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*Research paper*

# NUMERICAL MODELING OF THE EDENTULOUS MANDIBLE WITH A COMPLETE DENTURE USING MULTIBLOCK METHOD

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**Abstract:** *In this paper, finite element model of edentulous lower jaw (mandible) is generated, as well as the model of support layer and complete denture using various software. The aim of this study was to produce 3D digital mandibular complete denture, mucosa, and supporting bone models using reverse engineering and evaluate effect of mucosa thickness and resiliency on stress distribution of complete denture. In this study we used a model of mandibular complete denture and 5 mm thickness of mucosa (which represent the resiliences soft). The influence of resilient mucous membranes layer thickness is analysed by assigning loads to simulate the force due to chewing on the lower right and left central incisor and lower right and left first molar. Based on the numerical results, we conclude that the maximum stress values were concentrated in cortical bone.*

**Key words:** *mandible, complete denture, biomechanics, FEM, STL2MESH*

## 1. INTRODUCTION

A variety of treatment for the edentulous mandible has been employed. Complete oral rehabilitation including dental implants is a viable clinical treatment option for total edentulous patients with good acceptance on functional and social aspects. The implant supported fixed prosthesis is a preferable alternative to treatment with conventional complete denture, the main advantages are decreased resorption of the residual ridges; psychological benefits for the patients and maintenance of masticatory efficiency [1]. However, these prostheses are an expensive treatment due to the complexity of surgical and prosthetic phases and cost of implants and prosthetic components. For this reason, patients afflicted with the edentolouism usually wear less expensive, conventional dentures. Such dentures, also called the mucous membrane-supported dentures, function on the mucous membrane that covers edentulous processes of the denture foundation. This type of dentures can cause mucosal tenderness, ulceration and pain in most of patients because of instability of a loadedcomplete dentures. For this reason, knowledge of the transmission of mechanical load on supporting tissues in complete denture wearers is extremely important. Knowledge of load transfer to the surrounding bone and understanding of the distribution of stress and strain is essential to be able to assume the answer bony structures and adaptation to occlusal loads generated by natural teeth, a variety of dental restorations or implants.
Some previous in vitro studies indicated that the stress distribution in different attachment system on implants, but the effect of mucosal thickness and resilience to the stress distribution is not yet known [2, 3]. In addition, if the problem of understanding the distribution of stress on the supporting tissues to be studied carefully, it could have a very great benefit to the population that is forced to wear a prosthesis.
This study is a contribution to the solution of practical dilemmas related to prosthetic treatment. Understanding of the forces and patterns of stress distribution in the bone underneath the denture is a major factor during the planning of denture fabrication.

## 2. MATERIALS AND METHODS

This chapter explains the process of digitizing 3D physical model of the mandible and complete denture, the transformation of these models into the desired coordinate system, construction of blocks and resilient layer modeling. To generate the numerical model cadaver mandible was used and complete denture was made on it.
Model of the mandible and the complete denture was obtained by digitizing the 3D optical measuring systems ATOS (GOM, Germany). The denture was first sprayed with a thin coat of titanium-dioxide ($TiO_2$, white colour) due to increase its contrast for scanning. Models are digitized using two measuring projects, one for the upper side of the model, and the other for the lower. Upper and lower sides are connected via common reference points (at least 3 reference markers affixed to the models). System combines the different indivudual measurements [4] to render a complete 3D scan of surface (Figure 1).
Digitized models are transformed into a coordinate system that enables the simplest setting of boundary conditions. Blocks are generated using the sections (Figure 2a), in which all vertices of the blocks are set. Blocks generated for mandible, mucous layer and complete denture enables the creation of finite element models for these structures (Figure 2b). Multiblock

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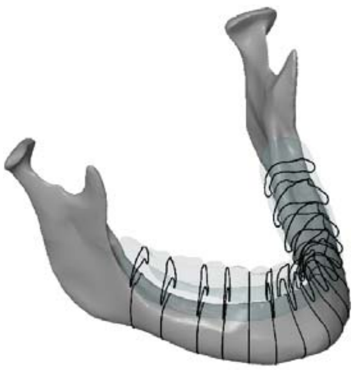
method implemented in software STL2MESH enables the nodes on the contact surfaces of these models have the same 3D coordinates [5]. Joining of models is performed by importing into the same project and merging nodes (Figure 3).

