17th International Conference
ENGINEERING MECHANICS 2011
Svratka, Czech Republic, 9 – 12 May 2011

STRESS-STRAIN ANALYSIS OF RESTORED FIRST MOLAR WITH CAVITY OF CLASS I.

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Abstract: *The presented paper is focused on the stress – strain analysis of the restored tooth. From the reason of general geometry, complex material properties and boundary conditions a computational modeling was chosen. For this problem finite element method (FEM) was used. Solved system is focused on the first lower molar where dental caries is modeled and on its subsequent treatment with restoration. The tooth, which is modeled from the dentin and enamel, is established in the segment of the mandible. The tooth with cavity class I. (according to Black) is modeled in this work. The size of dental cavity is considered in three sizes, depending on the range of dental caries. For restoration of tooth, filling materials were used. These materials are commonly used in dental practice. Force was prescribed at the occlusal surface of tooth. The model of physiological tooth was created for comparison of stress - strain states on the restored tooth. The analysis of the results shows that amalgam is the best material for tooth restoration in molar segment.*

Keywords: ***Save tooth, molar tooth, finite element method, amalgam, composite resin.***

1. Introduction

Currently there are only few people who can boast with healthy teeth without any intervention by a physician. Teeth are an integral part of the oral cavity and each person uses them several times a day for receiving and processing food. Important role of the teeth is their irreplaceable place in the overall appearance of person. In the case of the extensive damage or even loss of the tooth is appropriate to insert a dental implant (Borák, L., et al, Marcian, P., et al, 2010). For these reasons it is very important to take care of teeth and mouth and keep them in good condition. Although the teeth consist of the most resistant and hardest material in the human body, the tooth can be damaged by the mechanical, chemical and biological processes. The most common damage of the dental tissues is dental caries (Fontana, M., et al., 2010). The area of treatment of the dental caries is concerned with restorative dentistry. Tooth decay is removed by dental instruments and a new vacant place is ready for the application of the filling material. This procedure is called tooth restoration. Well executed restoration of the tooth helps to prevent further spread of dental decay and it maintains the basic function of teeth like separating and crushing food. In this activity the teeth are significantly mechanically loaded. Restoration of the teeth significantly changes coherence and mechanical properties of impaired dental tissue, which also affects the deformation and stress of loaded tooth. For saved tooth there is a sudden change in stiffness resulting in stress concentrations and it may cause undesirable break of the loaded tooth. Determination of stress and strain at the physiological and saved tooth is a problem due to the complex geometry, material properties, location, and last but not least, the boundary condition of the tooth. This problem can be effectively solved by computational modeling.

2. Material and methods

The finite element method (FEM) was chosen for solving of this problem. It is the most frequently used numerical method. It is possible to create a computational model on a high level using the advanced computing systems. For the solved system the FEM program ANSYS was used. To obtain

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the computational model it is necessary to create sub-models. These are a model of geometry, materials, loads and model of boundary condition.

The models of geometry which occur in biomechanics have generally complex shapes (Fig. 1). The creation of these models at a high level is difficult for software and hardware. To obtain the high quality models of geometry there are two possible approaches. One approach is based on technologies and methods of rapid prototyping. It means that a solved system is scanned by 3D scanner. The second method to obtain a high level model of geometry is use of modern imaging techniques like Magnetic resonance (MRI) and Computer tomography (CT) where the model of geometry is based on CT images (Valášek, J., et al, 2010). The first approach was used for this work. The tooth is composed of several layers and each of them has different mechanical and material properties. Due to the interaction between tooth and dental filling, the tooth was divided into two layers on the enamel and dentin. It was necessary to create the model of geometry of tooth cavity. The model of dental cavity was made in three sizes, which represents the different ranges of dental caries. For completeness of the solved problem the models of geometry for cortical and cancellous bone were created.

