THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620
2017

STRESS AND DEFORMATION ANALYSIS OF THE HUMAN MASTICATORY SYSTEM

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ABSTRACT

In this study we tried to analyze the stress and deformation of human mandible and teeth during mastication by using finite element analysis. Three dimensional models of an intact mandible, teeth and pivot were modelled to analyze stress distribution and bite force under loading conditions. The initial models were simplified due to low resources of the computing machine. Boundary conditions were considered at the top of the model and established as fixed supports. Loads have been set at the top of the teeth, in the area of the cusps. According to several studies, the maximum mandible force for an adult can be 0.53 kN.

Keywords: teeth, mandible, pivot, bone, FEM analysis.

1. INTRODUCTION

The mandible is a complex structure and it plays to an important role in facial aesthetics and many functional activities, such as mastication, swallowing, facial expression and speech. The mandibular system is composed of different tissues such as bone (cortical and cancellous types), teeth (enamel, dentin and pulp), ligaments and muscles.

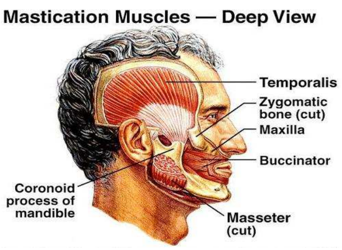

Fig. 1 Mastication muscle

As is presented in figure 1 the mastication system it is very complex from one point of view: are different materials with elastic property more or less known. This sophisticated combination of anatomic structures was simplified.

Simplifications were adopted regarding how the mandible is attached to the rest of the human skull. This is because at this moment interest lies in what happens in the mandible system regarding the action of the tasks resulting from mastication. Our mandibular system is composed of a pivot, mandibular bone and teeth. As time passes, the bone is subject to a remodelling process with areas of different mineralization and density grades. It is also important to consider that the main function of mastication depends on four major muscle groups. The suprahyoid and infrahyoid also contribute to the mandible stabilization and equilibrium.

2. THEORETICAL BACKGROUND

The ANSYS structural analysis software enables solving complex structural engineering problems and making better and faster design decisions. With the finite element analysis (FEM) tools available in the suite, solutions you can customized and automated for structural mechanics problems and they can be parameterized to analyze multiple design scenarios. For even greater fidelity they can be easily connected to other physical analysis tools. The ANSYS structural analysis software is used through the industry to enable engineers to optimize their product designs and reduce the costs of physical testing.

3. CREATING GEOMETRY

The geometry of the mandible, teeth and pivot was made in AutoCAD, and then imported in ANSYS Workbench. Figure 1 shows the models imported in ANSYS.

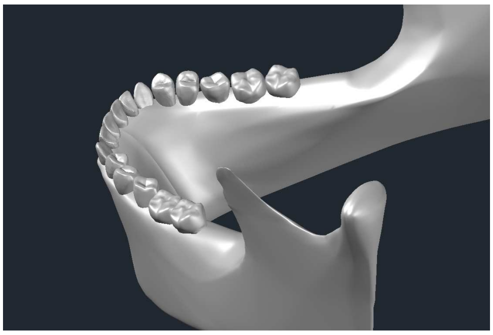

Fig. 1. The model of mandible

4. FEM ANALYSIS OF THE MANDIBLE

The 3D model of the mandible was generated from solid parts in AutoCAD. Then the model was exported with the .sat extension and imported in ANSYS Workbench. First the model was meshed.

There have been a number of difficulties in shaping the mandible. These difficulties were related to the number of volumes in which the mandible was discretized, this number determining the calculation time and the capacity of the equipment on which the calculation was made. So a computer with a 32 Gb memory was used. The model consists of 91.957 elements and 159.505 nodes.

Another problem considered to be solved was that of the presence of the two pivots in the mandible. To capture the effects they introduce, as well as the changes in the general tension and deformation state of the mandible, the area where the pivots were considered to fit, was finely discretized.

In choosing the meshing mode, the way to apply the teeth to the teeth during mastication had to be considered.

