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Numerical strength simulation of mandibular osteosynthesis by means of autogenous bone graft

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Autogenous bone grafts in maxillofacial surgery becomes one of the methods which are most often applied in the treatment of pathogenic cancer changes in mandibular bones. The parts of iliac bones are mainly applied as the transplanting material. The method, unfortunately, produces relatively high percentage of unsuccessful operational cases. It results in the resorption of the transplanting bone material, bone necrosis or inflammatory states. Those phenomena predominate mostly in the areas of contact of two kinds of bone material: iliac bone graft and mandibular hard tissues. The aim of the paper was to examine whether or in which way the change of the bone trabecular architecture and the way of occlusal loadings could influence the local resorption of bone material. Numerical simulations and calculations as well as the finite element modelling were done by means of ANSYS® programme. Numerical strength analysis revealed the areas of high effort in the mandibular hard tissues due to the autogenous bone graft implementation and asymmetric way of occlusal loadings.

Key words: mandible, implant, FEM, strength

1. Introduction

Autogenous bone grafts are applied in facial surgery, mainly in the cases of pathogenic cancer changes of the mandibular bones. Occurrence of cancer tissues in the area of a mandibular canal implies the necessity of resecting that part of the mandible because those changes, due to a weak resistance of the spongy bone to the penetration of the cancer tissues, are not submitted to the medical treatment. The parts of the iliac bones are most often applied as the transplanting material [1]–[7].

In the method, we have to apply the transplanting material, whose functional adaptability making possible the change in trabecular architecture due to the post-operational distemper of the occlusal way of loadings enables a fast adaptation of the bone graft to a patient mandible. The stress distributions and the functional adaptive properties of bone seem to be fundamental to the strength properties of bone materials. These factors also have a decisive influence on the choice of a successful method of clinical treatment.

A high degree of bone material stabilization necessary for autogenous transplants (such transplants in the form of miniplates can be used in the method of fracture osteosynthesis and are commonly applied in facial surgery) is practically not accessible. Applying the above method we frequently deal with a partial resorption of the transplanting bone material, necrosis of mandibular hard tissues, inflammatory states, particularly in the areas that are adjacent to the contact zone of both bone materials [1]–[3], [8–13].

The aim of the paper was to answer the question whether or in which way the failures of the clinical method of autogenous bone graft, quite often observed in medical practice, could be a consequence of the local overloads due to postoperational change of the normal set of occlusal loadings or due to the lack of proper mechanisms of functional adaptation of both different bone materials cooperating with each other.

Numerical strength analysis of autogenous bone grafts in mandibular reconstruction was carried out by means of finite element method with the use of ANSYS® program [14]. The analysis of stress fields as well as the principal stresses' distributions were carried out for the mandible reconstructed by means of bone transplant and, for comparison, for healthy mandibular bone tissues in normal occlusion.

2. Methods

Transplantation of autogenous bone grafts becomes the optional way of operational treatment in facial surgery for serious traumatic cases or for advanced phases of mandible cancer. The case of clinical mandibular reconstruction is schematically presented in figure 1. A large oncogenic part of mandibular body, angle and ramus, has been reconstructed from bone tissue taken from the patient's iliac bone.

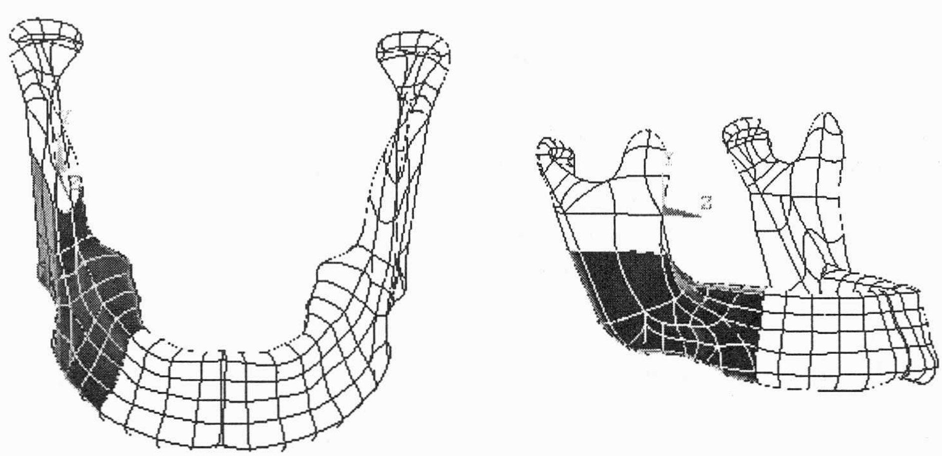

Fig. 1. Scheme of mandible reconstruction by means of autogenous graft taken from iliac bone

