Acta of Bioengineering and Biomechanics
Vol. 14, No. 3, 2012

Original paper
DOI: 10.5277/abb120309

The influence of a complete lower denture destabilization on the pressure of the mucous membrane foundation

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The results of previous studies on the pressures beneath the mucous membrane-supported dentures are contrary to the prevailing pain sensations and discomfort reported in practice. In this work, a FEM analysis of large displacements was used for calculation of the contact stresses beneath a lower denture that accompany destabilization under the realistic oblique mastication forces and stabilization of a non-working flange at the balancing contacts. The pressure on the surface of a mucous membrane beneath a denture that was loaded in a stable manner with a vertical occlusal force of 100 N was lower than the pain threshold. It was even more surprising as the extremely unfavorable lower denture foundation conditions were selected for this analysis. The lateral mastication forces destabilized the denture by means of tilting it and reducing its supporting area. Significant pressures calculated for the destabilization are consistent with the clinically observed decrease or a complete lack of chewing efficiency in the cases of unfavorable foundation conditions. A fundamental importance of the balancing contacts for the chewing efficiency was confirmed quantitatively. A remarkable development which has been achieved in the modeling of the denture functioning conditions is crucial for further biomechanical investigations of the mucous membrane-supported dentures, as well as for the implant-retained dentures.

Key words: *contact, denture pain, Finite Element Method, force, pressure, stress*

1. Introduction

Patients afflicted with the edentolouism usually wear less expensive, conventional dentures. Such dentures, also called the mucous membrane-supported dentures, function on the mucous membrane that covers edentulous processes of the denture foundation. Most of the patients wearing this type of dentures suffer from pain [1], [2]. Injuries to the soft tissue of denture foundation are numerous. Their rate reaches 15–20% [3]. The mucous membrane stomatitis, which is very difficult to cure, is also indirectly caused by the mechanical overloading [4], [5]. The mucous membrane overloading is mainly related to the lower denture. It intensifies especially for unfavorable foundation conditions.

The reduced number of the soft tissue injuries and pain sensations depend on a correct determination of the transmission of occlusal forces. In spite of numerous studies on biomechanics of the mucous membrane supported dentures, satisfactory determination of the mucous membrane loads is still lacking [6]. Pressures beneath the denture do not explain the reported pain sensations. Values of the pressure beneath the denture determined by means of various methods [6]–[8] are significantly lower than the pain threshold [9], [10], which is contrary to the clinical observations [1]–[5].

Kinesiographic study shows [11] that dentures experience large displacements during the transfer of mastication loads that do not result from the misfit to foundation but from specific lower denture working conditions. These specific working conditions are caused by the lack of a stable location on the founda-

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Received: November 22nd, 2011
Accepted for publication: May 26th, 2012

tion under mastication loads without the balancing contacts. The contacts are responsible for the lower denture balance by means of supporting the balancing flange with a more stable upper denture [1], [11]. The examination of dentures in excessively stable loading conditions might lead to an underestimation of pressures on the mucous membrane surface. The influence of the pressure sensors located under the denture on the manner of mastication has not been determined yet, although it can potentially disturb the measurement. This lack of determination of the loads beneath denture, which accompany destabilization typical of mastication, justifies further studies. A finite element method (FEM) model analysis [12], [13] was chosen for the purposes of the studies due to the limits of experimental determination of denture displacements and tissue loading.

The aim of this study was to verify the hypothesis that the lower denture causes remarkable mucous membrane overloading resulting from destabilization of the denture under oblique mastication forces. A detaching and sliding of the denture on its foundation significantly increases mucous membrane overloading, which results in pain sensations in the case of unfavorable foundation conditions.

2. Materials and methods

The finite element method nonlinear analysis with a large displacement formulation was used for determination of denture displacements during the destabilization under oblique mastication forces and the accompanying pressures beneath the denture. Denture biomechanics were modeled with the possibility of denture detaching and sliding on the surface of the mucous membrane foundation. Both interacting bodies were assumed to be deformable. The augmented multiplier Lagrangian method with an implemented classical linear friction model was used for calculations of the contact at the mucous membrane interface. The friction coefficient was assumed to be approximately 0.16 [14], [15], along with the lost denture adherence to the foundation when there are no negative interfacial normal stresses. The relatively low adhesive forces omitted in the contact calculation play a secondary role during denture destabilization by inducing incomparably higher forces during mastication.

