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Attachments of implant retained tissue supported denture under biting forces

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ABSTRACT

Purpose: In implant retained soft tissue supported type dentures functioning of attachments, presented by their producers as mechanically bio-compatible because of the ensured freedom of rotational displacements is accompanied by numerous problems that seem to be caused by excessive bearing of occlusal loads.

Design/methodology/approach: For the purposes of attachments loadings evaluation, built was a three-dimensional FEM model of a denture situated on an atrophic prosthetic foundation with joint supports assumed in the area of denture attachment to implants. Analysis of attachments loadings has been carried out under unilateral oblique occlusal forces of 100N in molars and incisors zones.

Findings: Used methodology made it possible to determine attachments loading in a quantitative manner. In spite of free rotational movements implantological supports bear significant part of horizontal occlusal forces components, which reach the value of 66N during chewing processes.

Research limitations/implications: Examined was only the most commonly used type of attachments. Hence, further studies, apart from constrains enabling rotational movements introduced should be also an axial compliance which is already offered by some types of attachments, and which additionally enables sedimentation of the denture towards the axes of implants.

Practical implications: Analysis of loadings related to implantological attachments in case of assuming only a vertical component of occlusal forces leads to a significant underestimation of implantological supports loads values. In the presented analysis, taking into account the influence of the obliquely acting occlusal forces that occur in real chewing conditions, it has been proved that freedom of rotational movements of overdenture`s attachments does not allow to use the natural supports of mucous membrane. That explains the reason of attachments and acrylic resin dentures damages, as well as the significant number of lost implants of upper denture resulting from biomechanical causes. In clinical practice, achieved should be the most anterior implants' placement, and especially in case of flat ridges because of the lack of any bearing surface.

Originality/value: Determined loadings of supports might constitute a starting point for further biomechanical evaluation of attachments solutions that function according to similar principles, without the necessity of building complex models of the whole system.

Keywords: Biomaterials; Overdenture; Attachment; Load; Finite Element Method

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ENGINEERING MATERIALS

1. Introduction

Assessment of mechanical loading state of implantological structures and adjacent tissues is one of the targets of engineering of biomaterials [1,2]. One of the basic problems is the selection of mechanical characteristics of the solutions because of the strength and wear [3,4], as well as because of the optimal loads distribution in tissues adjacent to implants [5,6].

As typical examples are here solutions of dental implants, in cases of which 90% clinical failures, based on implant lost, results from biomechanical reasons and only 10% from biological phenomena called “periimplantasis” [7].

The risk of implant loss decreases with their increased number and their diameter. Although, the costs connected with introduction of 6-8 implants makes this treatment financially available only for a group of rich patients [8]. Introduction of implants with bigger diameter is usually not possible because of the too narrow atrophic alveolar ridges. Researches carried out for many years now, aimed at reduction of the number of implants resulted in invention of numerous solutions [9].

One of these solutions is the overdenture, supported on bound together bars of four or even two implants with posterior bars extensions. These structures, on the other hand, bear almost all occlusal loadings and they are the ones of the most bent. Hence, reduction the number of implants to two has leaded the researches in the direction of relieving implantological supports by means of maximal use of mucous membrane supporting function. This directions of researches created generally separate solutions called: implant retained tissue supported dentures [10]. In case of using this type of solutions in mandible edentolouism, implants survival rate might reach almost 100% [11,12]. Natural, however, is here a tendency to look for a solution that ensures elimination of even these 3-4% lost implants. Biomechanical problems connected with bone tissue overloading [13] are still clearly visible in case of jaw, resulting in a significantly higher number of lost implants supporting upper denture.

In case of implant retained tissue supported dentures, they have to have a free mobility during occlusal loads in order to relieve the implants and adjacent bone tissue. Denture displacements and pillar’s loadings depends on the way, in which the denture is joined with pillar, or in other words: they depend on the type of attachment. In structures of the most economical solitary attachments, where there is no bar joining the implants, that increases the costs, commonly used are the ball/socket or stud attachments systems, presented in catalogues as advanced as far as their compatibility with mucous membrane resiliency [9]. Although, in practice a very common problem here appear to be the fast abrasion, failures of attachments and acrylic resin around sockets [11,14,15,16,17]. Hence, results of clinical researches prove an insufficient determination or lack of abilities enabling use of the already qualitatively determined relations between denture mobility and bearing occlusal loads by implantological attachments [18,19,20,21,22].

