Modelling of the stress-strain state of the lower jaw

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Abstract. Mathematical modelling is being used in modern dentistry to solve a wide range of scientific problems. The models allow one to predict and estimate the medical intervention impact during the calculations of stress-strain state of prostheses and medical devices. In the present research a mathematical model of the lower jaw, considering the individual characteristics of the geometry, properties of bone tissue and activity of the patient's mastication muscles using the finite element method is proposed. The work provides an example of determining the operational characteristics of dentoalveolar structures. The analysis of displacements, tensions, and deformations for a particular tooth as well as the selection of the implant diameter were presented as results.

1. Introduction
Active development of information technologies in dentistry leads to the fact that mathematical modelling methods become more and more common to solve a wide range of scientific problems. The usage of such methods makes it possible to predict and evaluate the impact of medical intervention when calculating the stress-strain conditions of prostheses and devices. Computer modelling allows optimization of the operational characteristics of dental structures, giving possibility to choose the most effective treatment options in each individual case. One of the main promising areas of biomechanical research is analysis of stress-strain state of human bones using computer simulation based on the mathematical modelling. The paper presents our results of computer modelling of the stress-strain state of the lower jaw based on the data of computed tomography of the bones of the facial skull. Such technique makes it possible to determine the type and optimal parameters of implants and their location in the lower jaw.

2. Objective
The aim of the research is the development of the lower jaw simulation computer model, taking into account the individual characteristics of the geometry, properties of bone tissue and activity of the patient's chewing muscles using the finite element method.

Research objectives: drawing up a biomechanical model of the lower jaw and determining the forces acting on it; development of a solid-state model of the lower jaw based on 3D computed tomography of the patient's facial skull bones using Mimics for modelling in the SolidWorks software environment; determination of stresses, displacements and deformations of the lower jaw in the SolidWorks software
environment for incisors and molars; calculation of the implant diameter and formulation of the main conclusions.

3. Modelling of the stress-strain state of the lower jaw

There are methods for modelling the stress-strain state of the lower jaw:

1) Modelling using the laws of mechanics. Schematization of the lower jaw in the form of a spatial frame is a mechanism, it can freely rotate around the hinges, until any restriction occurs (Figure 1). The lower jaw can be represented as a symmetrical frame with a symmetrical action of the chewing load $F_b$, which allows us to consider only a half of the system. The articular head of the jaw is a classical hinge, both in structure and in features of functioning. Before contact with the limiter, the lower jaw can be considered as the simplest lever mechanism. In the presence of movement restriction in the incisor area, the mechanism represents a flat statically definable frame pivotally supported at two points (in the area of the articular head and in the area of the incisors).

![Figure 1. Schematization of the lower jaw in the form of a spatial frame](image)

Muscle forces are balanced by biting force and joint responses. Estimation of the magnitude and direction as well as point of application of muscle forces is a difficult task. A significant amount of scientific researches is devoted to this problem [1-4]. In the present research they are considered to be known by magnitude, direction, and point of application according to [5]. Using this data, we can plot the direction of movement of the lower jaw muscles in space. Figure 2 shows the directions and points of application of the main muscle forces of the lower jaw during bite: force from the superficial masseter $F_1$; force from the deep masseter $F_2$; force from the anterior temporalis $F_3$; force from posterior temporalis $F_4$; force from the anterior medial pterygoid $F_5$; force from the posterior medial pterygoid $F_6$.

![Figure 2. Orientation of muscle forces in space](image)
We consider both joint reactions and static loads on the lower jaw (biting forces) to be unknown variables. Thus, since all the force factors in the chewing system are compensated, there is a static balance of the lower jaw. The conditions of static equilibrium can be written in the form of equilibrium equations of the lower jaw while biting and chewing. The solution of these equations makes it possible to determine the occlusion forces and the reaction forces in the articular head.

2) Modelling using finite element method. The model "tooth-bone tissue-implant-orthopedic prosthesis" is a complex system from geometrical and physical points of view, the calculation of which is possible only by means of numerical methods. The most convenient and effective technique is to study the characteristics of the system using software packages aimed at calculating stress-strain condition. The mathematical basis of such software systems is the finite element method [6-8].

To model the stress-strain state of the upper jaw understanding of the bite and chewing forces is required. The mass, dimensions, and coordinates of the lower jaw gravity center are determined by the analysis in SolidWorks package.

4. Results of the research
As a result of solving the equations of static equilibrium for the lower jaw, the occlusion forces on the incisors 400 N and on the molars 800 N were determined. A solid-state 3D model of the lower jaw with inhomogeneous properties obtained using Mimics 12.5 software was exported to the Solidworks 15 software environment, where finite element meshing was conducted and all further calculations were performed. The physical and mechanical properties of each finite element were set according to the experimental data presented in the literature source [4].

The grid step was set experimentally for the best image (Figure 3). As a result of statistical analysis, three plots were obtained: stresses, displacements and deformations, when force is applied in the area of the medial incisors and in the area of the first molars.

![Figure 3](image_url)

Figure 3. Creating a mesh for finite element calculation

We have constructed diagrams of stresses, displacements, and deformations for the molars. The stress of the lower jaw bone tissue during chewing is greatest in the area of molars and premolars and does not exceed 230 MPa. The displacement of bone tissue in the area of molars and premolars does not exceed 0.023 µm, while the elastic strain of bone tissue does not exceed 0.008 µm (Figures 4-6).

Using the finite element method in the SolidWorks software package, we can clearly see how stresses, displacements, and deformation are distributed under the influence of the biting force in the medial incisors and the chewing force in the first molar. We also managed to determine the values of these parameters, which are necessary for further calculation of the implant diameter.

Having determined the stresses on the incisors and molars, the diameters of the implants were calculated. For molars, the implant diameter should be at least 2 mm, for incisors - at least 1.4 mm.
Figure 4. Diagrams of stresses in the area of molars and incisors

Figure 5. Diagrams of displacements in the area of molars and incisors

Figure 6. Elastic deformation diagrams in the area of molars and incisors
The conducted research will be continued to determine the optimal location of the implants and their parameters.

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