Mihaela VATU, Daniela VINTILA, Rodica MERCUT, Sanda Mihaela POPESCU, Dragos Laurentiu POPA, Ilaria Lorena PETROVICI, Georgiana VINTILA, Allma PITRU

THREE-DIMENSIONAL MODELING OF THE DENTAL-MAXILLARY SYSTEM

Abstract: *In this paper, a virtual model of the dental-maxillary device was obtained by scanning a skull taken from a corpse, and using a few sets of tomographic images. These images were processed with a program that allows the transformation of tomographic images into three-dimensional geometries based on gray shades. In an initial phase these geometries were in the form of discontinuous surfaces, which were then processed, finalized and transformed into virtual solids. Thus, in the SolidWorks program the dental-maxillary device was obtained as virtual solids. Such a Multi Body model has undergone kinematic simulations in the Motion model of SolidWorks, where the entire load system to which the analyzed model is subjected. At the end of the paper, important conclusions were highlighted..*

Key words: *Dental wear, virtual mandible, virtual jaw, dental-maxillary model, kinematic simulation.*

1. INTRODUCTION

The human dental-maxillary device has undergone major changes, and modern nutrition has recently led to a number of dysfunctions that have produced various carious and non-carious lesions. Consumption of carbonated beverages, acidified, the presence of different acids in food often produces non-carious dental wear. We intend to make different models of dental-maxillary apparatus for the study of this phenomenon [1], [2], [3].

The objective of this study is to obtain a virtual model of the dento - maxillary system on which to simulate different movements of the mandible and subsequently these loads to be analyzed with FEM.

The design and modelling of this biomechanical system of the maxillo-dental-mandibular apparatus is based on "in vivo" models. Preliminarily, the bone components were considered to be rigid by applying the Adams modelling algorithm included in the SolidWorks Motion module. The movement deflections were defined, and the temporo-mandibular joint was originally defined as a mechanical rotation coupling (1R coupling - a space rotation), and the resulting loads were similar to the lowering and lifting movements of the mandible [3], [4], [5].

2. THREE-DIMENSIONAL SCANNING OF A HUMAN SKULL

The simplest way to get a three-dimensional model would be three-dimensional scanning. For this operation a skull was taken from a corpse, a teaching material of the University of Medicine and Pharmacy of Craiova. 3DSYSTEMS CAPTURE 3D scanner was used for the scan operation. This device allows three-dimensional, point-based clouds with a resolution of 0.08 mm and an accuracy of 0.060 mm to 300 mm and 0.118 mm to 480 mm [5], [6].

This scanner, featuring Geomagic for SolidWorks software, brings the geometric models into the interface of this CAD program, and initially, the geometric model of the skull consisted of a cloud of points. (Fig. 1) [7], [8].

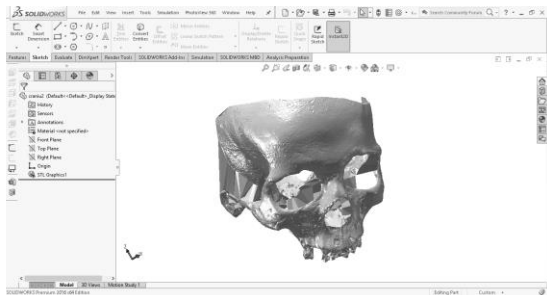

Fig. 1 The initial model of the human skull based on cloud points.

Using the capabilities of the Geomagic for SolidWorks program, this cloud of points has been transformed into solids and virtual surfaces (Fig. 2).

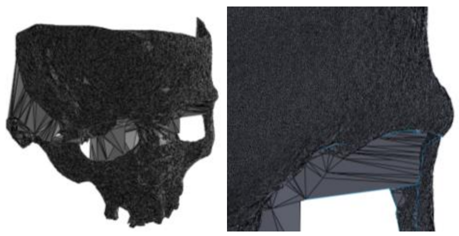

Fig. 2 The skull model composed by virtual solids and surfaces.