Structure strength assessment and its impact on adjacent tissues requires a complex biomechanical analysis, which can be performed by means of FEM [5,6,20,23]. The basis of an appropriate solution is determination of mechanical loads, which act on material in the real system of exploitation conditions [24,25,26]. An example of using FEM modeling in biomechanical analysis can be strength calculations of prosthetic restorations. The most commonly presented are the analyses of dentures loadings and loadings of the adjacent bone tissue. In case of a complete edentoulism, research methodology is based on reflecting the complete denture geometry with structure of implant-denture, implants and natural tissues of foundation [21,27,28]. In such an approach determining of loadings in various commercial solutions requires labor-consuming modeling and analysis of given solutions. Hence, the branch literature comparative studies of only chosen types of attachments, which is dictated by time and financial limitations of the researchers. Authors of this research proposed a various approach to loading assessment. They have assumed determination of forces acting on implantological attachments as the most important. Such an approach makes it possible to forecast the effects of bone tissue loading without the necessity to construct the whole system, each time a new type of attachment is tested. Determination of loads in bone tissue creates here a separate, next goal, significantly simplified, as it is limited to the analysis of one implant. Similarly is carried out the strength analysis of the attachment itself. Model limited to one implant loaded with forces determined during the previous phase, enables a more dense discretization and more universal contacts analysis, without limitations resulting from excessive model complexity that exceed even advanced computer computative abilities.

The aim of the presented research was the definition of real levels of loads associated to chewing processes for commonly used types of attachments for implant retained tissue supported dentures, presented on the market as advanced, as far as their compatibility with mucous membrane resilience is taken into account, due to their freedom of rotation around all the axes.

2. Methodology

Mechanical effects of co-operation of lower denture with two pillars, placed in a typical variant in the front chin part of mandibular alveolar ridges, were examined by means of FEM (Algor software). In three-dimensional models a simple system of directional constrains integrated with denture saddles has been introduced at attaching points. These constrains, according to the functioning rules presented by their producers, make possible a free rotation around their supporting point. Chosen for analysis was a case of osseous foundation with flat slopes, characteristic for atrophic alveolar ridges. This type of foundation creates most of the problems in clinical practice. Mainly because of the common difficulties with dentures retention, in this group of patients there is the biggest need of implantological treatment. In case of a strong atrophy the use rigidly fixed constructions is not recommended because of too poor osseous structures.

Foundation dimensions and shape was obtained on the basis of own measurements of denture bearing areas of gypsum models got from Prosthetic Department of Silesian Medical University and on the basis of literature data [29]. In the model reflected was a section of mandibular arch constituting denture bearing area. On the whole length of the arch, assumed was a constant shape of alveolar ridges and constant layers system, as shown on Fig.1. In the analyzed system, denture sedimentation under occlusal loads depends on mucous membrane resiliency. Average elastic properties of membrane have been assumed [30]. In order to simplify the computing procedures, linear elastic isotropic characteristic have been assumed for all the structures of the system. Mucous membrane was described by Young modulus E=3 MPa, and its incompressibility in given range was reflected by a high Poisson's coefficient ν=0.49. For cortical bone, Young modulus E=17 GPa; whereas for the spongy bone E=600 MPa have been assumed; by Poisson`s coefficients equal ν=0.3 in both cases. Properties of denture material were described by E=2000 MPa and ν=0.3.

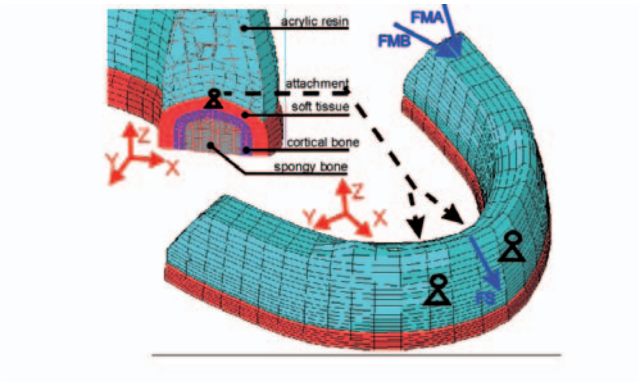

Fig. 1. Conditions of FEM model analysis

Attachments loadings, as reaction in supports were analyzed for three particular cases of locations and directions of occlusal forces of 100N. Chosen was the load on incisors (FS) with resultant directed under the angle of 45 degrees forwards. Horizontal force component acting forwards reflects more disadvantageous conditions [20,28] when the denture in not only pressed to foundation, but additionally forced is its horizontal displacement. As a result of it, horizontal forces components of attachments loads might increase.

