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Loading of overdenture attachments under simulated biting forces

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ABSTRACT

Purpose: The basis for effectiveness evaluation of over-denture attachments is the determination of loads on supports, and denture mobility. In cases of denture stabilized on two prosthetic supports, for most of the attachments constructions that are available on the market, the margin of dentures mobility is limited to rotation around axes of the attachments.

Design/methodology/approach: Determining attachments loadings during bearing of biting forces that accompany chewing processes was carried out by means of Finite Element Method model analysis. A three-dimensional model of a denture supported on mucous membrane and joint supports assumes to be fixed in places of denture anchoring to implants. This model was loaded on one side with unilateral oblique 100 N force at molars zone.

Findings: Maximum loading at pillar accompanies biting forces acting in a lateral direction toward buccal side.

Research limitations/implications: Researches were carried out exclusively for attachments not showing any resilience in any direction, without any rotational constrains. Hence, in further researches, at the first place, determined should be the influence of the vertical resiliency used in some of the commercial attachments on loads bearing.

Practical implications: Appropriate determining of loadings levels on over-denture attachments, requires necessarily that the oblique biting forces will be taken into account. In case of an assumption of only vertically oriented biting forces, there is a significant underestimation of the most dangerous horizontal loadings of prosthetic supports.

Originality/value: Presented displacements of denture and pillars loading as vertical and horizontal reactions causing pillar bending and leverage at the bone, constitute a starting point for evaluation of denture's behavior and strength estimation of analyzed types of attachments for implants and the surrounding bone.

Keywords: Biomaterials; Denture attachment; Bone; Biting load

MATERIALS

1. Introduction

The most economical treatment of complete edentulism of mandible by means of implants are dentures types of tissue supported retained implants. Implants in this type of solution, due to used special attachments, are aimed at increased denture retention and stabilization. At the same time, attachments should improve the relief of implants and bone tissue in their anchorage area, by means of taking over the highest possible portion of chewing forces acting on posterior zone of soft tissue foundation. Although, in practice achievement of low enough level of forces transmitted by the attachment is difficult. Numerous problems, damages of attachments, abutments screws and acrylic resin around attachments` sockets [1, 2] prove an excessive taking over of loadings bearing.

Clinical success in application of implants and dentures requires complex biomechanical analysis. Already, at the stage of conceptual work related to the solution, there is a necessity of determining mechanical loadings, which will act on material in the real system, in real exploitation conditions [3-6]. In this respect, effective research tool are numerical simulations using the Finite Element Method (FEM) [5, 7, 8]. Numerical experiment makes it possible, already in the concept phase, to eliminate the less effective or completely wrong solutions [9].

The aim of this research is to determine, by means of a model experiment (FEM) the real loadings levels born by the commonly used in clinical practice, attachments without rotational constrains, for which constructional limitations do not allow the denture to settle down on foundation in the attachments zones.

2. Methodology

Mechanical effect of cooperation between a complete lower denture and two prosthetic pillars was examined by means of FEM modeling. Constructed was a numerical, three-dimensional model of soft tissue supported denture supported on alveolar ridges of edentolous mandible: Fig. 1. A simplified shape of denture foundation area with unfavorable retention conditions was assumed, that reflects the conditions of atrophied alveolar ridges. Both, thickness and shape of denture bearing area layers on the whole length of the arch remained constant.

In two points reflecting the places of denture attachment prosthetic supports, marked in Fig. 1, displacements in three directions in the assumed coordinates system were constrained. Any of the angular displacements were not constrained.

Supports have been marked accordingly to their location: L-left, R-right. R side was always the working one. An ideal adherence of denture on the interface with mucous membrane was assumed, whereas the whole model has been fixed to the bottom bone surface.

The analyzed model was loaded with oblique forces of 100 N in molars zone. Examined were two cases of resultant biting forces directions: with a component directed buccaly at the angle of 45 degrees in frontal plane (FMB) and directed forwards in the saggital plane (FMA) also at the angle of 45 degrees.

In order to simplify the calculations, a linear elastic isotropic characteristic of all model structures has been assumed. For cortical bone Young`s modulus of E=17 GPa; for spongy bone - E=600 MPa; and Poisson`s ratio equaling, in both cases, ν=0.3. Properties of denture material were described by E=2000 MPa and ν=0.3. Average elasticity of mucous membrane has been assumed; modulus of elasticity E=3 MPa; Poisson's ratio ν=0.49.