The geometry of denture foundation was assumed based on the average of dozens of impressions reflecting characteristic foundation atrophy with a "knife-edged" crest. A common shape for the edentulous processes was assumed for the entire foundation. The model was designed with the CAD software (Autodesk Inventor™) and exported to a FEM software as surfaces. Computer modeling on the basis of computer tomography (CT) or magnetic resonance imaging (MRI) makes it possible to achieve precise individual models. However, the CT method requires that organisms be exposed to radiation, which cannot be justified by the purposes of the present paper only. Such exposure would also require a permission of an appropriate commission. Moreover, it would necessitate a search for cases that are representative of the selected type of foundation conditions. Thus, all local imperfections would have to be corrected before discrertization. A better control of the meshing of contacting surfaces is available in engineering calculations software.

The automatic generation of tetrahedral finite elements gives contact stresses of poor quality. The finite element discretization results in a non-unique representation of a normal between the contact surfaces because the normals are not continuous between the elements [16]. Reduction of the mesh size resulted in more time consuming calculations and concentration of stresses around the unfavorably positioned contact elements. The reason for that is the lack of control on the normals of the contact elements. The best way of eliminating the irregularities of contact stress patterns is to use a coherent mesh in the contact zone. The anatomical uneven surfaces make it complicated to achieve coherent meshes. Nevertheless, if the initial contact surfaces are known, then achieving a coherent mesh is possible by means of a special preparation and trim of contact surfaces in the CAD software. Finally, the contact bodies were divided into the linear hexahedral 8-node elements (ANSYS™ "185-brick"), for which the freedom of movement did not exceed computational capabilities of the computer system available. Contact stiffness was adjusted to a more compliant mucous membrane. The contact stiffness matrix was updated in each equilibrium iteration with a contact detection at Gauss points. Figure 1 shows the discretization of the contacted mucous surface that can be used for calculations that are less time-consuming and that make it possible to achieve the Newton–Raphson solution convergence.

Only a segment of the mandibular bone arch that constitutes the denture-supporting zone was represented in the model. Mandibular bone deformations play a secondary role because of the incomparably larger strains on the soft mucous membrane foundation (the modulus of elasticity in relation to a spongy bone is over 100 times lower, whereas in relation to a cortical bone it is thousands of times lower). The analysis testing the aforementioned assumption showed that omitting the bone in calculations using a model fixed at the bone interface did not influence the results to a significant extent. A precise mapping of tooth shapes, which unnecessarily increases the size of numerical analysis, was evaluated as not required.

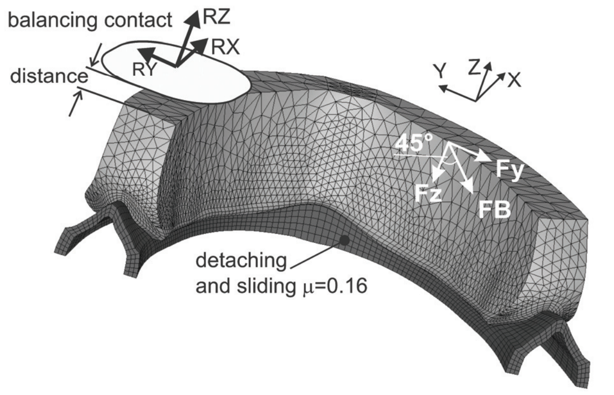

Fig. 1. The FEM model of a mucous membrane-supported denture with a view of the mucous/denture interface discretization with quadrilateral elements and a hexahedral brick mesh. Scheme of the analyzed loads: the occlusal vertical force (“Fz”) or the olique mastication force (“FB”), the balancing contact with a distance (vertical gap 0.1 or 1.0 mm) and reaction on the balancing contact

