**Influence of Choice of Crown Design on Load Transfer from Implant to the Bone**

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- Finite Element Method
- Digital Image Correlation

**Abstract**

Development of oral implants leads to great advancements in the field of oral rehabilitation of partially or completely toothless patients. Crown design is the crucial issue when load transfer from implant to bone is analysed. Therefore, the FEM models were created based on physical models that were used in DIC experiments, as well. Using both experimental and numerical technique, the influence of different crown design on load transfer from implant to bone was examined.

**INTRODUCTION**

Development of oral implants leads to great advancements in the field of oral rehabilitation of partially or completely toothless patients. Patient rehabilitation can be achieved in different ways, thanks to a large number of various implants and dentures. Testing of implant behaviour in realistic, in vivo surroundings is not simple, hence implants and dentures are tested in vitro, using various experimental or numerical methods. When tests are performed using numerical methods, the most commonly used is the Finite Element Method (FEM), which is applied to simulate mechanical behaviour. During the early seventies of the XX century, FEM started being applied in dentistry. Among the pioneers of its application were Farah and his associates. They were the first ones to use FEM for the purpose of solving of optimization and design of dental restoration problems, whereas Weinstein first used FEM for solving dental implants problems [1-2]. This method enables the testing of shapes and design of fillings, crowns, dental implants, extensions, mobile braces, dentures, as well as interactions between teeth, bone and implants, residual stress testing, testing of masticatory and occlusal forces, etc. Apart from the above mentioned, application of FEM in dentistry is justified by complying to the standards of good clinical practice and respecting of the decisions made by the ethical committee [1].

However, validity of numerical methods must be verified using experimental methods [3-5]. Experimental methods used for this purpose include 3D analysis of surface strain. One such method is the Digital Image Correlation.

For the purpose of this paper, several FEM models were created based on physical models that were used in DIC experiments, as explained in [3, 6-7]. The FEM models are made with certain simplifications in order to ensure simpler analysis. Then, the influence of crown design on load transfer from implant to bone was examined.

**EXPERIMENTS**

Finite element method is a numerical method used for obtaining approximate solutions for a large number of problems. Unlike other numerical methods, which are based on mathematical discretization of boundary equation problems, FEM is based on physical discretization of the considered domain [1]. Due to the complex geometry of teeth, it is extremely difficult to design appropriate numerical model. However, today this is made much easier thanks to optical digital scanners which enable the obtaining of a nearly realistic numerical model based on a scanned physical model. The geometry complexity has led the researchers to introduce certain assumptions in order to make the modeling feasible. The assumptions greatly affect the solution accuracy and can be grouped as follows: geometry, material properties, boundary conditions and implant-bone contact [2]. In addition, boundary and load conditions of dental implants are not accurately defined. In order to measure the loads and determine the reliability of dental implants, it is necessary to perform tests which are repetitive and enables testing of different kinds of implants subjected to the same load, under the same boundary conditions [8].

Two models (assemblies) were made in SolidWorks software, with the only difference between them being in the design of artificial crowns. Both models consisted of two teeth and two implants placed in a block which simulates the mandible. Implants Titamax GT, Neodent, were placed at the locations of the second premolar and the first molar, whereas real teeth were placed as first premolar and second molar. The difference between them was reflected in the crown geometry, in one model, crowns of the implants were connected, whereas in the other, they are separated. Cross-sections of the models are shown in Fig. 1.

Numerical analysis was performed using finite element method in ABAQUS v6.10 software. All materials were
considered to be linear elastic, and for every material, the Elasticity modulus and Poisson’s ratio were defined. Table 1 shows the overview of these values. Boundary conditions were defined in the same way for both models. Supports for the block are fixed, whereas the displacement along the upper surface of the block is constrained by the influence of these supports. Both models were subjected to load of 250 N at a point, on the occlusal surface of the first molar.

Table 1 Values of Elasticity modulus and Poisson’s ratio

<table>
<thead>
<tr>
<th>MODEL PART</th>
<th>MATERIAL</th>
<th>ELASTICITY MODULUS [GPa]</th>
<th>POISSON’S RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural teeth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First premolar dentine;</td>
<td>Dentine</td>
<td>18.6</td>
<td>0.31</td>
</tr>
<tr>
<td>Second molar dentine;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First premolar enamel;</td>
<td>Enamel</td>
<td>84.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Second molar enamel;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial teeth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second premolar facet;</td>
<td>Porcelain</td>
<td>69</td>
<td>0.3</td>
</tr>
<tr>
<td>First molar facet;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second premolar skeleton;</td>
<td>Ni-Cr-Ti</td>
<td>218</td>
<td>0.33</td>
</tr>
<tr>
<td>First molar skeleton;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second premolar implant;</td>
<td>Ti</td>
<td>110</td>
<td>0.35</td>
</tr>
<tr>
<td>First implant molar;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone</td>
<td>Block</td>
<td>Epoxy resin</td>
<td>0.21</td>
</tr>
<tr>
<td>Support s</td>
<td>Support 1;</td>
<td>Steel</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Support 2;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 a, b Cross-section of the model with separate crowns and the model with connected crowns

Model with connected crowns consists of a total of 245,317 tet elements, whereas the model with separate crowns consists of a total of 370,669 tet elements.

