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Finite element analysis of mandible equilibrium depending on the way of its loading and supporting

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Results of FEA of mandible equilibrium and mandible without one-sided support at temporomandibular joint were presented. Models were loaded with occlusal forces whose values were experimentally established. Forces of muscles were simulated by elastic supports with an assumption that reactions would lead to active forces generated by the system of muscles.

Key words: finite element analysis, mandible, loading, muscles, equilibrium

1. Introduction

Of head muscles, the masseter and the muscles of the floor of the mouth are those that directly influence the mandible. The latter are of importance while swallowing, straining the fundus of the oral cavity, lifting the tongue and lowering the mandible. Those muscles were excluded from further deliberation due to their little influence on the temporomandibular joints' loading while eating. It has been assumed that when biostatics is taken into account, the masseters are of vital importance. These very strong muscles attached to the mandible on one side and to the scull on the other generate active forces necessary for biting and chewing the food. Passive forces are generated in the temporomandibular joints and at the points of interdental contact during biting the food. In many cases, clinical observations show that the functioning of the mandible is possible in spite of upsetting the passive force symmetry due to the loss of the head of the mandible or even to the whole candyloid process. Although it is clear that equilibrium can be reached by the change of the values of active forces

system when one support is lacking, the share of individual muscles in this process has not been clearly defined so far. In the presented paper, an attempt has been made to evaluate the forces necessary to ensure the stability of the mandible, making use of model research carried out by means of a finite element method.

The masseters are located both outside (the temporal muscle and the masseter) and inside the mandible (the medial and lateral pterygoid muscles), which practically makes it impossible to carry out an experimental study of the degree of their tension. It is equally difficult to analyse the reactions in the temporomandibular joints. Only the occlusal forces between the opposite teeth are easy to be measured. These forces were defined by the authors by means of a method described in their earlier studies [1], [2]. The method was based on the correlation between the force pressing a spherical penetrator into an aluminium sample and the diameter of the imprint. In order to analyse the mandible equilibrium, its three-dimensional models supported at elastic bonds at the points of joints and insertions of individual masseters were constructed. First, models of both healthy and damaged mandibles were loaded on the dental curve with occlusal forces defined in the clinical research. This part of the study allowed a qualitative evaluation of the phenomenon studied. Then, the models were loaded with a force of an assumed constant value, which aimed at making a quantitative evaluation possible with elimination of an error resulting from a lack of comparable populations of people included in the research with healthy temporomandibular joints and joints deprived of the head.

Although the response of the bonds keeping the model in equilibrium is very likely to be different from the actual tension of the muscles controlled by the central nervous system, in the authors' opinion the results obtained allow us to reach the assumed goal of the study which is to specify the role of the individual masseters in ensuring the mandible equilibrium.

2. Methodology and research results

A three-dimensional pattern of the fibres [3]–[5] of the muscles named above indicates that the forces generated by them while biting can be in any case resolved into the components working along the axes orienting the following planes: frontal, sagittal and horizontal. This observation creates the basis for fixing, at the points of masseter insertions, the systems of elastic bonds directed along the axes located in relation to the mandible in the way shown in figure 1. Similarly, the reactions substituting the effect of the temporal part of the joints on the head of the mandible were resolved, yet in order to map the equilibrium with a one-sided lack of the head of the mandible, these bonds were removed from the left side of the model.

During the calculations the model was loaded with forces exerted subsequently on the places of teeth: 1 – right second molar tooth, 2 – right canine tooth, 3 – middle incisor, 4 – left canine tooth, 5 – left second molar tooth.

In the research based on the measurements carried out in clinical conditions, for a healthy mandible the average values of the occlusal forces rounded down to 50 N were assumed. For a mandible without support in the temporomandibular joint, such values of forces were assumed as the ones measured with a patient with a full dental curve who had lost the left head of the mandible due to a car accident two years before. These values in the subsequent points amounted to 254, 182, 98, 196 and 296 N. Another patient had lost the head of the mandible and the ability to bite with the incisors three and a half years before the occlusal force was measured. This patient, whose canine teeth and first molar teeth took on the function of the incisors, agreed only on the measurement of the forces between the molar teeth.

