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Can typical overdentures attachments prevent from bone overloading around mini-implants?

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Materials

ABSTRACT

Purpose: High level of successful maintenance of implants located in anterior part of mandible popularizes economical solutions of implant-retained soft tissue supported dentures including those using narrow mini-implants with small diameter - of 1.8-2.2 mm.
Design/methodology/approach: FEM modeling analyses were used to determine distribution of mastication loads between mucous foundation and bone tissue surrounding mini-implants that have 1.8 mm diameter. Examined were two types of commercial solitary denture attachments, described as biomechanically compatible due to their rotational movements freedom or due to the additional pivoting mobility.
Findings: In case of both types of attachments the most dangerous lateral implants loadings significantly exceed half of oblique mastication loads value. In mini-implants and bone tissue lateral forces generate a high level of stresses.
Research limitations/implications: Analyses were carried out with assumed linear characteristics of materials. Denture-to-soft foundation, as well as implant-to-bone complete adherence was assumed.
Practical implications: While using mini-implants it is crucial to carefully evaluate the condition of bone foundation, due to the risk of quick development of atrophic processes in case of insufficient bone parameters. In case of mini-implants very important is very high strength value level and surface quality, due to the fact that in case of diameter of 1.8mm there might occur local yielding and propagation of fatigue cracks.
Originality/value: Commercial types of attachments do not deserve the name of mechanically biocompatible, as they do not allow for such significant reduction of overloading effects, as the non-commercial silicone attachments.
Keywords: Biomaterials; Mechanical properties; Denture; Implant

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1. Introduction

Among implantdentures used in treatment of complete edentulism, depending on the type of supporting, there should be differentiated typical fixed implantdentures, implant-supported overdentures and implant retained soft tissue supported dentures [1,2]. In the first two of the mentioned solutions occlusal loads are completely transferred onto implantological supports. In this kind of solutions the choice of supports and planning their location requires "sense" of biomechanics and clinical experience. As a rule, the most effective protection against bone overloading around implants is based on increasing their quantity and diameter. Unfortunately, costs resulting from the necessity of introducing larger number of implants, price of superstructure, as well as relatively high requirements regarding medical personnel qualifications and experience, make these solutions affordable for more wealthy group of patients. Often, conditions of osseous foundation make it impossible to fix the required number of implants having required diameter. Hence, it is reasonable to search for alternative denture fixing methods – the least invasive, least complex and the most affordable for less wealthy patients [3].

In case of conventional soft tissue supported dentures failure in treatment mainly results from insufficient lower denture retention on the foundation during speaking and mimical facial movements. Slight increase of lower dentures retention, even realized by means of commonly advertized prosthetic glues, increases the level of dentures acceptance.

That is the main reason of popularity of such economical solutions [3] as implant retained soft tissue supported lower dentures. Implants, in this case, only support retention. Limiting the number of support to two, using the cheapest acrylic denture, relatively easier clinical treatment technical construction belong to the advantages of these prosthetic solutions. Such a solutions are also more „resistant" to lack of sense of biomechanics in optimizing their construction. Mastication forces can be transmitted onto mucous foundation, with significant analogy to conventional mucous dentures [4]. Sufficient use of mucous membrane support is directly reflected in the increased number of lost implants being the effect of overloading in bone tissue in case of w fixed supported solutions. On the basis of many years of experiences these solutions have been recognized as a standard in treatment of mandible edentulism [5].

In order to relieve implants and the adjacent bone tissue during transferring of occlusal loads by means of using supporting mucous foundations, denture connection to implant cannot be stiff. This task is generally realized in two different ways. The first method is to brace the implants by means of a bar, which constitute denture anchor point. The other one leaves implants separately and fixes the denture directly to the implants by means of solitary attachments. In case of sufficient mandible foundation conditions clinical success, as far as implants retaining is concerned significantly differs for these two solutions. Nevertheless, solutions based on solitary attachments are more economical, as costs related to construction of the bar connecting implants are substantial. The second solution that does not use the bar is in many cases the only one possible solution due to its lower requirements regarding space in denture saddle.