Next, the case of food biting on molar was simulated. Similarly to the incisors, assumed were disadvantageous for attachments loadings, cases of resultant of dynamically changing forces on teeth cusps. First case, where occlusal force directed buccaly at the angle of 45 degrees towards cheek in frontal plane (FMB). In the second case the force acts also at the angle of 45 degrees, but it is directed forwards in the saggital plane (FMA).

Between mucous membrane and the denture assumed was an ideal adherence, i.e. analyzed is not a situation where there are detaching or slipping areas under the denture – resulting in additional attachments loads. The whole model has been fixed to the bottom surface of separated mandible bone part.

3. Results

Results of the biomechanical FEM analysis of implant retained soft tissue supported denture are directional reaction components X-Y-Z acting on implantological supports and denture linear displacements in the assumed directions of coordinates system.

On Fig. 2 there are presented values of loadings taken over by attachments respectively for the considered variants of occlusal forces on molar FMB and FMA. For lateral forces causing pillar bending, absolute values of lateral forces resultant have been given (in horizontal plane „XY")..Values of axial reaction („Z") 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.

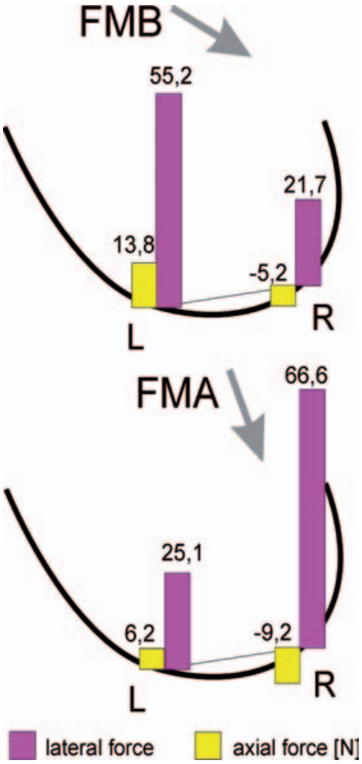

Fig. 2. Loadings on implantological supports for the analyzed variants of FMB and FMA biting forces

On Fig. 3 presented is the denture mobility in directions of the assumed coordinates system for this variant of lateral occlusal forces (FMB), as displacements of 9 check points located in the central point on the bottom surface of saddles along the entire denture length. Mobility has not been shown for the variant of occlusal forces on molar directed forward (FMA), because of space saving and due to the fact that in clinical practice, the biggest problems occur with lateral denture stability.

On Fig.4 presented are the axial and lateral attachments loads for occlusal force variant located at incisor (FS). Denture mobility for that variant is shown on Fig. 5.

