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Influence of tongue activity on lower complete denture retention under biting forces

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Tongue activity constitutes a helpful factor in using complete dentures. It has not however been identified, to what extent the force of the tongue can directly stabilize the denture during the occurrence of biting forces. Dislodgement force of the denture held by the patients tongue shows a significant dependence on the tongue strength efficiency, however only few patients are able to analyze the mechanisms of using their tongues to stabilize the denture. The results of the FEM analysis show that the tongue has a strong advantageous influence on denture lateral stability during chewing and also during biting, and a slightly lower ability of counteracting the denture destabilization towards the front. The role played by the tongue in denture retention is not only that it locates the denture by means of tactile sensation but also that it supports the forces counteracting denture dislodgement.

Key words: tongue activity, denture retention, biting forces

1. Introduction

During chewing by means of mucosal supported complete dentures a continuous activity of tongue, lips and cheecks takes place, which is performed in order to move and distribute bits of food on the occlusive surfaces of the reconstructed teeth [1]. These phenomena result from individually developed skills [1]–[8], enabling the retention of the denture on its foundation. The role played by these phenomena in denture retention as well as the possibility of developing additional skills that are favourable for using the denture observed in some patients have not been quantitatively determined yet. Using tongue and lips in order to hold the denture becomes particularly important in the case of difficult denture retention conditions such as alveolar ridge atrophy and not resilient mucous membrane of denture bearing area [8]–[11]. However, the influence of the tongue, due to its higher movement-force efficiency, is more significant for bio-static conditions of denture retention on its foundation.

In this study we assess the influence of tongue activity on lower denture stability under unilateral biting forces in the area of molar teeth and during biting in the area of canine tooth, by means of the FEM analysis. This study also assesses, in clinical conditions, the relations between the strength of the tongue and the force necessary to dislodge the denture off its foundation.

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2. Research methodology

2.1. Finite Element Modelling of denture stability with and without tongue support

The success of model studies depends on the method of reflecting object's characteristics that are significant for the phenomena analyzed. Hence, it becomes crucial to precisely identify the boundary conditions in a way that allows us to obtain numerical data. This points out the trends that decide about the biostatic conditions of the denture foundation. Because of that a virtual experiment has been carried out for the disadvantageous retention conditions of a denture, i.e.: lower denture – atrophy of the alveoral ridge – model view (figure 1-VI); membrane thickness of ca. 0.7 mm. For the purposes of that simulation the shape of the edentulous mandibular arch was re-constructed in a simplified manner. The linear elastic isotropic mechanical properties were assumed. For the mucous membrane the Young's modulus of 3 MPa has been assumed (at the Poisson's coefficient reaching $\nu = 0.49$). For the cortical bone the Young's modulus $E = 17$ GPa has been assumed, whereas for the spongy bone $E = 600$ MPa, and for the denture's acrylic resin $E = 2000$ MPa with Poisson's coefficients $\nu = 0.3$.

For a numerical experiment to be successful, loading forces acting on the denture must be appropri-