However, this method has a great disadvantage, because the internal structures of the analyzed system could not be highlighted. For this reason, the use of this method was dropped, but certain portions of this model were used to obtain an ideal model of the human dental maxillary system.

3. OBTAINING THE THREE-DIMENSIONAL DENTAL-MAXILLARY MODEL USING MEDICAL IMAGING AND CAD TECHNIQUES

For the internal components of the skull were used several "in vivo" models, respectively magnetic resonance imaging and tomographic images obtained with Emotion16 (Siemens) equipment. Tomographic images from eight patients, six female and two male patients aged 18 years to 75 years were used. Identity, or other personal data, will not be disclosed in this work. In Fig. 3 are presented tomographic images of these subjects [7], [8].

Fig. 3 The CT images of analyzed patients.

This model shows the internal skull components to which materials with certain mechanical properties have been attached. For the three-dimensional reconstruction of the dental-maxillary device which involves the transfer of geometric information from the tomographic images to the virtual model, Mimics developed by Materialise, two Mimics Medical workflows for transforming tomography images into three-dimensional geometry in format.stl, and the 3 - Matic Medical for file processing and transformation into editable surface geometries in SolidWorks-type three-dimensional environments. After transforming the tomographic images into geometry of the .stl type surface, the program interface is similar to that shown in Fig. 4 [7], [8].

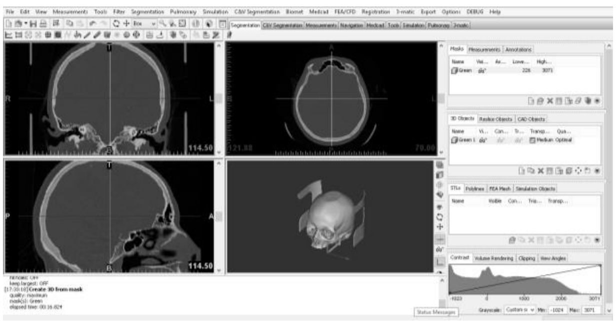

Fig. 4 The .stl surface obtained after the transformation of tomographic images into the Mimics program.

The .stl surface can be automatically transferred to the second module where the geometry can be converted into editable surface into CAD programs. The interface of the 3-Matic Medical module is shown in Fig. 5.

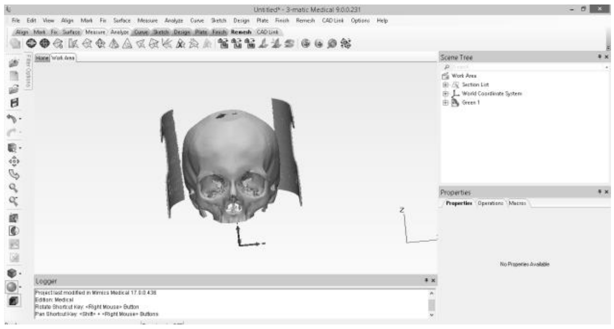

Fig. 5 The interface of module 3-Matic Medical.

After application of a series of procedures and software techniques, the mandible end model shown in Fig. 6 was obtained. These removal operations of certain components of the model were carried out in order to obtain a simpler model and a high degree of accuracy. Also, various components have been used that have been taken from multiple sets of tomographies. Because some of the studied patients did not have complete dentition or some had pathological dental problems, only models of almost ideal dental geometry were introduced into the model [7], [8].

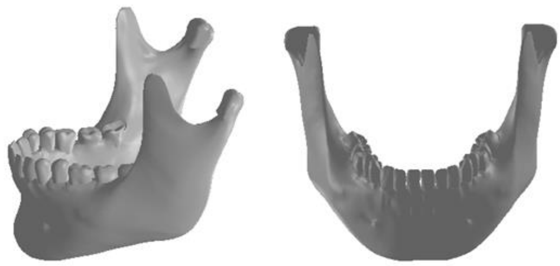

Fig. 6 The final model of mandible.