*a)*

*b)*

*Fig. 1. Poligonized mesh of surface: (a) mandible and (b) complete denture*



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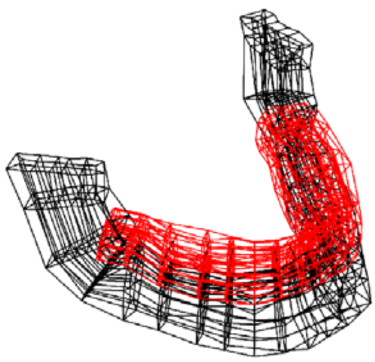
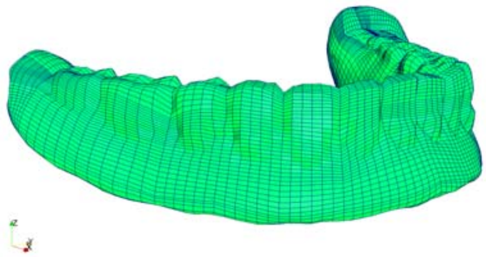


*b)*

*Fig.2. Block generation: (a) sections for design blocks and (b) blocks for mandible, mucous layer and complete denture*



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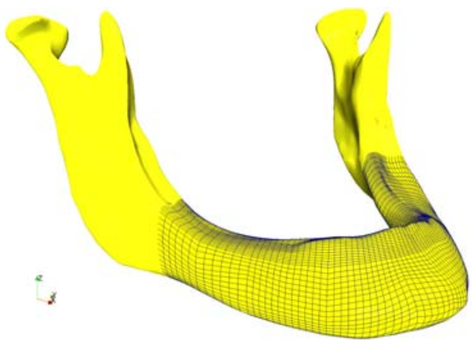

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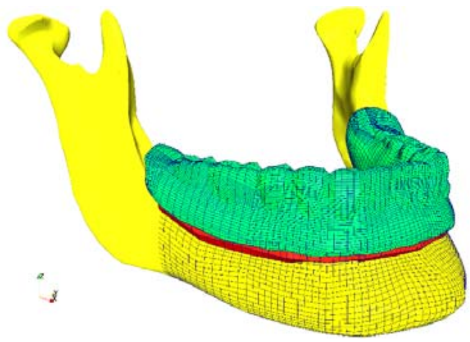


*d)*

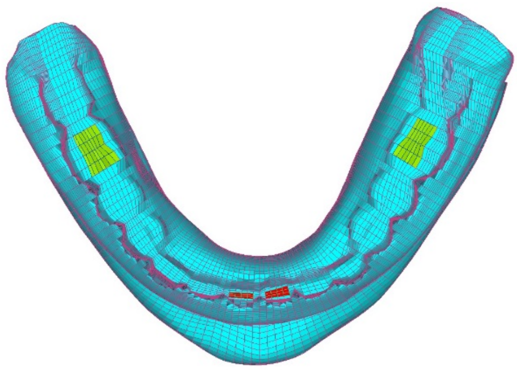
*Fig.3. Finite element models: (a) complete denture, (b) mucous membrane, (c) mandible, and (d) full model*

Mechanical properties of materials complete denture, mucous membrane, mandible are given in Table 1. Total denture was considered as a homogeneous structure since it is constructed of acrylic resin and acrylic teeth. Thickness of cortical bone is modeled is a uniform: the thickness of 2 mm on the outside of the bone and the thickness of 3 mm on the inner side.

An occlusal load of 120 N was applied onto the left and right cental incisor and the left and right first molar teeth, simulating occluding and clenching forces (Figure 4a). Constraints are specified at locations shown in Figure 4b. The masticatory stress distribution was studied with FE software (PAK).

*Table 1. Materials mechanical propreties*

| Material | Mechanical properties | |
|---|---|---|
| | Young Modul [MPa] | Poason Coefficient |
| Cortical bone | 15000 | 0.30 |
| Trabecular bone | 1500 | 0.30 |
| Acrylic tooth | 3000 | 0.35 |
| Acrylic resin | 3000 | 0.35 |
| Mucosa hard | 680 | 0.45 |
| Mucosa resilient | 340 | 0.45 |
| Mucosa soft | 1 | 0.37 |



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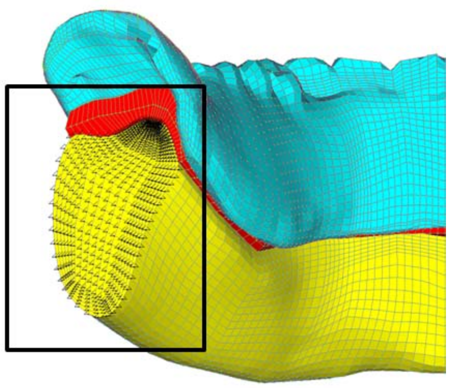