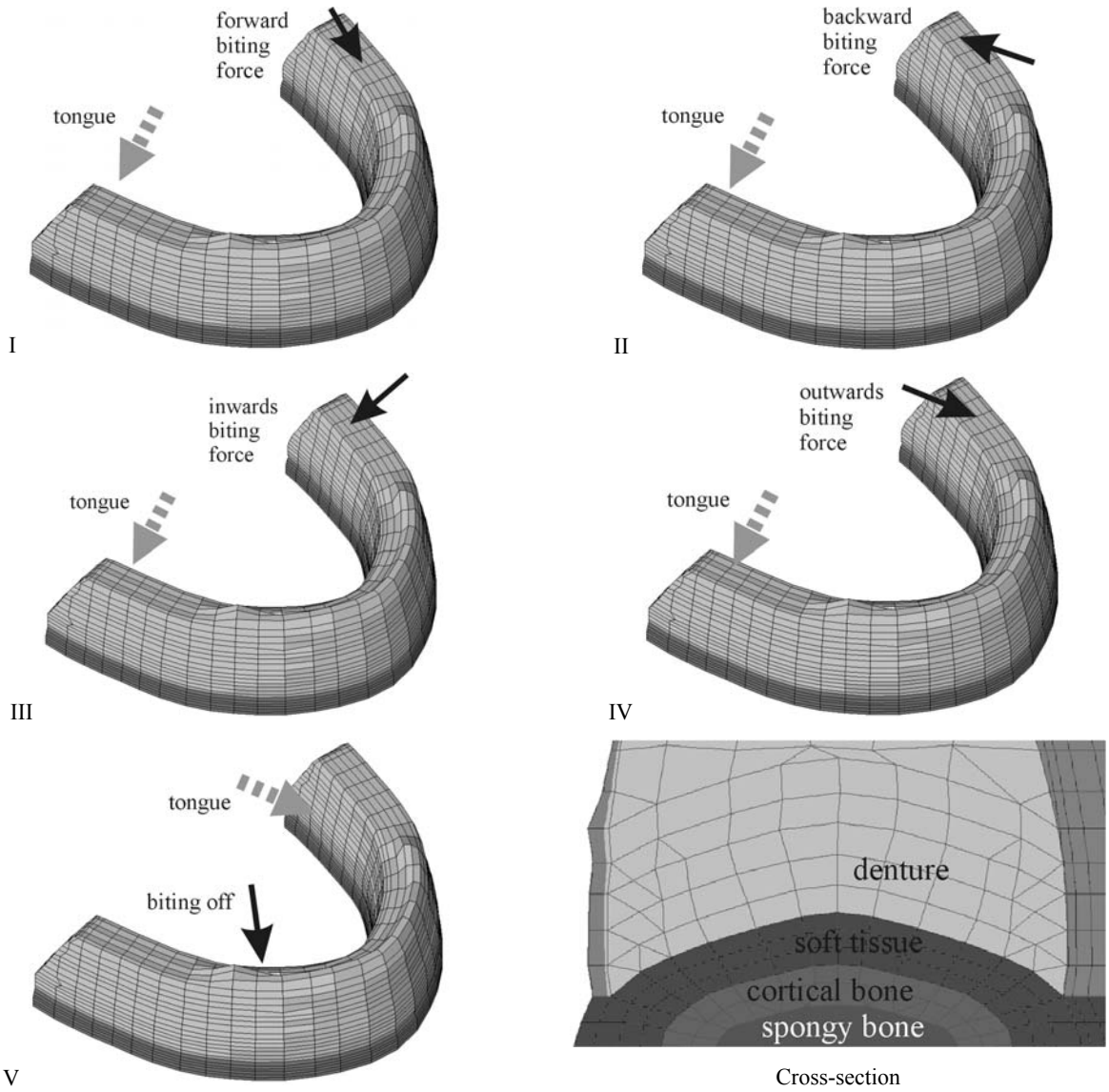

Fig. 1. Variants I–V of loading with biting forces and with an additional tongue force. Cross-section shows the system of layers and the shape of foundation

ately assumed. During the contact between teeth and food there do occur some dynamic changes in loading on cusps. The direction of the resultant force might vary with time causing denture's spatial displacement. In calculations, we assumed the selected hypothetical causes of 50 N forces pressing on the molar tooth cusps at the angle of 45 degrees.

A large angle has been assumed in order to make force's destabilizing influence as disadvantageous as possible. Additionally, we assumed two cases of loading acting in the direction in the frontal plane, and one acting in the saggital plane along with their accompanying, adequately to the chosen situation, stabilizing tongue activity. It was presumed that the tongue is able to act with the force of 15 N on the denture flank surfaces at the balancing side, in its frontal plane – at the oblique angle of 45 degrees. The holding at the loaded side was also analyzed, however this action did not bring such effects as it did at the balancing side. Hence, none of these analyses have been presented here. The value of the tongue acting force has been assessed on the basis of the authors' own studies (see clinical part for explanations). The evaluated model, taking into consideration marking of load cases, is shown in figure 1, where:

I. Biting force directed obliquely towards the front area (figure 1-I).

II. Biting force directed obliquely towards the rear area (figure 1-II).

III. Biting force directed obliquely inwards (figure 1-III).

IV. Biting force directed obliquely outwards (figure 1-IV).

Apart from the loading of 50 N biting forces in the area of molar teeth that simulate chewing, biting pieces of food were also considered, taking into account the characteristic for complete dentures, excluding incisor teeth from the biting process.