The denture-loading conditions that reflect oblique occlusal mastication forces were assumed. At the first stage, a vertical force ”Fz” of 100 N was applied in the premolar zone. Then, in the second step, a laterally oriented horizontal force ”Fy” of 100 N was applied in order to achieve oblique mastication loads ”FB” of 141 N at an angle of 45 degrees in the frontal plane. Analysis of the occlusal loads located on incisors can be excluded for the case of the mucosal-borne dentures. A balancing contact with the opposing occlusal surface of the upper denture was made possible at the balancing side. Two variants of distances between the dentures were assumed. In the first variant, the distance to occlusal surface of the upper denture was set to 0.1 mm, whereas in the second variant to 1.0 mm. Interactions of the balancing contacts with the opposing denture were simulated with the assumed possibility of sliding, e.g., on a food bolus with the salivary lubrication.

The linear isotropic elastic mechanical characteristics were assumed [17]–[22] in order to simplify the calculation procedures of large displacements. The mucous membrane during the chewing process works mainly in the elastic range. An unfavorably “hard” 0.5 mm thick mucous membrane, described by Young’s modulus E = 5 MPa [23] was assumed; its incompressibility was, to some extent, represented by a high Poisson ratio ν = 0.49. The denture material was described by E = 2000 MPa and ν = 0.3.

3. Results

The analysis conducted resulted in denture displacements, contact stresses and a slide on the mucous membrane beneath the denture. The results are shown in the form of distributions in figures 2–4 depending on the load caused by the occlusal force as well as by the distance to the balancing contact. Apart from the scale for the total displacements, the displacements were shown at three control points. At all the three control points the vertical displacements were negative if a vertical occlusal force was applied. Hence, the denture settled down on the foundation also at the balancing side. In the case of an oblique mastication force the denture faced greater displacements. The settlement took place at the working side only. It has reached the value close to –0.1 mm. The loaded side slid in the posterior direction (negative ”X’ and ”Y” displacements). Denture lifting occurred at the balancing side. The distance to the opposite denture was eliminated and the denture was supported on the balancing contact. Reduction of the distance to the balancing contact decreased the slide by half

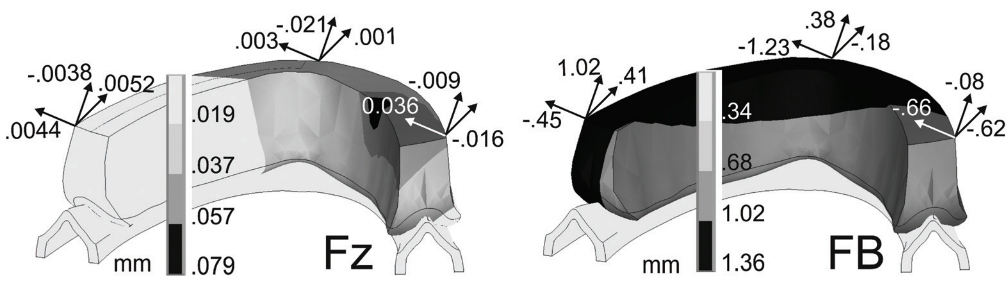

Fig. 2. Denture displacements depending on the loading by the occlusal vertical force (“Fz”) or the oblique mastication force (”FB”). The distance of 1.0 mm to the balancing contact

(figures 3–4). The reaction on the balancing contact increased for a smaller distance (figure 4). The stresses beneath the denture also decreased from 2.9 to 2.12 MPa. The decrease of contact pressures resulted from the increased contact area.

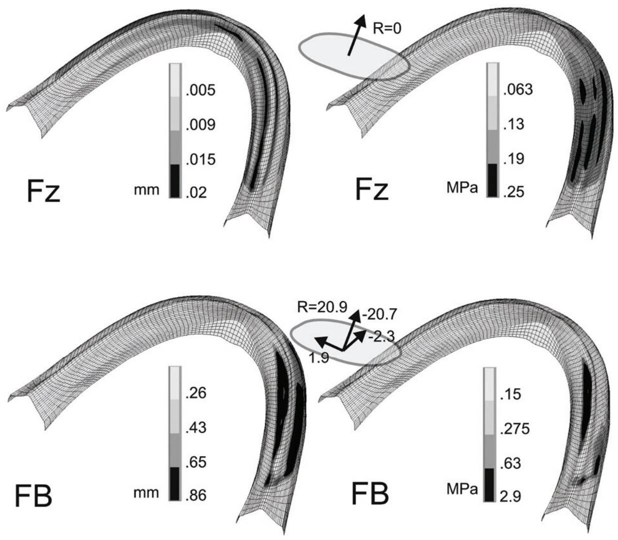

Fig. 3. Values of the slide (mm) and the contact stresses (MPa) on the mucous membrane interface and the reaction force (“Fz”) and the mastication force (“FB”). The distance of 1.0 mm to the balancing contact