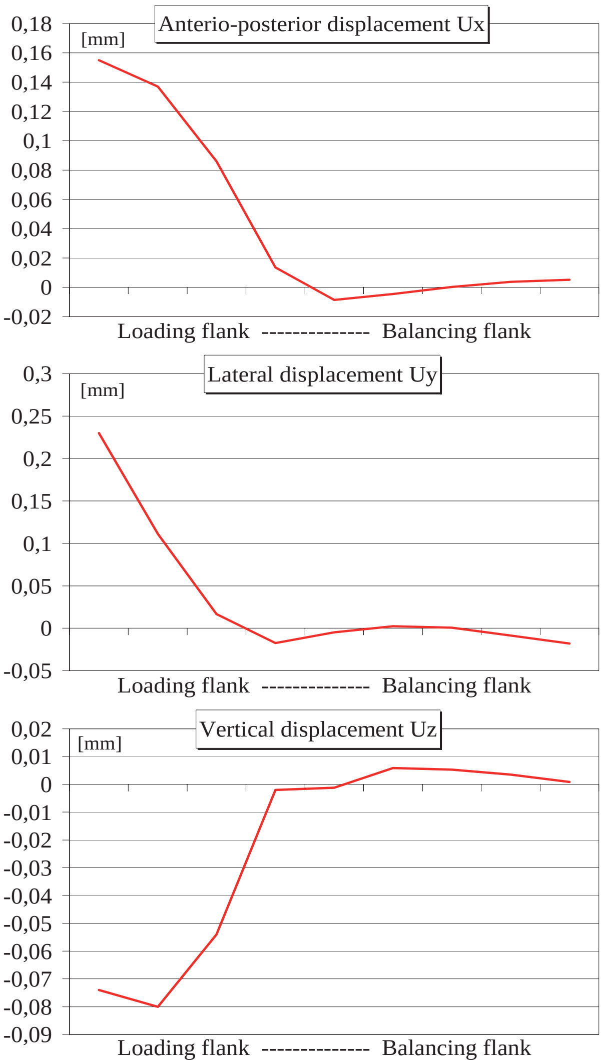

Fig. 3. Denture displacements in directions X, Y and Z under lateral biting loading on the molar (FMB)

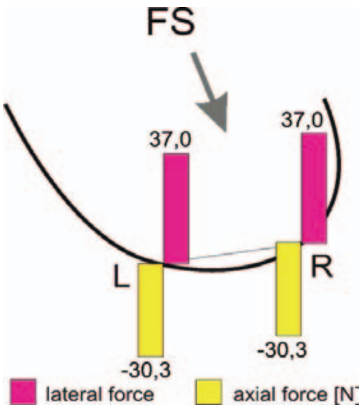

Fig. 4. Loading on implantological supports for the variant of occlusal forces on incisors (FS)

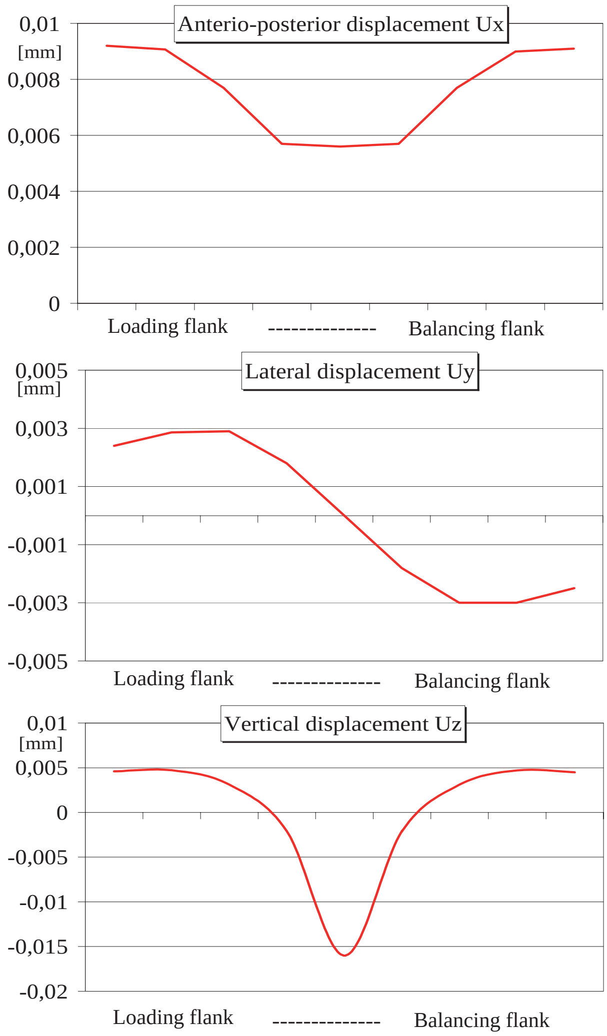

Fig. 5. Denture displacements in X, Y, Z directions under lateral occlusal loading on incisors (FS)

4. Discussion

Appropriate drawing of conclusions on the basis of FEM requires evaluation of the influence of made modeling assumptions on achieved results. An important simplification in the presented analysis was the replacement of implantological supports by directional constraints. A real implantological support along with its anchorage zone in bone tissue, opposite to the support assumed in the model shows some compliance. However, deflections are so small that achieved reaction values cannot be significantly overestimated. Also simplification of bone geometry by means of separating only its part constituting a direct load support of a denture does not influence remarkably the carried out analysis, as the deflection of whole mandible is incomparatively lower than the mobility of a denture working on a resilient mucous membrane foundation. Questionable might be the assumption of an ideal adherence on mucous membrane interface, because in the real system, in the areas of positive stresses perpendicular to mucosal surface there takes place a detachment of denture flanks, as well as slipping, in case of tangential stresses. On the other hand, a patients feeling a loss of denture stability reduces occlusal forces and tries to move the denture saddles back to their correct position. It seems not to be probable that some incidental situations can take place, where in spite of loss of denture adherence a patient would still cause biting loadings. Occurring in real conditions small local slip and detach effects might, to some extent, give higher reaction values on implantological supports, than those achieved under assumed model conditions. Nevertheless, the achieved results can be applied to loadings conditions accompanying stable mastication.