Boundary conditions were considered at the top of the model and established, for this stage of research, as fixed supports. Then a force of 0.53 kN was applied on the top of the teeth, in the cusps area. This value corresponds to a normal person mandibular system.

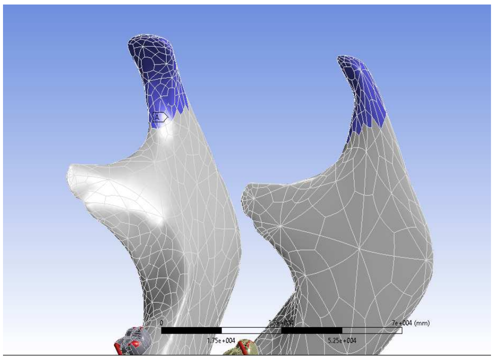

Fig. 2. Boundary conditions

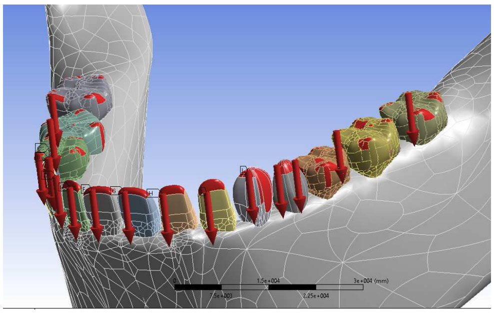

Fig. 3. Loads

5. DEFINITION OF MATERIAL PROPERTIES

Mechanical properties of the elements that we analysed are:

1. Mandible bone: with Young's modulus of 1370 MPa and Poisson's ratio of 0.3.
2. Pivot: we choose the titan as material, having Young's modulus of 114000 MPa and Poisson's ration of 0.3.
3. Teeth have Young's modulus of 72700 MPa and Poisson's ratio of 0.33.

6. NUMERICAL ANALYSIS AND RESULTS

After analysis the values of stress and deformations are as follow:

6.1 Deformation

➔ Mandible deformation – maximum displacement: 0.33 mm

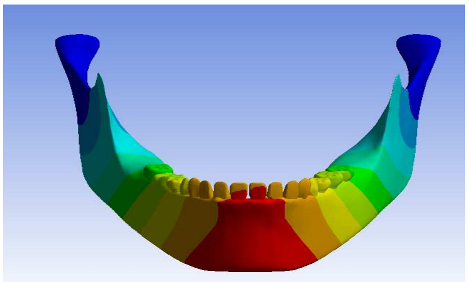

Fig. 4. Mandible deformation

➔ Teeth deformation – maximum displacement: 0.30 mm

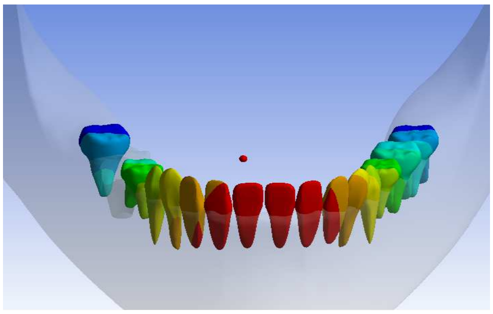

Fig. 5. Teeth deformation

➔ olars deformation – maximum displacement: 0.20 mm.