V. 50 N force applied obliquely on the outer side of the arch in the area of canine tooth, under the simultaneous pressing the denture by the tongue at the balancing side in the area of molar teeth (figure 1-V).

The case, where only the biting forces act on the denture, was compared with another case, in which additionally the holding tongue force acts on the denture. It should not, however, be forgotten that the total adherence of the denture to its foundation was presumed. Hence, the stresses achieved on the surface of the mucous membrane, caused by the denture displacement, have not yet led to denture's dislodgement, although their distribution enabled us to assess a potential destabilization.

2.2. Clinical research

The measurement of the tongue pressing force towards the frontal area has been carried out in a group of 128 denture users (average patient age: 64.5 years; average denture exploitation period: 6.5 years), all having difficult denture foundation conditions resulting from the atrophy of the alveolar ridge. Afterwards, a horizontal force dislodging the denture has been measured, after instructing the patient to hold the flank of the denture with his or her tongue in the area of molar teeth as hard as possible. A dislodging force has been applied in the area of incisor teeth and a catch was placed between the tooth's saddle and the base.

3. Results

The results of numerical calculations in the form of stress patterns on the surface of mucous membrane are presented in figures 2 to 4. In the case I, the holding of the denture (figure 2) results in stresses decrease at the balancing side on the lingual slope of alveolar ridge from 20 kPa, which might cause denture dislodgement off the mucous membrane, to –76 kPa. On the other hand, in the area of molar teeth at the loaded side, a slight decrease in pressure has been observed. In the area of the canine tooth, the positive stresses remain at the level of almost 60 kPa.

In the case II (figure 3), in which the biting force pushes the denture backwards, tongue activity causes an advantageous increase in pressing force at the balancing side with –23 kPa from the level of –121 kPa. In the area of canine and incisor teeth, from the loaded side a detachment takes place, which in the case of tongue activity increases from 89 kPa to app. 109 kPa. However, taking into account the fact that the denture could have been detached in this part anyway, then in the case of tongue activity, despite loosing its adherence in that area, the denture still has a better chance to retain its stability.

In the case III (figure 4), where the biting force is applied on the front plane acting obliquely towards the inner parts of the ridge, holding the denture with the tongue causes an advantageous increase in pressing force at the balancing side in the area of canine tooth from –120 up to –142 kPa. The advantageous effects outweigh a slight disadvantageous increase in detachment forces in the area of canine tooth on the loaded side from 84 to 95 kPa. The area of acting the pressing force is broadened, which

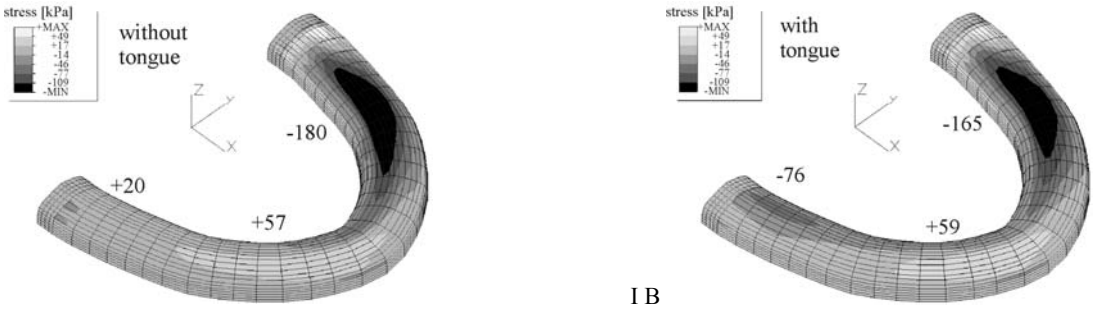

Fig. 2. Comparison of stresses on mucosal surface under biting forces in the saggital plane directed obliquely towards the front area without tongue activity I (A) and with tongue holding activity I (B)