Dentistry market offers many various solitary attachment systems. Advantages resulting from choosing particular dentures presented by their producers create decision-making problems [1]. Branch literature is full of clinical evaluations of implants retention and conditions of foundation that is favorable for given solutions, and evaluations of dentures effective influence during various functions. Nevertheless, in spite of numerous elaborations, there is a clear lack of a comprehensive analysis of the problem that would make it possible to determine clearly the issue of denture attachments.

In spite of significant differences among solutions of attachments constructions their function results from frictional forces on contacting surfaces of the matrix-patrix system. Combinations of these two component elements is possible by means of the surfaces matching one to the other: concave and convex. Concave surface is called the matrix, whereas the convex – patrix. Patrix is usually located on the implant, matrix in the denture. Usually patrix is the spherical surface. Denture fixed by means of ball attachments is retained thanks to frictional forces acting on the narthex surface of the ball. Also usually in ball attachment inside of a metal nest, which is located in the denture, there is introduced an elastic-frictional retention component. This matrix component is made of metal or polymer. Components can be replaced and they are available for various levels of retention. O-rings made of highelastic polymers are used as retention components. It is possible to differentiate retention characteristics thanks to various shapes and elasticity of retention component material. Shape modifications of contacting surfaces in the direction of constructions using snap fasteners are mainly aimed at decreasing attachments size maintaining at the same time the required retention capability.

The leading dentures producers offer their own attachments solutions. They also use solutions offered by independent specialized in construction and production of attachments. Usage of independent solutions is possible in two-piece implants by means of screwing the abutment of an independent producer. Among the leading independent producers there is a company Sterngold, that, among other, offers a few types of attachments that are compatible with implants sold by most of the producers. The best offered Sterngold solution, which has a lot of supporters, is the attachment ERA. Attachment Sterngold ERA, thanks to replaceable nylon matrixes having various elasticity makes it possible to adjust the retention force depending on the actual need. ERA attachments are presented as especially advanced, as far as adaptation to resiliency of denture foundation, due to the fact that the denture has the possibility to prosthesis settling in the direction of implant axis. Apart from ERA attachments, Sterngold offers ball attachments with metal matrixes called Dalla Bona. One of the potentates on the market of attachments is Rhein 83. They propose ball attachment, in which mobility of the ball makes it possible to achieve inclination of 7.5 grades in all directions. It creates better abilities of adaptation to particular clinical case. On the other hand, Zest Anchors for many years now promotes press stud attachments Locator, in which there is used a system of double retention (inner and outer), which increases retention surfaces. Thanks to its unique construction Locator Zest Anchors is characterized by relatively small vertical dimension – only 3.17 mm, whereas the self-guiding matrix makes it easier for the wearer to install the denture. Here, there are also available nylon matrixes for various retention levels.

The cost of attachment in relation to the average implant cost is insignificant (app. 2%, as shown in Fig. 1). Hence, the total cost of solutions mainly results from the chosen type of implant. In the final cost, prices of analogues necessary to create a denture, as well as tools necessary to install and remove matrixes are insignificant.