*b)*

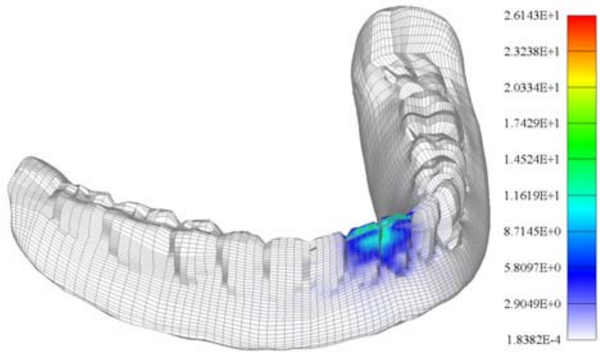
*Fig.4. Boundary conditions: (a) loads and (b) constraints*

## 3. RESULTS AND DISCUSSION

In finite element analysis studies, the assumptions made regarding geometry, mechanical properties of the materials, and loads and constraints applied to the model have a key role in the accuracy of the experiment [6]. The present study used 3D models to evaluate the stress distribution in complete denture regarding mucosa 5 mm thickness and soft resiliency. Results of the analysis are shown in Figure 5.

In dentistry, the first study of stress distribution using 3-D FEM began with a mandibular complete denture, due to its simple shape [7]. The mandibular denture model was initially developed with graphical methods using computer aided design (CAD) software to mimic the mandible anatomically. However, the simple CAD model can only provide basic information for FEA of stress distribution. For this reason, there is a need for better methods.

It is well known that 3D eightnoded elements provide a better solution results than tetrahedral elements. Improvement of tetrahedral elements' solution accuracy is achieved by forming meshes with a large number of elements which requires greater computer time and/or hardware resources. Generation of finite element models for complex biomechanical structure allows a small number of software.

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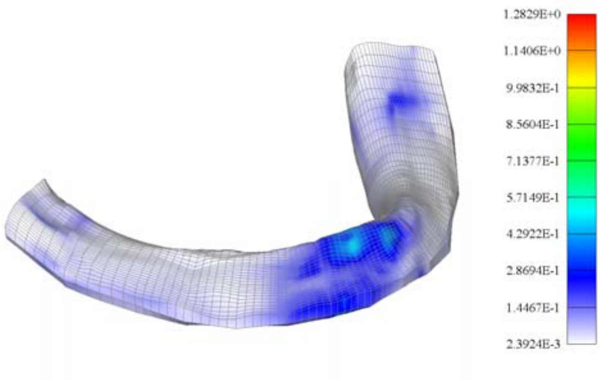


*b)*

*Fig.5. Field of von Mises stress: (a) cemplete denture and (b) resilient layer*

In this study, it was observed that the highest stress values were concentrated in the zone below of assigning load (the contact surface of the mandible with a resilient layer, inside the acrylic teeth). For the 5-mm mucosa models, which simulates a soft mucosa in a clinical condition, the maximum stress values in supporting bone were 26. 96 MPa in the area of incisors and concerning the supporting tissues, cortical bone showed the highest stress values. Song et al. evaluated the energy relieving effect of different mucosa thickness beneath mandibular complete denture using a 3D FEA [8]. The authors observed that as mucosa thickness increased so did the energy relieving, leading to lower bone tissue deformation. Therefore, thicker mucosa is benefit to reduce bone loss [8]. In general, these results are in accordance with the present study. The decrease in stress values in supporting tissues when softer mucosa is present could be explained by the principle that softer structures absorb more impact caused by loading. Therefore, softer mucosa would relieve the stress in the supporting tissues. Assuncao et al. evaluated the effect of different mucosa characteristics on stress distribution in complete denture and implant-retained overdenture by use of a FEA-2D. They showed that cortical bone showed the highest stress values [9]. These results were in accordance with our study.

## 4. CONCLUSION

This paper presents a method for modeling the complete denture and the supporting tissue (mandible and resilient layer) using the finite element method. To generate the finite element model software GOM Inspect and STL2MESH were used. Presented method of modeling preprocessing is performed in a program GOM Inspect which is not intended for use in the finite element method. This has several advantages: (a) manipulation of point clouds is much easier in programs that are designed to work with polygonal models, (b) construction of blocks is a much simpler and user-friendly compared to the currently existing methods, (c) finite element model is created directly over the digitized model, which is primarily to avoid time-consuming steps to create NURBS surfaces and solids, and indirectly increases the accuracy of the model because the steps that cause errors and approximations are bypassed, (d) when complete software development, STL2MESH will be able to generate the finite element models of complex structures fully automatically, assisted by engineers only when defining blocks.

In the space between the mandible and complete denture is modeled mucous membranes, as resiliences soft (5 mm thickness). Numerical analysis was performed in the software PAK. In this study the maximum stress value occured in the zone below of assigning load (the contact surface of the mandible with a resilient layer, inside the acrylic teeth). Regarding supporting tissues, the maximum stress values were concentrated in cortical bone.

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