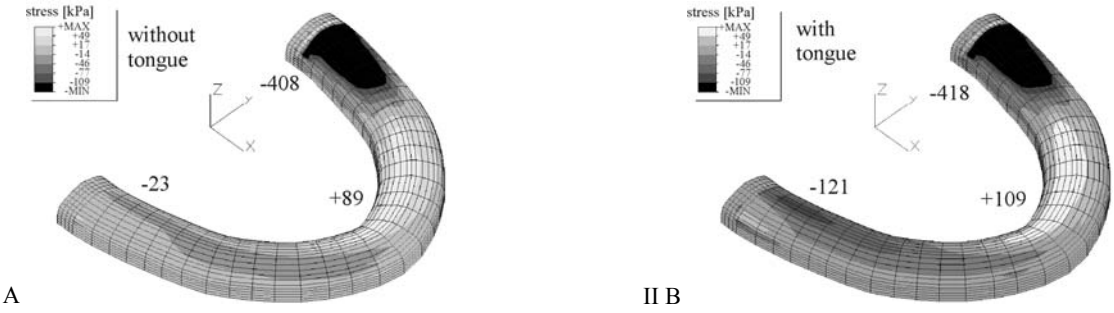

Fig. 3. Comparison of stresses on mucosal surface under biting forces in the saggital plane directed obliquely towards the rear area without tongue activity II (A) and with tongue holding activity II (B)

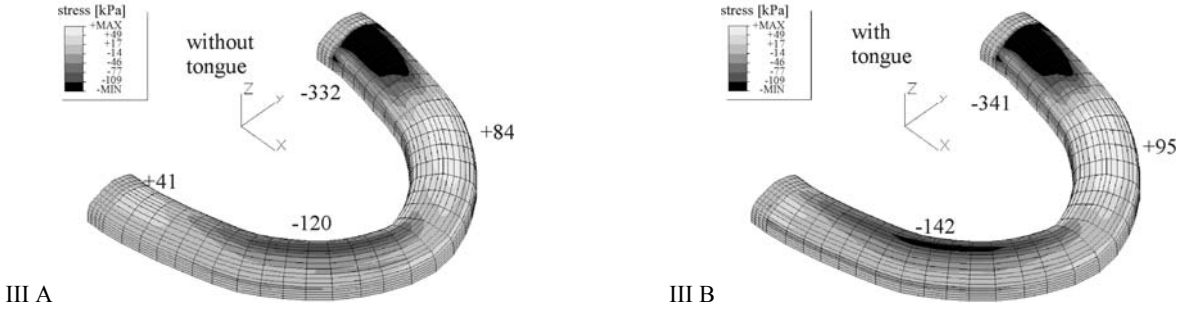

Fig. 4. Comparison of stresses on the mucosal surface under biting forces in the frontal plane directed obliquely towards the inner part without any tongue activity III (A) and with tongue holding activity III (B)

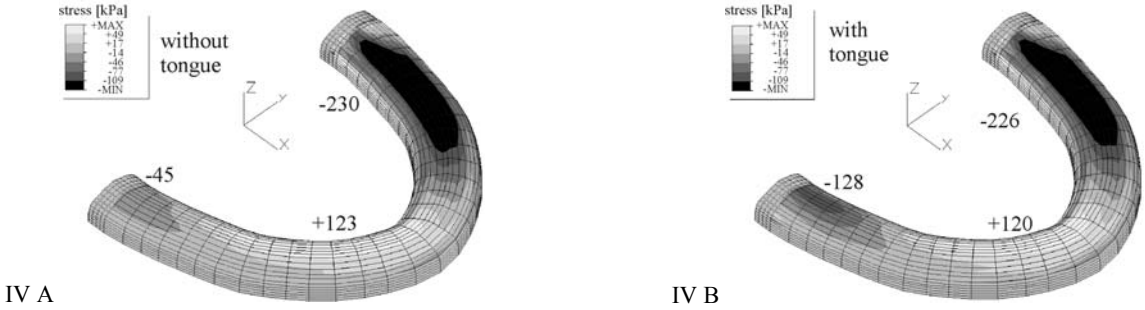

Fig. 5. Comparison of stresses on the mucosal surface under biting forces in the frontal plane directed obliquely towards the outer part without any tongue activity IV (A) and with tongue holding activity IV(B)

causes the vanishing of the detachment at the balancing side that previously reached 41 kPa in the area of molar teeth.