Numerical simulations have been done by means of finite element method ANSYS® program. A numerical model accurately representing anatomical features of mandible and simplified scheme of constrains and occlusal loadings has been designed [15]. Due to the finite element method program limitation some simplifications of the mandibular geometry itself have been done. The details of the following anatomical features were neglected: maxillary tubers, maxillary crests and alveolodental part. Those simplifications seem to have no influence upon the calculated values of effort of mandibular hard tissues. The bone tissues of the model of healthy mandible were described in terms of orthotropic mechanical properties [16], [17], while the bone graft represented isotropic strength properties of transplanted spongy parts of iliac bones [18], [19]. The average values of material strength constants of mandibular and iliac bones are presented in the table.

Table. Material properties corresponding to the hard tissues of mandibular and iliac bones

Material – mandible	E_x [MPa]	E_y [MPa]	E_z [MPa]	G_{xy} [MPa]	G_{yz} [MPa]	G_{xz} [MPa]	ν_{xy}	ν_{yz}	ν_{xz}	ν_{yx}	ν_{zx}	ν_{zy}
Orthotropy	11300	12500	20500	3900	5700	4800	0.43	0.23	0.24	0.45	0.41	0.37
Material – bone graft	E [MPa]						ν					
Isotropy	8000						0.33					

A scheme of distribution of constrains and loadings is based on literature data. An interaction of two main groups of mandibular muscles, i.e. masseters and temporomandibular muscles cooperating in occlusal and mastication activities, has been considered. Numerical calculations have been done for both mandibular models: healthy mandible and mandible with bone graft implanted. For the first case the total symmetric occlusal loading of 700 N was divided, respectively, into 250 N transferred by temporal muscles and 450 N transferred by masseters. It corresponds to the literature which defines the ratio of both muscles groups in occlusal activities as, respectively, 36% and 64% [20]. For mandible with the bone graft implanted, the total occlusal force of 700 N was one-sidedly reduced by ca. 80% due to a partial resection of the masseters muscles' attachments removed together with the cancerous mandibular hard tissues. So, the model was loaded with a total asymmetric occlusal force of 520 N. For both models the rigid constrains were applied in the alveolar part of the mandible, while the occlusal forces were applied in the areas of mandibular angle and condyle according the anatomical features of a proper occlusion.

3. Results

The results of numerical calculations are presented in the form of the maps representing the strength and effort of various anatomical parts of healthy and implanted mandible, and particular attention being paid to the planes of anastomosis of both bone materials. The effort of mandibular bones is represented by the von Mises equivalent stress σ_{red} as well as by means of maximal principal strain ε_1.

Figures 2 and 3 present, respectively, distributions of the von Mises equivalent stress in the parts of mandibular body and ramus in the cases of healthy and implanted mandibles. In the first case an occlusal loadings result in a symmetric stress distribution, while bone graft transplantation (at asymmetric occlusion) induces a strong increase in the effort of the implanted iliac bone tissues with reference to relevant original mandibular hard tissues.