3. Results

The result of the carried out FEM analysis are the directional reaction components X-Y-Z acting on prosthetic supports and denture linear displacements in the assumed directions of coordinates system.

Determined forces values are shown in Fig. 2 according to the analyzed loads FMB and FMA variants. Absolute values of lateral forces resultant have been given (in horizontal plane „XY”) taken over by the attachment, and resulting in pillar bending. Values of „Z” axial reaction are given with a distinction into negative values resulting in pressing in bone and positive values resulting in pulling up till the moment of achieving the force level limited by attachment retention.

In Fig. 3 juxtaposed are the denture displacements read in 9 check points located on the bottom surface of saddles along the entire denture length. Displacements are shown only for the variant of lateral biting forces (FMB), as in this case, in clinical practice, there occur the biggest problems with denture stability.

Carrying out a FEM taken into account should be all the limitations resulting from the presumed modelling assumptions. In the presented research it was not possible, nor purposeful to analyze all of the cases of biting forces or individual variations of denture foundations shape. In this respect, selected were the unfavourable conditions of foundation, because the flat slopes of alveolar ridges assumed for the whole length of the mandible arch, in case of applied oblique biting force, are characterized by significantly lower ability to resist the horizontal denture displacements. Hence, in that case the highest loading of prosthetic supports is to be awaited.

Assumption of a complete adherence on denture saddles interface with foundation leads to determining, to which extent pillars are loaded in the conditions of a stable chewing using soft tissue supporting to the full and without loosing the adherence.

During chewing the resultant of occlusal forces might change its direction, which in an obvious way affects denture displacements and reactions on pillars. Due to this fact considered were the variants of oblique acting forces, which is unfavorable for pillar loading.

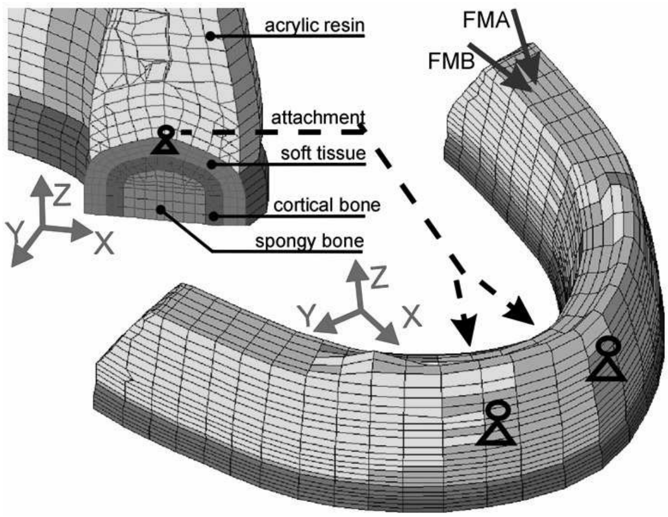

Fig. 1. Conditions of FEM model analysis

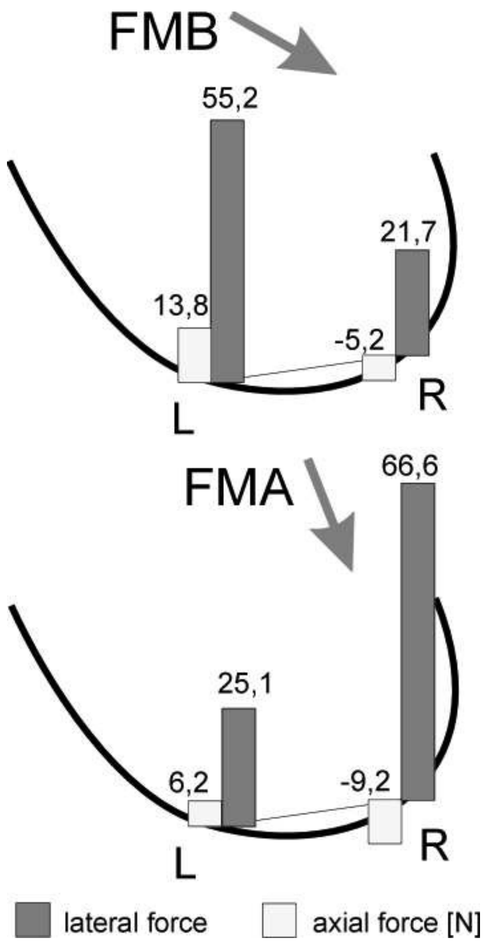

Fig. 2. Loadings on prosthetic supports for the analyzed variants of FMB and FMA biting forces

The assumed 45 degrees angle of the acting force is higher than it might be concluded from the branch literature in order to simulate extremely unfavorable pillar loading [10]. Forces values reflect the upper range for complete dentures with mucosal supporting. Assumed unfavorable hypothetical oblique biting forces that favor pushing of the denture off its foundations, enable an analysis of lateral loads, to which pillars might be exposed in real chewing conditions. Obviously, bending of pillars depends not only on lateral force, but also, to some extent on implant and attachment structure. The higher is the location of the point of the force resultant for lateral forces on pillar, the higher is the pillar bending.