It has to be taken into account that assumed were linear elastic mechanical characteristics. Characteristics of mucous membrane have basic importance for attachments loadings. It may be however assumed, that effects of the viscous flow along with membrane elasticity result in total deformation, which for the purposes of the carried out attachments loadings simulation might be replaced with resiliency. Although the characteristic of attachments loadings rate during initial chewing cycles is not known, the most crucial values, which are the maximum reaction values on implantological supports for a given occlusal load variant can be determined. In the model, assumed was average mucous membrane resiliency, nevertheless the search for the influence of this individual variable characteristic on attachments loadings might constitute an object for a separate research. The reason for existence of various types of mucous membrane are the remodeling processes of soft tissue caused by cyclic loads. In case of an atrophic osseous foundation, overloading effects [31] intensify adaptation processes [32]. Apart from pressure created by the denture or, on the period prior to denture wearing, created by food, mucous membrane faces friction on its surface resulting from tangential stresses. In superficial soft tissue layer, in case of tangential stresses, there occur keratenization at the cost of deeper located layers. Natural processes aimed at creation of more dense tissue layer that is more resistant abrasion, result in hardening and thickening of mucous membrane, which is easily detectable during palpable examinations of denture foundation [33]. Apart from a thin hard membrane there is another membrane type, also having poor resiliency, although, in this case resulting not from its insufficient thickness but from its very low density. That combined with remarkable thickness, might result in an increase of pressure on implantological supports, which should be determined in further studies at the first place.

Basic importance for the obtained reactions around supporting zones has the way, in which occlusal force has been applied. In most of the researches presented in literature sources, assumed was a vertical direction of force. In real conditions, biting forces are acting obliquely. The lacking horizontal force component limits presented analyses results. Because of the vertical denture sedimentation according to implants axes, no lateral reactions will be generated on attachments. Hence, under real biting forces, causing denture displacements obliquely to the pillar, the freedom of rotation on attachments will not eliminate the direct taking over of horizontal components of biting forces. Especially, in case of atrophied ridges, the effects are getting even more important, because it cannot be assumed that a part of the loadings will be taken over by bearing surfaces on slopes of convex alveolar ridges. This theory has been confirmed by measurements of implants loadings during real chewing functions [21], where it has been determined that values of transversal forces remained at the level exceeding 100-300% of axial components values. The fact is that not the axial forces, but bending has more influence on disadvantageous changes in bone tissue surrounding implant [18, 21,34,35]. The influence of the method of loading with simulated chewing forces on the evaluation of examined attachments, is also confirmed by an experiment carried out by means of a photoelastic method [28]. Oblique forces acting on molar are transmitted onto foundation in a quite different way than the vertical ones [28]. In case of vertical forces, load is transmitted onto mucous foundation in posterior zones. Oblique acting forces cause high loads in bone tissue adjacent to implant at loaded side. Authors conclude that in case of a misfit to foundation, as well as in case of not-resilient attachments, awaited can be a bone tissue overloading. Authors point out the similar results of research [21]. Also in FEM experiment [20], stresses in case of vertical loads increased from app. 3,5MPa to more than 25MPa for loadings applied at an angle of 60 degrees to implant axis. Although, the significant influence of chosen analyzed types of attachments on bone tissue loading examined by the authors [20] is rather questionable. Obtained were here differences in the range between 25,3 and 28,1 MPa. Such differences might result from a variable lateral pressure distribution on pillars of various types of attachments, which leads to insignificant differentiation in location of resultant of those forces, as well as of the bending moment for the whole pillar. These results prove correctness of the assumption of supports instead of attachments in the analyzed model, due to which neglected was the insignificant influence of attachment construction, in case of its low compliance. Bones' loading, as it was proved, depend mostly on the lateral forces arm, i.e. the section between bone surface and the point of applied lateral forces. It denotes that the various effects of bone tissue relieving for given type of attachments do not results from any remarkable differentiation of taken over biting loadings, but only on differences in transmitting them into bones because of characteristic for given commercial system the pillar and abutment solution.