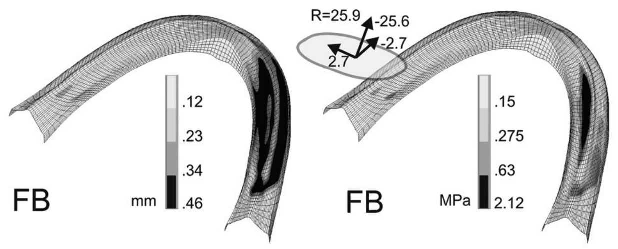

Fig. 4. Values of the slide (mm) and the contact stress (MPa) on the mucous membrane interface and the raction force (“R”) at balancing contact for the simulated mastication force (“FB”) for a smaller distance of 1.0 mm to the balancing contact

4. Discussion

The reliability of the numerical models was verified by means of compatibility evaluation of the calculated values and available results of the test on pressures beneath dentures and clinical observations. A compatibility between the calculated pressures and the available results of experiments obtained in conditions of a stable transmission of vertical occlusal forces was confirmed. Denture stick was observed in a significant area beneath denture for the vertical occlusal forces; also at the balancing side. The highest stresses under the denture reached 252 kPa. In paper [24], stresses beneath the dentures caused by the 100 N vertical force measured in the lab reach 80 kPa on alveolar slopes at lingual side and 250 kPa at the buccal side. In paper [25], stress values reached 310 kPa, whereas in paper [7], occlusal vertical force of 50 N on the alveolar process slopes at the working side causes stresses of 21.1–214.1 kPa. Taking into account the influence of the differences in foundation and occlusal loads on stress values, there is a visible convergence between the calculations and the measured values.

Nevertheless, stresses on the level of 200–310 kPa do not explain pain sensations as the pressure pain threshold in lateral edentolous mandible processes is remarkably higher. The pain threshold is at the level of approx. 630 kPa [9], [10] (force of 2 N divided by the pressure area of the indenter – 2 mm in diameter). Creating pressure at the threshold level in a situation of stable denture pressing on its foundation would require 2 up to 3 times higher vertical occlusal force. Whereas, in practice, the opposite tendency is observed, i.e., occlusal forces and chewing efficiency decrease for unfavorable foundation conditions due to the pain sensations felt on the foundation.

In contrast to the vertical occlusal force, the impact of the oblique mastication force lead to remarkable denture displacements, detaching and sliding. Denture was tilted towards the applied occlusal force. The flange at the balancing side was lifted, whereas in the remaining areas the denture no longer stuck to the foundation but was sliding on it. However, the denture was not dislodged off the foundation thanks to the contact with the opposing denture at the balancing side. The slope in the canine zone at the lingual side was most exposed to the frictional injuries due to the simultaneous pressure and a large sliding. The balancing contact conditions influenced the loading under the denture. Significantly lower pressure and sliding values were determined for the variant of the smaller distance to the balancing contact. Remarkably higher denture displacements were observed together with the increased distance in the range up to 1 mm. Hence, the sliding on the mucous membrane increased two times up to the value close to 1 mm, whereas the pressure that accompanied the sliding has reached almost 3 MPa.