Carrying out of the analysis with a full modeling of attachments and implants geometry results in a very serious increase of model complexity. Assumption of supports in place of implant significantly simplifies the model and accelerates effective determining of supports loading. Due to that the results of this analysis gain universal character. Determined loads might constitute a starting point for a strength analysis of any structures of attachments working in accordance with the given assumptions.

On the obtained displacement graphs, there is a clearly visible deficiency in denture mobility in the anterior zone in the area of attachments. These constraints of displacements do not have any significant influence on support pressing. Under FMA biting loads acting forward, borne is only the force of 9.2 N, and in case of lateral biting forces FMB: only 5.2 N. It results from the possibility of using the soft tissue supporting by means of a vertical denture settling down in posterior zones.

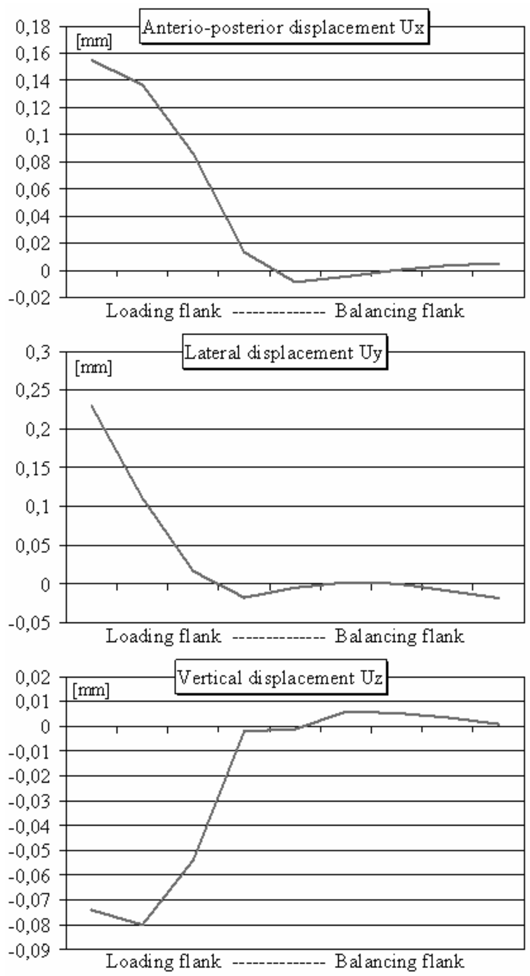

Fig. 3. Denture displacements in directions X, Y and Z under lateral biting loading on the molar (FMB)

Horizontal constrains of denture displacements result in a situation, in which denture supports bear a remarkable part of biting forces components. In case of lateral forces FMB, born are even 55 N at the balancing side, whereas, in case of forces acting forwardly (FMA) 66 N at the working side. In cases of lateral loads, most of the surface of alveolar ridges might constitute a supporting surface because of the perpendicular orientation of slopes in relation to the direction of the loading biting force.

Pillar bending loads, are particularly unfavourable ones [11-15]. Excessive leverage off the bone, causing an overload atrophy of bone tissue increases the risk of pillar exposure and even a fatigue damage of the pillar on exposed threads, which constitute notches. Even in cases of a clinical success in the aspect of implant retention in the bone, such serious lateral attachments loadings explain the causes of mechanical failures in attachments exploitation. Assuming only vertically directed biting forces results in a significant underestimation of real attachments' loadings [16]. Root-causes of attachments damages, abutments` screws and acrylic resin damages around sockets occurring commonly in clinical practice, have been identified in this research in a quantitative manner.

4. Conclusions

In the conditions of a FEM model analysis it has been proven that making possible rotational displacement on attachments, limits the possibility of using the natural soft tissue supporting function during bearing of forces that occur while chewing, which is the root-cause of direct overloading damages of attachments components and acrylic resin saddles.

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