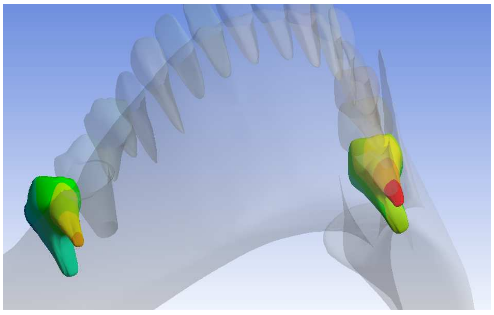

Fig. 6. Molars deformation

➔ Canines deformation – maximum displacement: 0.29 mm

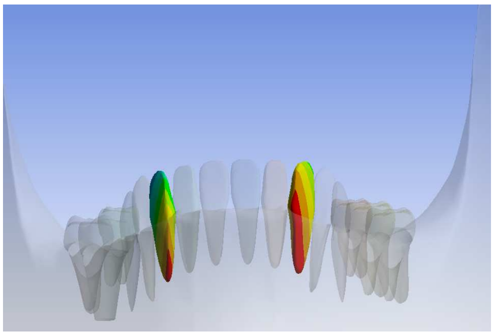

Fig. 7. Canines deformation

➔ Incisors deformation – maximum displacement: 0.30 mm

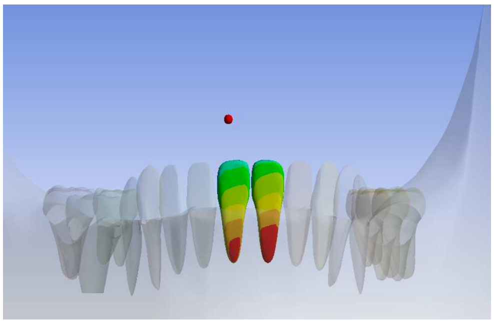

Fig. 8. Incisors deformation

6.2. Stress

➔ Total maximum stress: 0.06 MPa

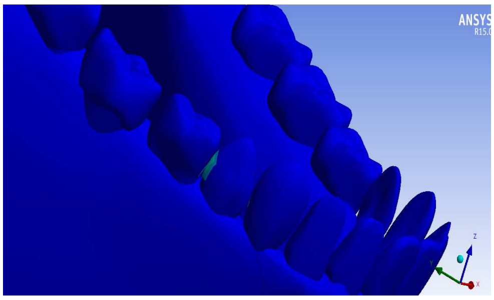

Fig. 9. Total tensions

➔ Teeth maximum tensions: 0.06 MPa

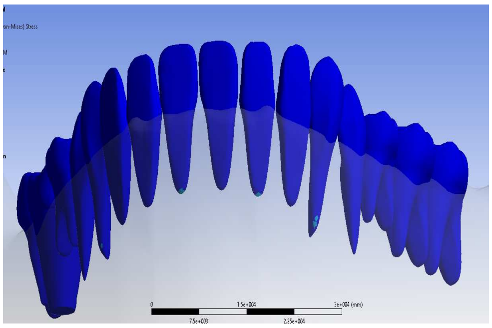

Fig. 10. Teeth tensions

➔ Pivot maximum stress: 0.002 MPa

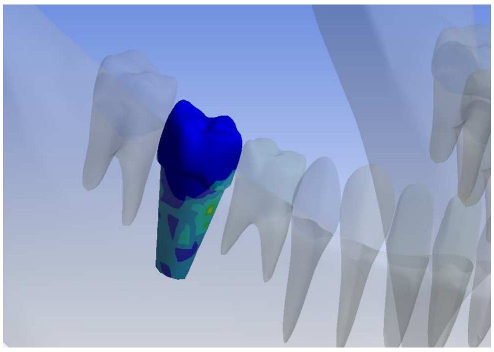

Fig. 11. Pivot tensions

➔ Molars maximum stress: 0.003 MPa

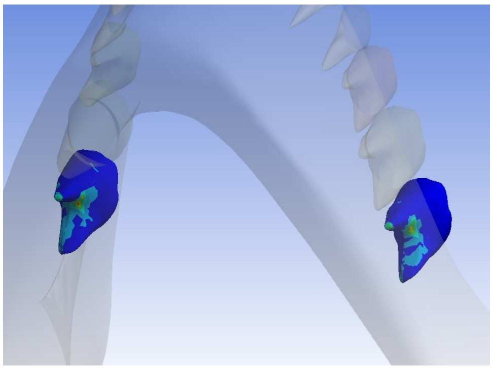

Fig. 12. Molars tensions

➔ Canines maximum stress: 0.009 MPa

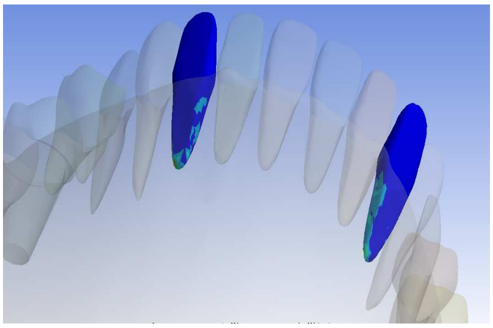

Fig. 13. Canines tensions

➔ Incisors maximum stress: 0.003 MPa

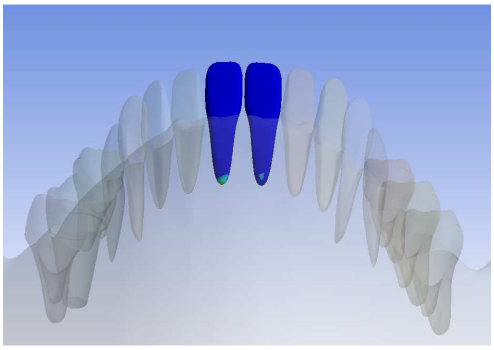

Fig. 14. Incisors tensions

➔ Mandible cavities maximum stress: 0.009 MPa

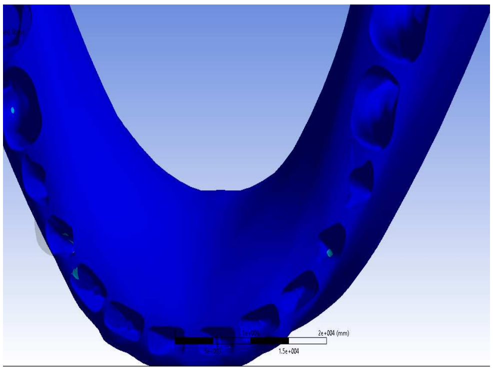

Fig. 15. Mandible tensions

➔ Mandible maximum stress: 0.007 MPa

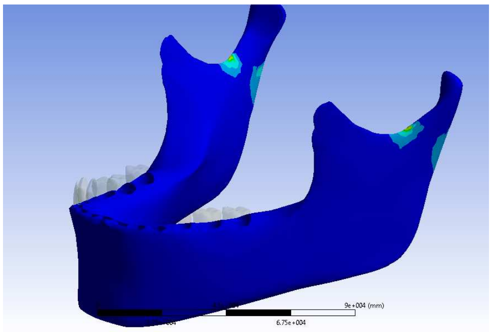

Fig. 16. Mandible tensions

7. CONCLUSIONS

The numerical analysis shows that tension and displacement in the jaw are due to the edge conditions. In the areas of interest, where there is a dentition, the movements are in 0.30 mm, respectively the tensions are 0.06 MPa. These are accepted values for the mandible's human bone. In the area where the implant is located, there are tensions at the contact between the implant and the bone. These stresses are the results of contact between different materials. It is mentioned that we have introduced contact as follows: bone on the bone and titanium on the bone. This type of contact should be studied later in this study.