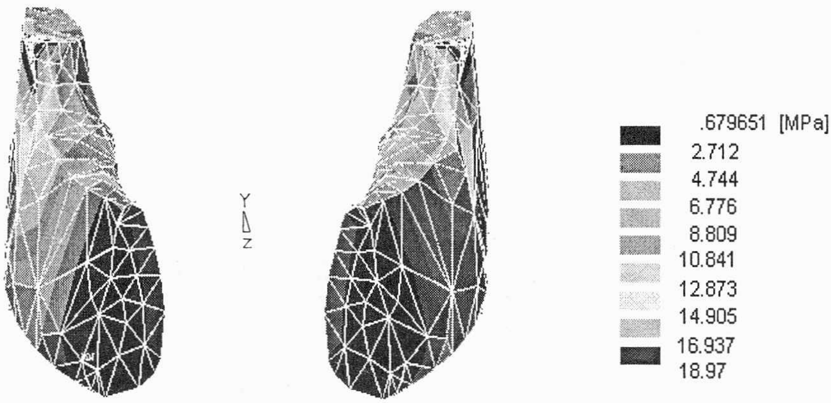

Fig. 2. Distribution of the von Mises equivalent stress in a part of a ramus of reference ("healthy") mandible – symmetric occlusal loadings

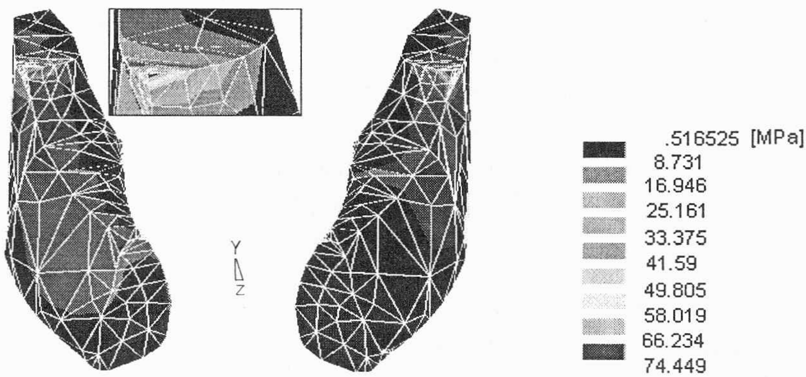

Fig. 3. Distribution of the von Mises equivalent stress in an autogenous implant (left) – antisymmetric occlusal loadings

On the other hand, figures 4 and 5 illustrate distributions of the von Mises equivalent stress in the genial and condylar parts of the mandible. Both figures show a comparison of hard tissues' effort, respectively, in reference ("healthy") and implanted mandibles. In the case of autogenous bone transplant, an essential increase of stresses, particularly in the areas of anastomoses' planes, has been observed.

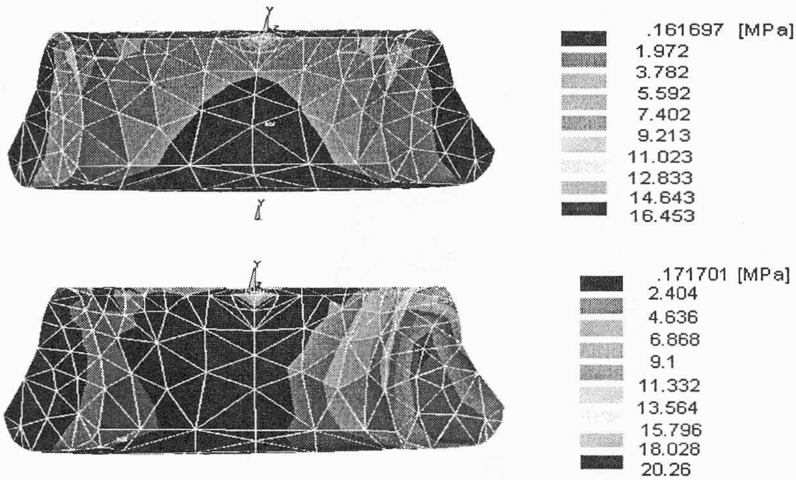

Fig. 4. Stress distributions in a genial part of the reference and implanted mandibles represented by the von Mises equivalent stress