The numerically calculated pressures were significantly higher than those previously described in other studies. The pressures beneath a destabilized denture have notably exceeded the pain threshold. They exceeded the threshold by 4.7 times, which means that pain sensations should also be expected in the case of more favorable foundation conditions. Contrary to the model studies presented in paper [8], the model behaved according to the real clinical observations of the lower dentures during mastication, i.e., a specific foundation slant is not necessary until a remarkable slipping occurrs. Due to the assumed restraints of the model symmetry with respect to the sagittal plane, the model conditions presented in paper [8] significantly deviate from the real conditions. These restraints block the freedom of denture lateral displacements. The occurrence of oblique occlusal forces was a sufficient condition for sliding. The denture displacements calculated for the model correlate with the oral cavity measurements [11], in which displacements accompanied the loads in the area of the first molar reaching 1.1 mm.

The underestimation of pressures in the previous studies results from an insufficient projection of the typical denture loading conditions. Recording pressure values beneath the denture is basically related to individual patients. If the selected denture is difficult to destabilize, the pressure values are remarkably underestimated as compared to the average pressure values observed in the case of other denture wearers. Correctness of the present analysis and model behavior not only confirms convergence to pressure measurements for a stable loading with vertical forces and compliance with displacements that accompany chewing but it also confirms the pain threshold to be remarkably exceeded. The prevalence of pain during chewing for unfavorable foundation conditions was successfully explained.

The methodology presented enables a quantitative verification of the common denture manufacturing principles based on the stabilization of lower denture by means of the occlusal contacts at the balancing side [1], [26], [27]. A better denture stabilization observed for the smaller distance between occlusal surfaces confirms the importance of the bilateral food comminution ability or at least the ability to distribute the food symmetrically between flanges. Food located at the balancing side reduces lifting of the flange and the denture's tilt. It results in limiting both sliding and pressures beneath the denture, which reduces pain sensations and a tendency to develop frictional injuries. Detaching the balancing flanges from the foundation does not denote directly a dislodgment of the whole denture. It is crucial for the efficiency of chewing to develop the ability of "finding" denture stabilization on the balancing contacts. The variety of directions of occlusal forces that destabilize the denture in real oral cavity conditions makes it more difficult to develop the above mentioned skills that is a typical problem for movement rehabilitation of non-repeatable activities.

It should be mentioned that development of remarkable mastication forces might be eliminated by too high pain sensations (2–3 MPa) that occur in the case of unfavorable foundation conditions. The upper tolerance limit for pain caused by the pressure is not defined in the literature. A decrease of chewing efficiency caused by the pain sensations is observed in the cases of unfavorable foundation conditions [28], [29]. The results of the calculations are consistent with the above-mentioned fact. The estimated proportional calculation shows that it is necessary to reduce the oblique occlusal force resultant to 30 N in order to decrease the pressure beneath the denture to a level of the pain threshold. A force of at least 50–110 N [30] is necessary to comminute most of the food.

Results of the calculations also explain the differences in chewing efficiency between cases characterized by similar foundation conditions. For the conditions analyzed, food mastication with forces that remarkably exceed 100 N without pain sensations would only be possible if the lateral forces were minimized. A development of an appropriate chewing technique depends on the individual motor-ability. The lateral physiological movements of mandible conducted in the last mastication phase constitute obstacles to achieving this ability. Some of the patients cannot develop a technique different than the physiological one. Therefore, the study of the less expensive single-implant retained dentures [31] and denture-to-implant elastic attachments [32] made of antifungal silicone [33], [34] is necessary.

Further studies should investigate what other forces, apart from the occlusal loads, influence the injuries of the soft tissue. Especially, loads resulting from the misfit of denture saddles to foundation should be examined. Hence, the contact stresses generated on the surface of the mucous membrane as a result of denture manufacturing inaccuracies have to be investigated in detail.

5. Conclusions

The high usefulness of the FEM simulations of large displacements and contacts is of fundamental importance for the development of modeling biomechanics of the mucous membrane-supported dentures. The lower foundation loading that was measured for the smaller distance to the balancing contact confirms the importance of the ability to comminute food bilaterally. The compressions beneath the denture were transferred in conditions of a slide on the mucous membrane, which is in accordance with the clinical observations of the frictional sores. The possibility of evaluating stresses and slide beneath dentures is crucial for further denture design with the individual fit to the foundation and occlusal conditions.

Acknowledgements

This research was completed with financial support of the Polish Department of Science and Higher Education (MNiSW), under project number N N518 425636.

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