Following the numerical analysis carried out in this study, the following important conclusions can be drawn:

- The meshing of the structure of the mandibular system must be done with great precision to fully capture the effects of mastication on the alveolar void;
- The application of the tasks must be done with great precision because, as it is known, the contact does not occur on all the teeth, the teats and canines at the same time but gradually depending on the size of the ingested food;
- The ligaments of the mandible with the skull must be made through the masticatory muscles, which in the case of the analyzed structure can be approximated with resonances to which the elastic constants must be known.
- On the basis of experiments, it will be possible to see how the contact between the pivot and the mandible is to be considered. At this time, literature has not provided any concrete and accurate information about how this contact should be considered.
- Another issue that will be addressed in future studies is that of pivots mounting. It is desirable to establish a practical methodology for screwing the pivots into the mandible and the jaw so as to avoid bone fracture and / or injury by breaking the bottom of the cavity where the pivot is mounted.

This study opens new research directions for CCAN, being a first step towards an interdisciplinary collaboration between the faculties of Naval Architecture and Medicine and Pharmacy from "Dunarea de Jos" University.

Acknowledgements

The research was supported by the Research Centre of the Naval Architecture Faculty, in "Dunarea de Jos" University of Galati, which is greatly acknowledged.

8. REFERENCES

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Paper received on December 28th, 2017