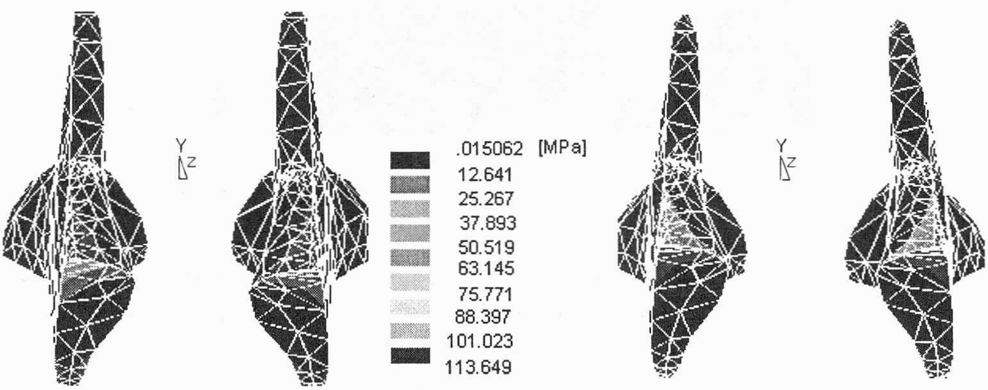

Fig. 5. Stress distribution in a condylar part of the reference and implanted mandibles represented by the von Mises equivalent stress

The same feature is presented in figure 6. The effort of hard tissues of the implanted mandible has been assessed in terms of the hypothesis of the maximal principal strain ε_1.

4. Discussion and conclusions

• In the mandible with a transplanted autogenous part of iliac bone graft, the character of stress fields changes in comparison with the "healthy" mandible. The change mainly manifests itself as the local increase of stress values in mandibular bones within the areas of transplantation. The increase of effort in a genial part of mandible is relatively smaller (by ca. 20%), while in the condylar part, above a mandibular angle, the increase is almost twice as great.

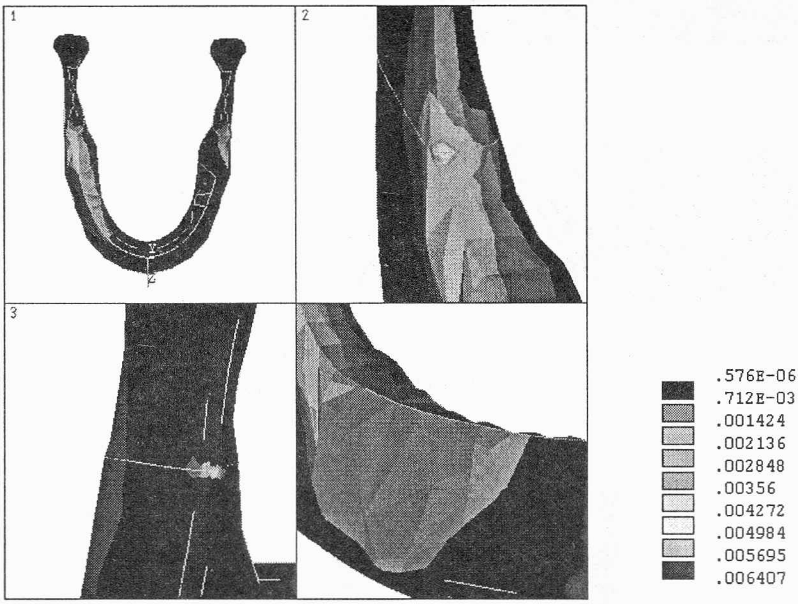

Fig. 6. Distribution of the maximal principal strain ε_1 in the implanted mandible with a particular regard to the midsurfaces of two kinds of bone material

• The areas of increased effort are also typical of nearly whole transplanted autogenous iliac bone. That effect is observed neither on the opposite site of the reconstructed mandible nor in "healthy" mandible. In this case, the effort of hard tissues of autogenous iliac bone graft, especially in the area of mandibular oblique line, increases more than twice.

• The increase of bone effort occurs mainly at the implanted site of the mandible, where the effect of asymmetric way of occlusal loadings is particularly visible. It is due to the lack of the occlusal forces as the result of the partial resection of masseter muscles at this site of mandible. The changes of the stress values and distributions are most intense in the areas of the contact of both different bone materials cooperating with each other.

• Stress concentrations affect mainly the areas of the mandible, where the resorption of the transplanting bone material as well as the necrosis of mandibular hard tissues are observed in a clinical practice. So, the numerical simulations and calculations, currently done, can explain in terms of the strength the failures of the mandibular reconstruction method by means of autogenous bone grafts, relatively often observed in the facial surgery practice.

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