In the case IV (figure 5), where the force is applied in the frontal plane obliquely towards the outer part of the ridge, holding the denture with a tongue

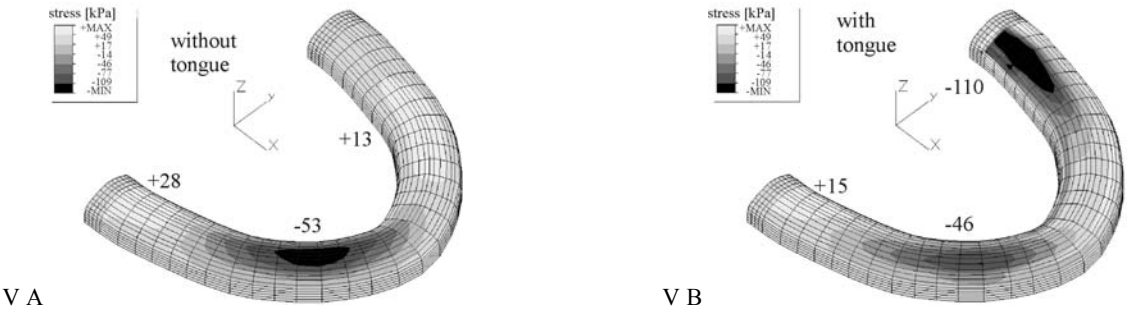

Fig. 6. Comparison of stresses on mucosal surface during biting processes: without any tongue activity (V A), with tongue holding activity (V B)

causes a strong advantageous increase in the force pressing on the denture to its foundation in the area of molar teeth at the balancing side – from –45 up to –128 kPa. However, in the area of canine tooth the disadvantageous detaching stresses remain, reaching app. 120 kPa.

A similar advantageous stabilizing influence has been observed during biting processes (figure 6), as the tongue force pressing the denture's flank at the balancing side causes the occurrence of significant loadings of –110 kPa instead of detaching forces of 13 kPa, from the lingual side of alveolar ridge slopes.

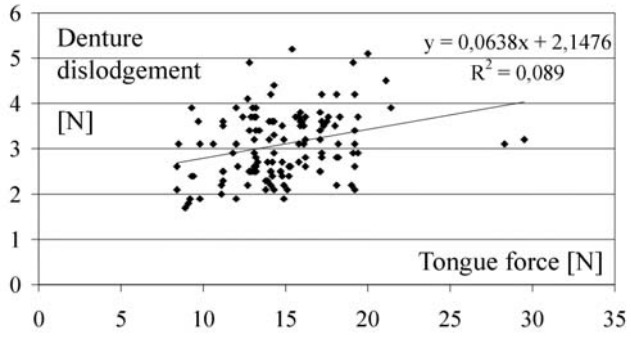

Fig. 7. Clinically measured dislodgement force versus tongue strength in the case of pressing the flank of the denture towards its foundation

The average measured value of tongue strength directed forwards equalled 14.8 N (standard deviation: 3.4 N), with limit values of 8.9 N and 29.5 N. The results of the clinical studies presenting relations between tongue strength and the denture dislodgement force in the case of "holding" the denture with the tongue are shown in figure 7. The force required to destabilize a denture held by the tongue is significantly higher in the case of higher efficiency of tongue strength.

4. Discussion

In the real environment of the oral cavity, there do exist changeable denture loading and support conditions. What is changeable are the locations and directions, in which biting forces act, the amount and viscosity of saliva, the shape and resilience of foundation as well as the neuro-muscular efficiency in the area of facial-cranium. On the basis of the clinical studies of denture detachment forces and tongue mechanical efficiency, a relation between the analyzed parameters has been found. Although, the changeability of these individual factors brings the clinical examinations only to pointing out the statistical significance of the given phenomena. On the other hand, an unequivocal determination of the role that tongue plays in denture retention during chewing requires a physical description of the phenomena examined by precise biomechanical criteria. The numerical methods that allow us to keep the experiment conditions settled are irreplaceable here. A basic advantage of model simulation studies is that they enable us to control denture loading and supporting in a way that is not achievable in the oral cavity. The limitations of model studies resulting from numerous simplifying assumptions should not however be forgotten. In the studies carried out, although the case of the foundation that causes most difficulties during prosthetic procedures has been analyzed, its shape has been idealized. The linear mechanical characteristics of mucous membrane were also introduced. Due to these facts, at the current stage, the phenomenon of denture dislodgement was analyzed as a state of a momentary balance, in which for the purposes of simplification, the phenomena of soft foundation shape changes resulting from the temporary deformations have not been taken into account. An ideal denture adherence to its foundation has been presumed, while the determination of values of forces