Hence, results of the presented in branch literature comparative tests carried out on the basis of photoelastic examinations, as well as forces measurement on implants cannot be treated in categories of evaluation of loading taken over by attachments. In case of clinical evaluation in oral cavity, the results are even more disputable because of the remarkable differences of supporting conditions on denture foundation, resulting from numerous system characteristics, such as: foundation shape and mucous membrane resiliency, as well as pillars position and theirs axes arrangement. Only a measurement carried out for same individual patient enables comparative test of commercial systems. It is however, not possible to test attachments, for which abutment does not match with the implanted pillar. Nevertheless, part of the huge companies have their own systems that do not match with pillars produced by other manufacturers, whereas independent companies producing attachments, adapt their abutments only to those mass-used pillars. Results obtained in this research, because of their universal character, might constitute a starting point for a strength analysis of any construction working according to the analyzed rules.

Freedom of rotational movements on the attachment, as shown on the presented displacements charts, makes denture mobility possible in posterior zones. Because of the limitations in denture sedimentation in the anterior area, in case of loading in incisors zone a remarkable part of biting force is taken over by implantological supports. It is worth mentioning here, that the occlusal force in the model was assumed centrally. In real conditions awaited should be an asymmetric shirting biting force towards attachments resulting in a higher loading of attachments. Under occlusal forces on molars denture flanks mobility allows achievement of relatively low values of app. 5-10N, however only the axial ones. A lot higher risk results from taking over by attachments remarkable (55-66N) horizontal components of chewing forces. Here also, any movement of the force assumed in model on molar forwards in the direction of the attachment will result in increase of attachments' loading. According to the description of food communition given by some patients, and according to measurements of occlusal forces, it appears that during biting on molars the denture more easily loses its stability than in case if food is located in premolars zone [19].

Researches results explain unambiguously such a high percentage of clinical failures based on implant loss in case of jaw. In the presented model assumed was the direction of axial reaction on support compliant with vertical component of biting force. In case of mandible, because of anatomical arrangement of atrophied alveolar ridges, implants placements in the presented way is to remarkable extent possible. In case of jaw, alveolar ridges shape makes it impossible to arrange pillars' axes in a direction of the vertical resultant of biting forces. Depending on atrophy rate, forced is a remarkable angle of declination outwards. Hence, the vertical biting force, which has to be treated as a dominant, results in serious lateral loadings on implants. Although oblique abutments are commonly used, it has to be taken into account, that thanks to them forces arm can be shortened, which reduced, to some extent, the unfavorable bending, but it will not eliminate it.

Even in case when there is no implant lost, such remarkable values of lateral forces explains the reasons of mechanical failures of attachments exploitation. Quick wear and damages of attachments causing most of the patients' problems are exactly the result of underestimation of significant lateral loadings during design. They accelerate drastically the abrasive wear, fatigue processes related to attachments' elements, as well as they lead to acrylic resin damages surrounding attachments sockets [14,36,37,38,39,40,41]. In clinical practice, time of a trouble-free functioning of attachments seems to be limited to only few months [11,36]. As an effect of frequent repairs or replacements of attachments, significantly increases the cost of denture exploitation [42]. There is also a risk of respiration of broken small attachments' elements. Bearing additional costs might discourage many patients from the choice of implantological denture stabilization.

Presented results point out, that a appropriate direction of further studies on implant retained soft tissue supported denture is the search for solutions, in which the attachment, thanks to appropriately selected compliance does not limit the denture sedimentation in its supporting zone [19], at the same fulfilling time its basic function of increasing denture retention on the level high enough for chewing most of food, and at the first place the function of ensuring a basic comfort to its wearer during speech, laugh and sneezing functions, a comfort that is still not available for indigent patients.

5. Conclusions

Denture attachments loadings analysis in case of assuming only the vertical component of occlusal forces leads to a significant underestimation of loadings acting on implantological supports. In the presented analysis, taking into account acting of oblique biting forces that occur in real conditions of chewing, it has been proved that freedom of rotational mobility in denture attachments does not allow to use natural supporting on mucous membrane foundation, which explains the reasons for attachments damages and acrylic resin denture, as well as the significant number of implants losses in jaw resulting from biomechanical reasons.

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