THREE DIMENSIONAL STRESS ANALYSIS IN THE CROWNED HUMAN TEETH

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Abstract. The stress distribution on a mandibular right second premolar tooth was investigated by using a three dimensional finite element model. Three crowns cast in different materials were subjected to a simulated biting force of 100 N with six different postures. The distribution of compressive and tensile stresses on cule and apex was evaluated by using a computer program. The stress component in transverse direction on the cule with porcelain crown was found to be most compatible with enamel when compared with other materials.

1. INTRODUCTION

One of the famous numerical methods to obtain the solutions to problems is the finite element method. Cailleteau, Rieger and Akin [1] used this method for the teeth application. The finite element method was used to compare stresses along the inner canal wall in four two dimensional models of an average maxillary central incisor. The four models evaluated were on intact incisor, an endodontically treated incisor, an endodontically treated crown-restored incisor and a cylindrical post and crown-restored incisor. Anusavice [2] et al. found stress distribution in anterior metal ceramic crowns fabricated with either gold-alloy or nickel-alloy coping of reduced thickness by using the two dimensional finite elements. Anusavice and Hojjatie [3] investigated the influence of incisal length of ceramic and loading orientation on stress distribution in ceramic crowns.


In this study the stress distribution in a mandibular right second premolar tooth for different crowns was investigated by using three dimensional finite element method (FEM). Fortran 77 was used as the programming language.
2. MATERIALS AND METHODS

In this study the finite element method was used to determine the stress distribution in a mandibular right second premolar tooth. The geometry of the tooth was taken from Wheeler [16]. The following assumptions have been made regarding the properties of tooth materials and geometry.

1) The tooth was considered to be composed of enamel, dentin and pulp tissue since periodontal ligament and cementum were very small.

2) The tooth materials were assumed to be isotropic, homogeneous and elastic.

3) The bone structure which supports the root was assumed to be rigid and a distributed external load of 100 N [10] was applied to occlusal margin of the tooth. The angle between line of the force and the horizontal axis was accepted as 45 degrees [10].

A three dimensional model of mandibular right second premolar tooth was prepared to investigate the stress distribution. The model was divided into 7 part along the longitudinal axis (Fig.1). Each of the parts was divided into smaller cubic elements. Totally 840 cubic elements were obtained. Each element consisted eight nodes with a total of 1032 nodes.

Fig. 1. Three dimensional finite element model of tooth

A tooth possesses three different pieces. The mechanical properties of which are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus (MPa)</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>41400</td>
<td>0.30 [1]</td>
</tr>
<tr>
<td>Dentin</td>
<td>18600</td>
<td>0.32 [1]</td>
</tr>
<tr>
<td>Pulp Tissue</td>
<td>0.003</td>
<td>0.45 [1]</td>
</tr>
</tbody>
</table>
In the analysis, different crown materials were used. The mechanical properties of
them are given in Table 2.

**Table 2. Properties of crown materials**

<table>
<thead>
<tr>
<th>Crown Materials</th>
<th>Elastic Modulus (MPa)</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-Pd</td>
<td>89500</td>
<td>0.33[2]</td>
</tr>
<tr>
<td>Ni-Cr</td>
<td>206500</td>
<td>0.33[2]</td>
</tr>
<tr>
<td>Porcelain</td>
<td>68900</td>
<td>0.28[2]</td>
</tr>
</tbody>
</table>

It was assumed that the temperature is the same at every point in the tooth, therefore
thermoelastic stresses can be neglected. The thickness of crown was chosen as 1.5
mm. The node number on the upper surface of the maxillary right second premolar
tooth are shown in Figure 2.

![Fig. 2. The upper surface of tooth](image)

**3. NUMERICAL RESULTS AND DISCUSSIONS**

In this investigation, six different types of external forces were used. An external
force of 100N was applied transversely, as shown in Figure 3. Namely, the angle
between the external force and z axis was 90° and nodes 923, 939, 955 were
submitted to it. Longitudinal stress $\sigma_z$ is much larger than the lateral stress
components, therefore only $\sigma_z$ is illustrated on the x and y axes. For $x=4.5$ mm and
$y=4$ mm the intensity of $\sigma_z$ is the highest. The results for porcelain crown approximate
to those for enamel.
The angle between $z$ axis and the external force (100 N) is taken as 45 degrees and the longitudinal stress $\sigma_z$ on the apex and the cole is shown in Figure 4.