causing denture dislodgement was neglected, which was dictated by the limitations of the calculation technique (i.e. difficulty to achieve reliable results and convergence after the introduction of contact phenomena in complex models, where there was a strongly variable elasticity of the contacting surfaces [12], [13]). Generally, the assumed conditions for models and evaluation criteria, i.e. stresses perpendicular to mucous membrane surface, allow us to compare denture model destabilizing tendencies in the case of loading it only with biting force with the case where during chewing the denture is also additionally influenced by tongue forces. The studies based on FEM analysis are mainly focused on the determination of occlusive transfer to the prosthetic foundation [12]–[16]. The authors do not know any publication, in which an attempt has been made to simulate the retention conditions and to determine unequivocally the evaluation criteria of denture retention in its foundation, hence a direct comparison of the simulation carried out with other FEM analysis results in that field is not possible.

No precise data related to force values, which tongue generates in the assumed holding directions, has been found, hence all the directions and values have been presumed in a rated manner, on the basis of the general data published in the professional literature [16], as well as on the basis of our own clinical measurements. The method of holding a denture was presumed on the basis of an assumption that a stabilizing influence should be based on tongue pressing denture flanks at the chosen side: loading or balancing. Practice shows that the best, in this aspect, is the balancing side, because the tongue influences denture stabilization in this area the most. The results of the numerical analysis confirm quantitatively the advantages of using the tongue for the purposes of increasing the lateral denture stabilization, on which the chewing efficiency depends. In addition, during biting the tongue strongly counteracts denture's destabilization.

The results of the model analysis explain, to some extent, the strong relations observed between the ability of the oral cavity organs and the increased efficiency of chewing by means of dentures [1], [7], [12], [17]–[20]. However, it has to be taken into account that the higher tongue strength and efficiency do not necessarily have to result directly in a skillful utilization of the denture, just as in the case of the jaw muscles ability, biting forces, foundation parameters or the denture itself [19], [21]–[29]. In order to present the whole phenomenon, we also have to analyze the ability to feel the momentary denture destabilization tendencies and to appropriately coordinate all muscles on the basis of signals transmitted, both by the tongue and the remaining soft tissue [2], [9], [20], [30]–[38]. It should be emphasized here that the tongue activity during biting is not a natural reaction, because at that moment the tongue naturally ceases any activity [1], [30], [38], [39]. The mechanical receptors of the oral cavity tissue have up to 40% straitened influence on masseter activity as compared with 70% of periodontal ligament receptors [38]. After losing this perceptual abilities along with the loss of teeth, not all of the patients (left on their own with only some too general instructions) are able to develop appropriate techniques of using the denture and the lack of any development of these skills during the adaptation process can be observed quite often [1], [5], [19], [40]–[42]. In the case of a long period of edentulism, as well as along with age, an additional difficulty is caused by the loss of muscles activity and tissue arrangement [8], [43], [44]. It is hard to determine precisely to what extent the reactions described depend on patients' will and how they can be shaped in that period, nevertheless the strength and efficiency of oral cavity organs can be improved [2], [45]–[47].

The physical evaluation of tongue importance for denture stabilization presented in this study and the clinically observed huge, if not deciding, influence of oral cavity and jaw muscles coordination on the skill of utilizing dentures show the direction of further studies. The training methods should be further investigated [45], [46] in order to develop individual skills of the active correction of a denture position and to select dentures' biomechanical characteristics [48]–[50] that would, for particular individual features of the chewing system, support a stabile denture retention in a manner that avoids any randomness.

5. Conclusion

1. The role played by the tongue in denture retention lies not only in the ability to locate the denture by means of tactile sensation but also in supporting the forces counteracting denture dislodgement, which was physically identified through the model experiment.

2. The results of the studies proved the purposefulness of searching for the solution in the manners, in which the tongue surface of denture's flanks is shaped, which should enable utilization to the possible maximum the supporting pressing force of the tongue.

3. In order to increase the individual tongue ability to stabilize denture in practice, it is necessary to de-

termine the possibilities and methods of developing muscles activity completely different from those before the loss of teeth.

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