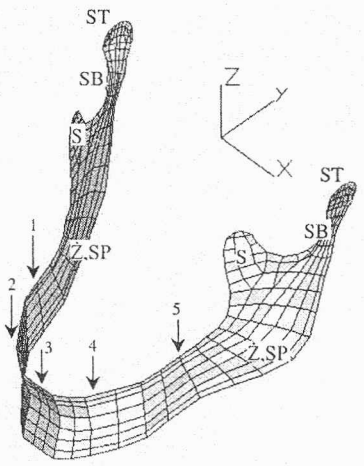

Fig. 1. Mandible model with points of occlusal force application and bonds placed at the points of temporomadibular joints (ST), and muscles insertions: SB – lateral pterygoid, S – temporal, SP – medial pterygoid, Ż – masseter

Although the results obtained have not been taken into account in the calculations, the authors of the study find it purposeful to give their values which are 682 N with loading of the healthy side and 748 N with loading of the side without the mandible head. These results are placed in the top ranges obtained by healthy patients. As one can notice, in spite of considerable differences in the value of the force, in both cases a bigger loading was transferred while biting with the side lacking a joint.

Having made the calculations for each imposed loading, the values of individual components of the reaction maintaining the mandible in equilibrium were read out, moving from the right to the left side of the dental curve. The results obtained are shown in the form of diagrams presented in figure 2A (for the healthy mandible) and 2B (for the mandible without support in the left joint). The letters R and L in the diagrams denote the right and left sides, respectively.

Analysing the curves obtained one can see that the reactions of the bonds working along the *X*-axis for the healthy mandible have very small values at the points of the joints. Yet, the components *X* on the working side are definitely smaller than those on the balancing side. The component *X* behaves similarly at the points of temporal muscle insertions. This value is only slightly higher than the values of the reactions in the joints. The unloading of the working side is also observed at the points of insertion of the lateral pterygoid muscle. However, in this case the values of the forces exceed the values of the forces in the joints more than five times. The components *X* defined in the area of the insertion of the masseter and the lateral pterygoid muscle reach maximum values (the same as for the lateral pterygoid muscle) while loading the molar teeth. Moving into the area of the incisors makes the component *X* drop almost four times. The component *Y* at all points of the support had almost flat characteristics