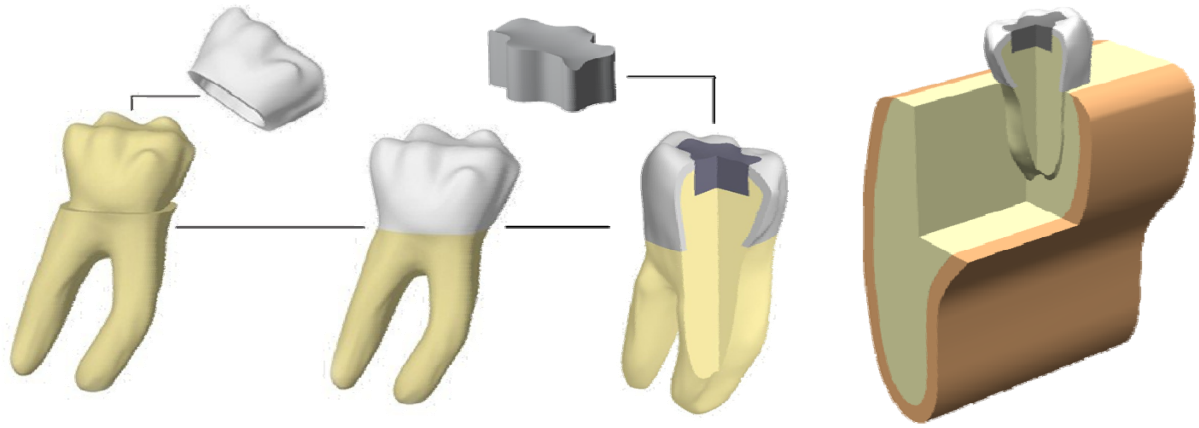


Fig. 1: Parts of solved system.

In the solved systems which occur in biomechanics, there is interaction between living tissues (bone, muscle, dental tissue) and technical materials (titanium implants or fixation, dental filling material). The material properties of technical materials are well known but obtaining the material properties of real objects occurring in biomechanics is a difficult problem. In terms of the level of the solved problem, the appropriate and validated model of mechanical properties is a homogenous, isotropic and linear elastic model, which is explicitly described by two material characteristics: Young's modulus E [MPa] and Poisson's ratio μ [-]. Model of material was created for each part of the solved system. Used material characteristics are shown in Tab. 1.

During mastication, the tooth is loaded in a general direction and force directed into the occlusal plane. After a decomposition of the general loading to the coronoapical (CP), buccolingual (BL) and mesiodistal (ML) directions, the dominant component is in the coronoapical direction. It is direct to the occlusal surface of the tooth. The study is considering a dominant load of 200 N, which is usually reached in the molar section. The load of the solved system was obtained from the study (Curtis, D.A., et al., (1999).

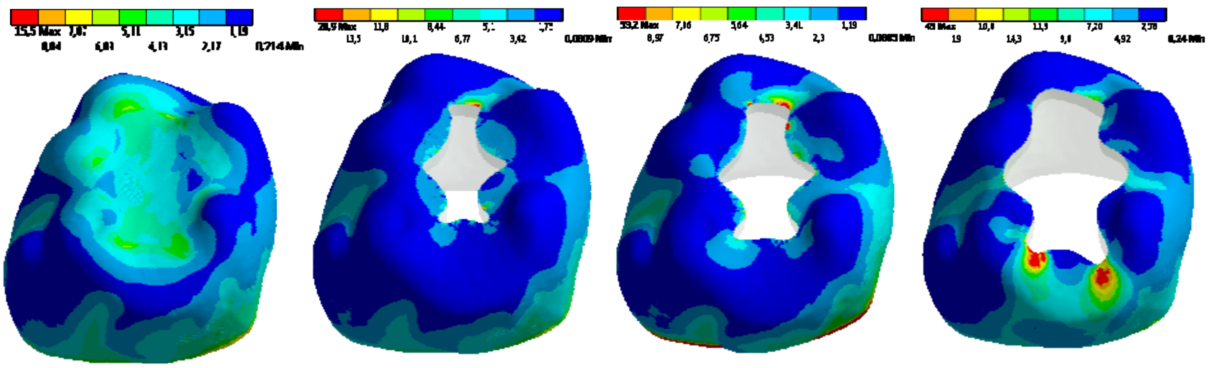
The computational model is necessary to clearly defined in a space. For the solved system boundary conditions were prescribed for the cortical and cancellous bone. On the edge of the cortical and cancellous bone were prescribed prohibitions displacements in all directions. The connection between organic tissues (enamel, dentin, cortical and cancellous bone) were modeled like solid connections (elements have shared nodes). The boundary conditions between the dental tissue and the dental filling were modeled with contact pair where friction was prescribed. The discretization was created hexahedral and tetrahedral elements with quadratic approximation (SOLID 186) and a pair of contact elements (TARGE 170 and CONTA 174). Maximum attention was paid to the meshing and the number of elements was within 200 thousand.

Tab. 1: Material properties for solved system.