RESULTS AND DISCUSSION

Shown in figures 2 and 3 is the load distribution for the models with separate and connected crowns, respectively. In case of the model with connected crown, the distribution is uniform and maximum Misses stress is 503 MPa, whereas in case of separate crowns, it is 953 MPa. In both cases, highest stress occurs in the region where the point of load is located. For connected crowns, the load is transferred to the connected skeletons and through both implants to the bone, thus the bone is subjected to lower maximum load since it is of a more uniform distribution. On the other hand, in case of the model with separate crowns, the load is entirely transferred to the skeleton of the first molar and then to the implant places instead of the first molar. Load transferred in this way is of much greater magnitude.

If maximum Misses stress that occurs in the bones for both models is compared, i.e. 13 MPa for connected crowns and 49 MPa for separate crowns, it can again be concluded that higher stresses are present in the model with separate crowns. Shown in figures 4 and 5 are load distribution in the bones for these two models. In case of the model with separate crowns, it can be noticed that the load is higher in the area of the bone around the root of the second molar. In addition, higher stresses are located around the implant neck at the tip of the bone. As expected, high stresses occur in the part of the bone surrounding the top of the implant as well. Due to the load only being transferred by implants which is located at the first molar, there are stresses present in the bone between the implants. These stresses do not appear in the model with connected crowns, since the distribution is more uniform. In both models, the Misses stress distribution in the implants is very similar. In other words, the values of stresses differ, however the locations of maximum stresses are the same. Concentrations occur on the outer side of the implant which is in contact with the bone, particularly on the implant located at the first molar which was expected, since the point where the load is applied is on the crown of this molar. For the model with connected crowns, the stress is 94.7 MPa, which is much lower than 172.4 MPa which corresponds to the model with separate crowns.

Figure 2 Stress distribution for the models with separate crowns

Figure 3 Stress distribution for models with connected crowns

Figure 4 Stress distribution in bone (separate crowns)
Once the results obtained in this study are taken into consideration, it can be concluded that the difference in load transfer, as well as the values of maximum Misses stresses is evident. Same results were obtained in studies shown in [3, 7, 9, 10]. Maximum Misses stresses that occur in the bone, for both designs, are present around the top of the bone near the implant neck regardless of the number of loading points. Such distribution was recorded in studies [3, 6, 7, 11].

Differences in values of Misses stress are a consequence of a more uniform load distribution, since in case of connected crowns the load is transferred to a larger area compared to separate crowns. When two implants are placed adjacent to each other, the dentist needs to decide whether the dentures that carry these implants, will be connected or separated. This decision is influenced by the way in which the implants are placed, i.e. by their location and angulation [9]. Also, even though the making of separate crowns in simpler, adjusting their proximal contact is not, mostly due to the absence of periodontium. For separate crowns, every crown individually receives and transfers the load. During the choice of such design, interproximal contact is very important since the presence of passive elements depends on it. On the other hand, for connected crowns, stresses due to occlusal forces are concentrated in skeleton joints and in that way lower stresses are further transferred to the bone [9]. Stress concentration at the joint of skeletons of second premolar and first molar can be observed in Fig. 3.

During the analysis of these results, one should have in mind certain simplifications which were introduced for the purpose of making the numerical analysis easier. Namely, thread were removed from the implant, hence the analysis was performed for cylindrical implants. Results are affected by defining of boundary conditions, as well as the load. The way in which it was done in this paper differs from realistic conditions, since they are not entirely investigated. Here it is important to mention that for the block, i.e. bone, the properties of epoxy resin were used, which in turn have noticeably lower elasticity module compared to that of a cortical bone. This suggests that the strain determined in this study are higher than the ones that would occur in realistic conditions, assuming the same load as used here. Additionally, the jawbone is made of the cortical and cancellous bone, whereas in this paper the bone was approximated using a block made of a single material.

**CONCLUSION AND FUTURE DIRECTION OF RESEARCH**

Toothlessness represents a great issue today, since in addition to functionality, the aesthetics are also important for the patients. Therefore, restoration of a partially or completely toothless jaw is of great importance. Knowing the biomechanics of oral implants and dentures they are connected to ensure proper indication, good choice of implants and superstructure design. Problem related to oral biomechanics are not simple to investigate in vitro due to inaccessible locations and invasive methods. Because of this, numerical methods are often used for this purpose. For the results obtained to be clinically significant, validation of numerical results is necessary. It is of great importance to accurately determine the model geometry, material properties, as well as to define adequate corresponding boundary conditions and load.

Based on the results presented here, it can be concluded that connecting of crowns when it is possible, can lead to a significant stress and strain reduction.

**REFERENCES**


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