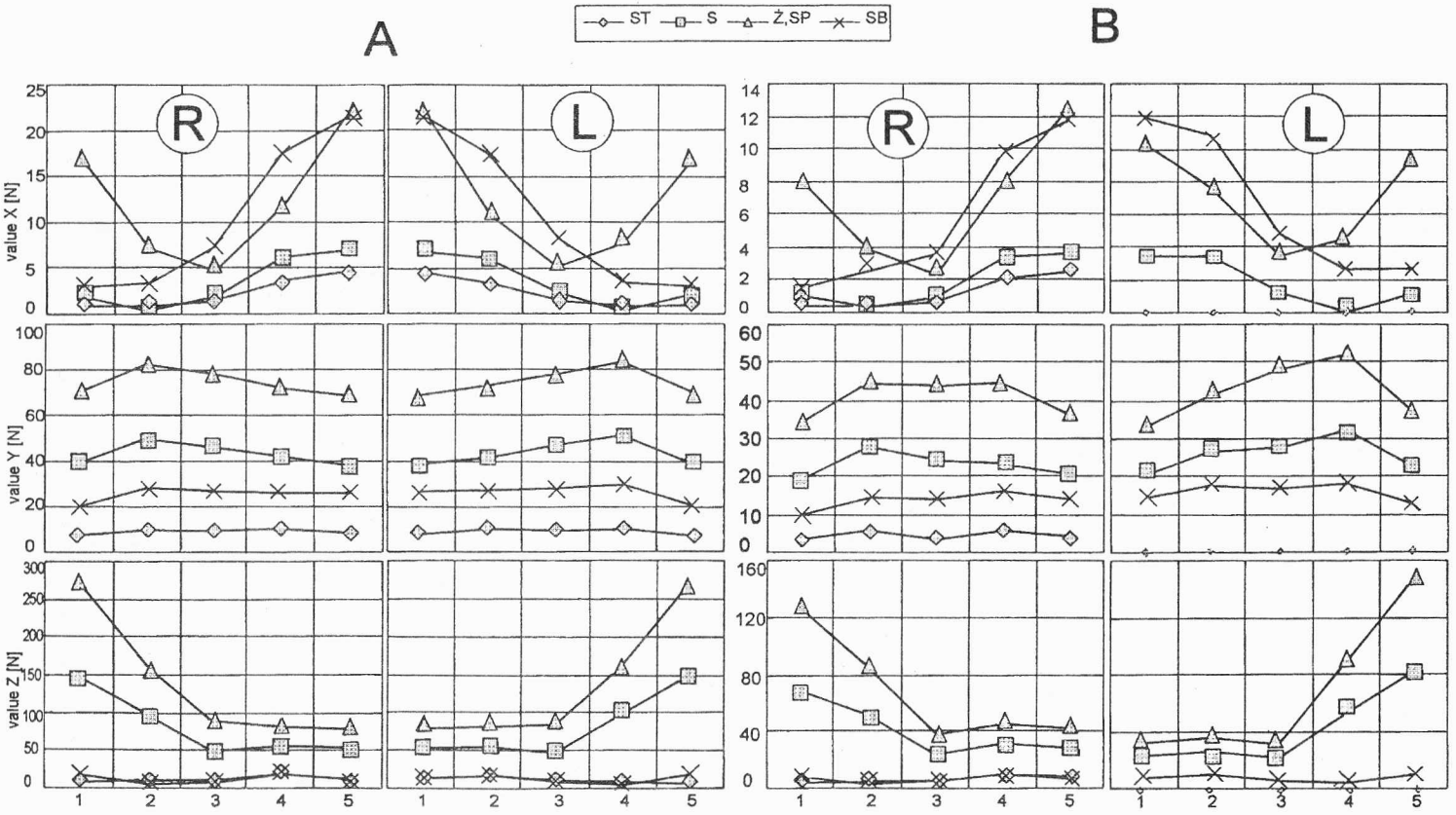

Fig. 2. Values of the reactions on the right side (R) and left side (L) maintaining the mandible equilibrium. A – healthy mandible, B – mandible without support in the left temporomandibular joint. Points of occlusal force application on the places of teeth: 1 – right second molar tooth, 2 – right canine tooth, 3 – middle incisor, 4 – left canine tooth, 5 – left second molar tooth. Places of record: ST, and muscles insertions: SB – lateral pterygoid, S – temporal, SP – medial pterygoid, Ż – masseter

showing small value drops at loading of the molar teeth and increases at loading of the canine teeth. The smallest values of the reactions were in the temporomandibular joint; higher values were reached by the reactions at the points of insertions of the lateral pterygoid muscle and then of the temporal muscle. Definitely the biggest values of the reactions directed along the *Y*-axis were obtained at the points of insertions of the masseter and the medial pterygoid muscle. In the author's opinion the latter response of the model analysed to a given loading can be far different from the actual state. The components *Z*, like in the previous case, showed the smallest values in the joints. Practically, the reactions at the points of the lateral pterygoid muscles' insertion agreed with them. Maximum values occur at the points of insertions of the masseter and the medial pterygoid muscle on the working side at molar teeth loading. The more one moves into the area of the incisors, the lower their values. At the same time the reactions on the balancing side remain on the fixed level. The components *Z* have a similar course, at lower values of the forces, at the insertion points of the temporal muscle.