Using some "smoothing" software techniques the model obtained the final skull model shown in Fig. 7.

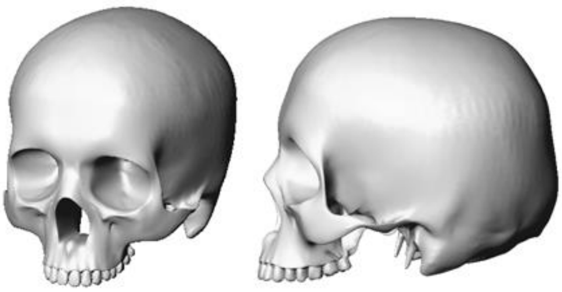

Fig. 7 The final model of the skull.

In order to achieve the three-dimensional model of the dental-maxillary device, the Assembly module of the SolidWorks program was used. The two main bone components were loaded in an Assembly session. To achieve the Multi-Body model, motion constraints were made such that the joints of this dental-maxillary device were approximated by biomechanical rotation and translational couplings so that the main motions were possible. In Fig. 8 is a model of the dental-maxillary apparatus, a model that has been used for various simulations of this biomechanical system [3], [7], [8].

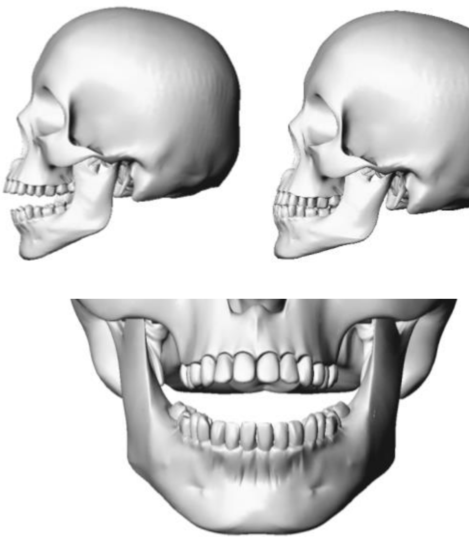

Fig. 8 The final model of the "ideal" analyzed system.

4. EVALUATING RESISTANCE FORCES DURING THE MAIN MOVEMENTS OF THE MANDIBLE

The Multi Body model allows the performance of the skeleton of vertebrates and soft parts to be estimated. It is a simulation technique used to study the behavior of biomechanical systems that have significant flexibility. This simulation method assumes that the deformation of the structure does not affect the dynamic behavior. Even though the structure is somewhat flexible, it is considered rigid, and flexibility is used to evaluate internal forces and deformations. The method also allows the study of tensions or stress in tissues during chewy functional movements.

To determine the amplitude of the resistance forces during occlusal contacts, we started from the assumption that the teeth have occlusal contacts during the propulsion, retropulsion, right and left lateral movements, and the mandible lift movement.

For this, a kinematic simulation of each of the mandibular movements mentioned above was performed and the amplitude of the reaction forces at the level of the upper premolars (24,25) was determined. The dental-maxillary model was automatically transferred to the Motion and Dynamic Motion module. In this program, kinematics (working joints) and free kinetic couplers (non-working joints) were established for each movement. These laws of motion went to the simulation for a second [7], [8].

Simulation of these mandibular movements did not take into account the force of muscle contraction, the amplitude of the forces being determined by the properties of the tissues that are part of the dental-maxillary apparatus and the skull.

Kinematic simulations were made for all of the above-mentioned movements. For example, the simulation of the lateral movement that requires the highest loading of the dental-maxillary apparatus was detailed.

For lateral movement, the virtual motor couples defined in the analysis program are the linear and rotary motor of the mandible to move lateral and vertical (Fig. 9) [7], [8].