Model of material	***E [MPa]***	***μ [-]***	***Literature***
Enamel	80 000	0.3	*(Gei, M., et al., 2002)*
Dentin	20 000	0.3	*(Gei, M., et al., 2002)*
Cortical bone	13 700	0.3	*(Carter, D., et al., 1987)*
Cancelous bone	1 370	0.3	*(Bratu, E., et al., 2003)*
Amalgam	15 870	0.3	*(Beatty, M.W., 1993)*
Composite resin	6 260	0.3	*(Beatty, M.W., 1993)*
Glassionomer cement	3 000	0.3	*(Beatty, M.W., 1993)*

3. Results

To assess the mechanical interaction between filling material and tooth tissue, especially enamel, 9 variants of computational model were created. Individual variants differed in modeled size of dental caries and various filling materials used for restoration of the tooth. Distribution of stress and strain in restored tooth were compared with these distribution in healthy tooth. On closer study of distributions of stress and strain for individual dental tissues it was found that enamel is the most affected tissue by restoration. For this reason an analysis will be focused to the enamel. The first analysis was done for parameter of the effect of size of the dental decay. The first picture from left is a model of the healthy tooth. Towards the right the results for different sizes of tooth cavity are plotted. The equivalent stress reached value σ_{HMH} = 9.5 MPa for the healthy tooth on the occlusal surface. The maximum value σ_{HMH} = 15.5 MPa is reached on transition between enamel and dentin. Fig. 2 shows that if the contour of cavity reaches a place between the dental bumps, the concentration of stress may occur. The maximum value $\sigma_{HMH}^{(3)}$ = 43 MPa is achieved at cavity size 3 on the mesial wall. In the case of cavity sizes 1 and 2 the equivalent stress reached the values $\sigma_{HMH}^{(1)}$ = 20.9 MPa and $\sigma_{HMH}^{(2)}$ = 23.8 MPa on the contour of cavity in distal direction. The maximum value of equivalent stress is $\sigma_{HMH}^{(2)}$ = 53 MPa and it is reached on transition between enamel and dentin. This value is caused by influence of geometry of solved system especially crossing between dentin and enamel.



Healthy tooth. *Cavity size 1.* *Cavity size 2.* *Cavity size 3.*

Fig. 2: Equivalent stress for enamel with amalgam filling.

The next analysis was focused on the influence of dental filling materials onto the distribution of stress and strain in the dental tissue. For every filling material the equivalent stress was observed for the enamel and dentin. The values of equivalent stress were plotted in Fig. 3. The graph shows that an amalgam was used as a filling material for the specific cavity class, the values of equivalent stress are the lowest. For other filling materials the values of equivalent stress rise.

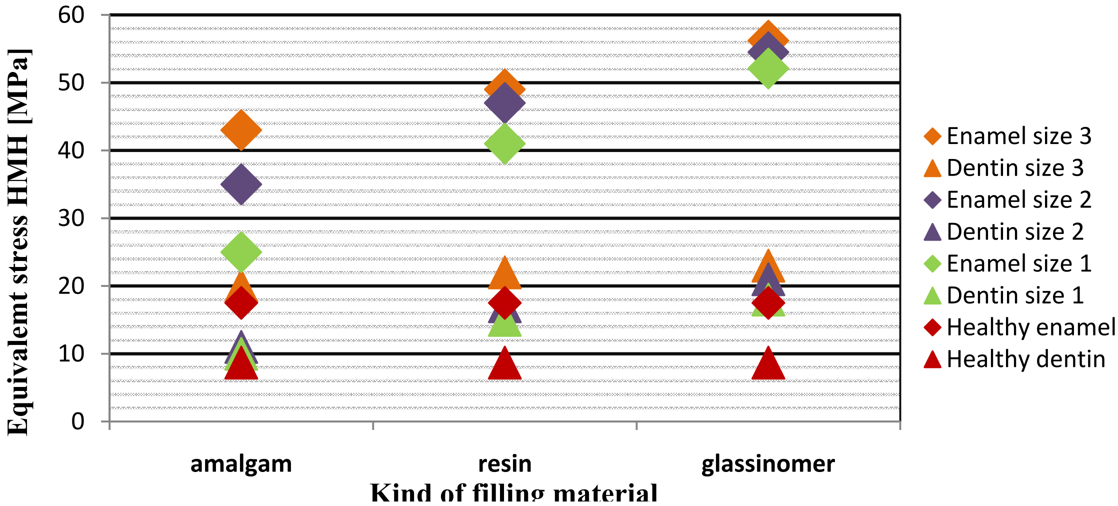


Fig. 3: Equivalent stress in enamel and dentin for different cavity size.

4. Conclusion

The presented biomechanical study was focused on stress-strain analysis of the restored first molar tooth with three sizes of dental caries. Three different types of filling materials were used for restoration. The values of equivalent stress were evaluated for solved problem. The analysis of the influence of the different tooth cavity sizes shows that if a tooth decay is large and newly created cavity reached the places between the dental bumps, there is a place where the stress concentrations may occur. These places are dangerous with considering of the high values of equivalent stress for beginning of the crack. This behavior is reflected in clinical practice, which confirmed the results of this study. The next influence that was analyzed was the influence of filling material. The analysis shows that due to the large masticatory forces for restored tooth in a molar section amalgam should be used as a filling material.

Acknowledgement

This work was supported by grant project FRVS No. 2829/2011 and specific research FSI-J-11-3.

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