Evaluating the reactions that maintain in equilibrium the mandible without support in the left temporomandibular joint, we have to remember about the values of the occlusal forces changed according to the results of clinical examination. Thus, the analysis of the diagrams was limited to the evaluation of the change of their shapes in relation to the healthy mandible, without taking into account the calculated values of the reactions. The characteristics of the change of the components *X*, *Y* and *Z* on the right side is similar to that of the healthy mandible. On the left side, in the case of the component *X*, it is only the diagram shape at the point of the temporal muscle insertion that remains unchanged. At other points of support, the values of the reaction *X* increase when the left side becomes the working side. The components *Y* at the points of the insertions of the temporal muscle and the masseter increase when the left incisor is loaded, whereas at the point of the insertion of the lateral pterygoid muscle their values increase for the loading variants from 1 to 4, and they slightly decrease when the left molar tooth is loaded. All components *Z* increase when the left side becomes the working side.

In order to improve the readability of the phenomenon studied, the definition of the reactions for both models considered was repeated, assuming for all variants of loading a constant force value of 100 N. This allowed us to prevent the effects of a change of the loading value from overlapping the effect of removing one of the supports, which allows a quantitative evaluation of the changes of individual reactions. The results obtained are shown in figure 3 constructed in the same way as figure 2. Comparing the diagrams illustrating the components of reactions maintaining the models of the "healthy" mandible in equilibrium, we see that loading of the mandible along the dental curve with a constant force value caused significant changes of their shapes. Bending downwards of the curves illustrating the changes in the components of reactions *X* occurrs on the balancing side, whereas the components of reaction *Y* show a distinct maximum when the incisors are loaded and we can observe an increase in the value of the component *Z* reaction for the following muscles:

