigid posts (ceramic and titan) have a lower resistance to external load and the stress distribution is unfavourable for the root and for the restoration longevity, because predispose to vertical, irreparable root fractures.

4. Conclusions

Post material has a significant effect on the stress concentration.

The rigid metal and ceramic posts produce the greatest stress concentration at the post-dentin interface, which predispose to vertical irreparable root fractures.

The fibre reinforced post shows the lowest peak stresses inside the root because of its stiffness that is much similar to dentin. Because of their low Young's modulus, the non-metallic posts made from resin composite reinforced with carbon and glass fibres have a protective effect on the dental supporting tissues by reducing the risk of root fracture and therefore increasing the longevity of the restoration. Except for the force concentration at the cervical margin, the fibre reinforced post induces a stress field quite similar to that of the intact tooth.

Knowing the advantages and disadvantages of different type of post, the dentist will be able to avoid a post that predispose to irreparable root fractures.

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