Fig. 3. $\sigma_z$ stress distribution at cole a) along x axis b) along y axis.

Since the longitudinal stress $\sigma_z$ is greater than the lateral stress components, only $\sigma_z$ is denoted. The results for porcelain and Ni-Cr are the same at apex. The intensity of $\sigma_z$ at apex is nearly eight times higher than the intensity of that on cole. When the external force (100 N), is applied to nodes 925, 941, 957 transversely (angle is 900), the largest longitudinal stress component $\sigma_z$ on the apex and cole is illustrated in Figure 5.

In this solution the longitudinal stress $\sigma_z$ is shown on y axis, since $\sigma_z$ on y axis is higher than that on x axis. The results are the same on the apex for every material. On the cole the results for the enamel and porcelain are close to each other. The
difference between the enamel and Ni-Cr results is large. When the external force is applied to nodes 925, 941, 957 and the angle between the force and z axis is 45 degrees, $\sigma_Z$ is shown in Figure 6.

![Stress Distribution](image)

**Fig. 5.** $\sigma_Z$ stress distribution a) at cole along y axis. b) at apex along x axis.

Results for every material are the same on the apex. On the cole the results for the enamel and porcelain are the nearest. $\sigma_Z$ on the apex is nearly six times higher than $\sigma_Z$ on the cole. The difference between those of enamel and Ni-Cr is the largest on the cole. When the external force is applied to node 904, 953, 954, ..., 968 transversely the longitudinal stress $\sigma_Z$ is illustrated in Figure 7.

![Stress Distribution](image)

**Fig. 6.** $\sigma_Z$ stress distribution a) at cole along y axis. b) at apex along x axis.

It is seen that the longitudinal stress $\sigma_Z$ is the same for every material on the apex and it is the nearest for enamel and porcelain on the cole. The difference between the results of enamel and Ni-Cr is the largest on cole. External force applied to node 904,
transversely, $\sigma_Z$ on the apex is illustrated in Figure 8. In this figure the results are the same for every crown material.

![Stress distribution](image)

**Fig. 7.** $\sigma_Z$ stress distribution a) at cole along $y$ axis. b) at apex along $x$ axis.

In a similar study by Rubin [9] the stress distribution of a mandibular molar tooth was investigated. Although the loading and the structure of the mandibular molar tooth and second premolar tooth are quite different, when the results are compared, the maximum lateral tensile stresses values are found to be 23 MPa for dentine and 13 MPa for enamel, and the maximum longitudinal stress values are about 29 MPa for dentine, 8 MPa for enamel. The maximum lateral compressive stresses are 19 MPa for dentine, 11 MPa for enamel and the maximum longitudinal compressive stress values are about 34 MPa for dentine, 17 MPa for enamel. As a result, the compressive stress values are higher than the tensile stress values and there is no stress in pulp tissue.
4. CONCLUSIONS

In this study stress distribution for six different kinds of loading is investigated in the mandibular right second premolar tooth for different crown materials. Crown materials are chosen as Au-Pd, Ni-Cr and Porcelain. The longitudinal stress $\sigma_z$ is larger than the lateral stresses, as shown in the figures. The longitudinal stress $\sigma_z$ on the apex is higher than that on the cote. It is the largest on the boundary of the tooth. Inclined load stresses are higher than vertical load stresses. There is a bending moment effect of inclined load. There is no stress in pulp tissue.

The longitudinal stress $\sigma_z$ for the enamel and the porcelain crown is the nearest on the cote. The longitudinal stress $\sigma_z$ for the enamel and Ni-Cr crown is the most apart on the cote. It is nearly the same on the apex for the crown materials Au-Pd, Ni-Cr and porcelain. The longitudinal stress in transverse direction on the cote with porcelain crown was found to be most compatible with enamel when compared with other materials. Porcelain crown is the best crown of three types.

REFERENCES