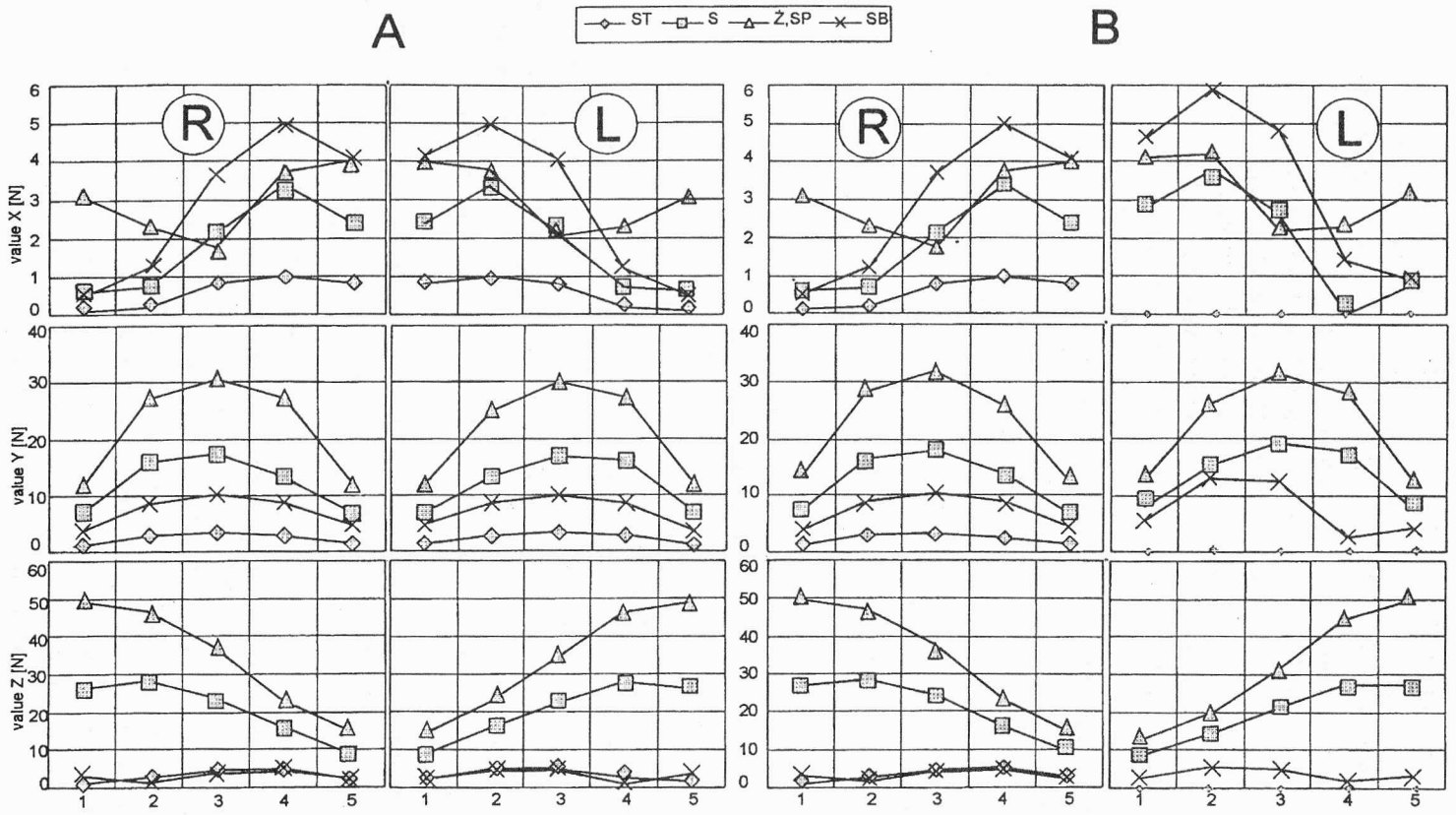

Fig. 3. Values of the reactions on the right side (R) and left side (L) maintaining the mandible equilibrium. A – healthy mandible, B – mandible without support in the left temporomandibular joint. Points of force 100 N application on the places of teeth: 1 – right second molar tooth, 2 – right canine tooth, 3 – middle incisor, 4 – left canine tooth, 5 – left second molar tooth. Places of record: ST, and muscles insertions: SB – lateral pterygoid, S – temporal, SP – medial pterygoid, Ż – masseter

temporal, masseters and medial pterygoid ones with a simultaneous bending of the curve upwards. Assessing the changes of reaction values caused by the lack of support in the left joint we see that at this side of the mandible almost all reaction values go up. The biggest increments occur at the point of the medial pterygoid muscle insertion. At the time when the left side is the balancing one, the component X increases by 18%, Y – by 40% and Z – by 21%. At the time when the left side is the working side, the component X increases by 30%, Y – first decreases and then grows by 13%, and Z increases by 50%. The increasing reaction values at the other points fluctuate in most cases between 2 and 10%, exceeding this limit only for the components X and Y working at the point of the temporal muscle insertion. On the right side supported at the point of the temporomadibular joint the changes of reaction values visible on the plot can be regarded as insignificant.

3. Conclusions

The research results presented in the study, although imperfect, constitute the basis for continuation of the experiment and allow us to draw the following conclusions:

- The reactions occurring in the temporomandibular joints of the models tested have small values compared to the occlusal loading imposed. This fact accounts for the possibility of mandible working with one deffective joint.
- Assuming that the reactions of the bonds placed reflect the influence of masseters on the mandible, we can say that without support in one of the joints the equilibrium of the mandible model under consideration is maintained mainly by the change of forces generated by the lateral pterygoid muscle on the side of the damaged joint. The temporal muscle participates in a lesser degree in substituting the lacking joint.
- With the method applied no significant influence of the masseter and medial pterygoid muscle on stabilisation of the damaged joint has been detected.

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