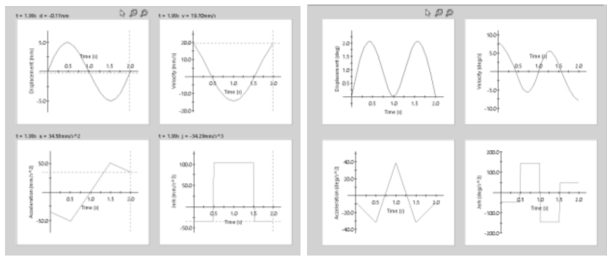

Fig. 9 The variation of kinematic parameters in the mandible's virtual motors.

With these defined motion laws, the two-second simulation was completed. A first result was the simulation movie. Thus, the following important points presented in Fig. 10. The simulation film was presented for the interval t = 0 sec. up to t = 2 sec.

Fig. 10 Five important sequences of the analyzed movement [3,8,9].

After running the simulation, the entire kinematical and dynamic behavior of the dental-maxillary device can be obtained for the lateral movement of the mandible. Thus, Fig. 11 shows the temporal variation of the resistance force at the level of the premolar 24 during occlusal contact in the lateral movement of the mandible [7], [8].

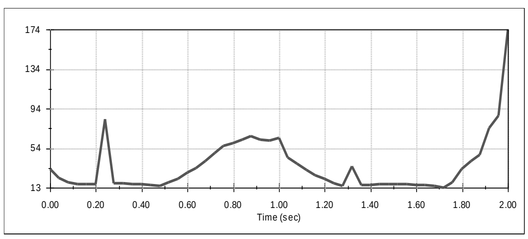

Fig. 11 The temporal variation of the resistance force at the premolar 24 during occlusal contact in the mandibular lateral movement.

5. CONCLUSIONS

This study provided a three-dimensional model of the dental-maxillary device by scanning a corpse skull and 1256 CT and MRI images from 8 patients.

Several software have been used in the three-dimensional reconstruction of the dental-maxillary device: SolidWorks, Geomagic for SolidWorks, "smoothing" software, Assembly module, Multi-Body module.

Surfaces obtained from scanning and reconstruction have been transformed by applying the AutoRemesh function, which allows the control of the number of triangles in a skull with editable geometry in SolidWorks CAD software, respectively a solid skull with all its components.

To achieve the Multi-Body model, motion constraints were made such that the joints of this dental-maxillary device were approximated by biomechanical rotation and translational couplings so that the main movements were possible.

To simulate these mandibular movements, the strength of the muscle contraction was not taken into account, the amplitude of the forces being determined by the properties of the dental-maxillary tissue and the skull.

This study allowed the simulation and determination of the resistance forces occurring in the dental structures (dental-maxillary components) in the functional movements of the mandible with occlusal contacts.

The value of these resistance forces was comparable to the value of occlusal forces determined in other studies.

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Authors:

Mihaela VATU, Assistant Professor, University of Medicine and Pharmacy of Craiova, Faculty of Dentistry, E-mail: mihaela_vatu@yahoo.com.

Daniela VINTILA, Professor, Faculty of Mechanics, University of Craiova,, E-mail: vintila_dnl@yahoo.com.

Rodica MERCUT, Professor, University of Medicine and Pharmacy of Craiova, Faculty of Dentistry, E-mail: veronica.mercut@yahoo.com.

Sanda Mihaela POPESCU, Professor, University of Medicine and Pharmacy of Craiova, Faculty of Dentistry, E-mail: sm_popescu@hotmail.com.

Dragos Laurentiu POPA, Associate Professor, University of Craiova, Faculty of Mechanics, E-mail: popadragoslaurentiu@yahoo.com.

Ilaria Lorena PETROVICI, PhD student, University of Medicine and Pharmacy of Craiova, E-mail: ilaria.petrovici@yahoo.com.

Georgiana VINTILA, student, University of Medicine and Pharmacy of Craiova, E-mail: vintila_georgiana9@yahoo.com.

Allma PITRU, lecturer, University of Medicine and Pharmacy of Craiova, Faculty of Dentistry, E-mail: allmapitru75@yahoo.com.