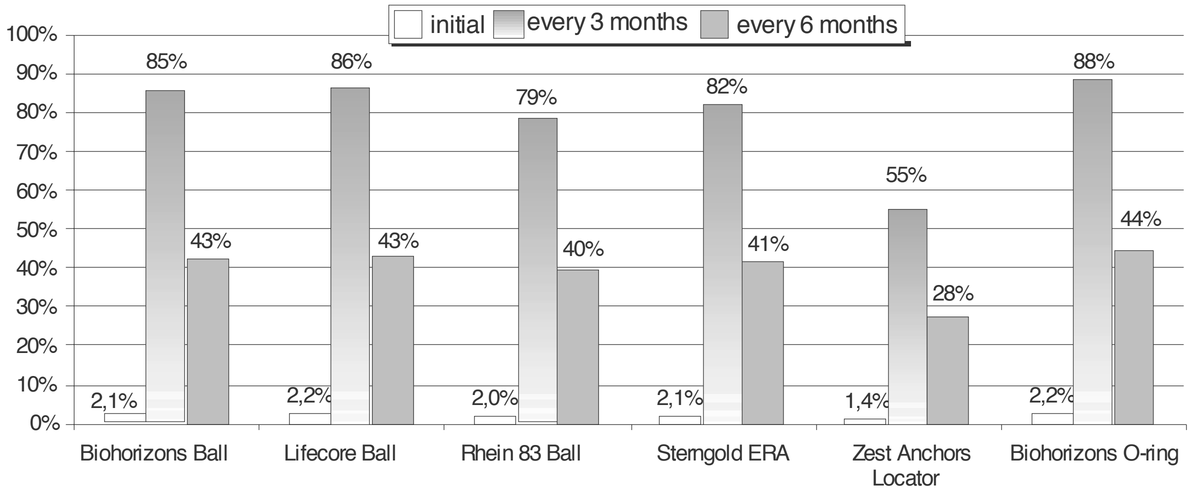

Fig. 1. Percentage relation of matrix prices to the price of the whole set: implant, attachment, abutment at the beginning and after 10 years of wearing; there was assumed the necessity replace matrixes every 3 or 6 months

During denture exploitation it comes out that attachments are the weakest link of the solutions, which results in difficulties and increased cost of the exploitation [3,6-11]. Attachments components belong to delicate precise constructions. It is required to introduced the implant as parallel one to the other as it gets. Then, the prosthetic work carried out on laboratory analogues has to be precisely parallel in order to ensure common direction of denture introduction. Otherwise, some of the mechanism components will be additionally loaded, which will result in a remarkably earlier lost of retention and failures. Lack of axial alignment of implants results in rapid wear, especially of o-rings, in case of which there were recorded multiple replacements of at 50% of the wearers. Particular o-ring attachments construction creates unfavorable limitation of deformation freedom of the rubber-like ring during the transfer of occlusal forces. Due to the material incompressibility, attachments along with increased loading are getting „stiffer" and become extremely not resistant to wear.

Even in case when there is ensured an ideal precision of construction, retention of all types of attachments decreases in time due to abrasion and material fatigue. Numerous studies presented in branch literature comparing attachments retentions characteristics have little relation to practice. In real conditions, the main reason of wear constitute frictional phenomena occurring in attachments during the transfer of mastication loads. Yet, in in vitro tests there is examined retention lost resulting from abrasion effects that accompany introduction of the dentures.

During denture wearing attachments condition requires regular inspections and replacements of retention components in the frequencies required by their producers. Manufacturers offer solutions, in which time needed for replacement of matrixes is reduced to the minimum thanks to special tools. Such solution reduced the costs related to prosthetics technician labor that are to be incurred by the patient.

Nevertheless, in a long-term forecasts all costs related to replacement of attachments retention components are remarkable. In a 10-years forecast the cost of two matrixes (even if the indirect and service costs are not taken into account) reaches app. 40% of the primary implant cost. This assessment regards the most optimistic assumption, that there would be no premature matrixes wear and that the replacements take place every 6 months. In case of a less optimistic scenario, if there is assumed a premature wear and a necessity to replace the components every 3 months, the average cost reaches already approximately 80% of the primary implant cost. Hence, the insignificant relation of matrix-to-implant cost might create a misleading impression regarding the costs of attachments use. Remarkable, additional profit resulting from sales of spare parts for the products do not constitute factors that motivate producer to implement any innovations.

Wear and the necessity of regular attachments matrixes replacements is not the only one weak points of these solutions. Due to the overloading combined with premature wear, some of the components get damaged before their foreseen replacement. Loosen, lost or broken attachments retention components constitute over 40% of all dentures defects [12]. Significant increase of the number of damages is caused by the increase of occlusal loading, e.g. in case of bruxisms the ratio of damaged attachments reaches 62% [13]. It has to be taken into account that excessive loading also results in the lack of denture fit to its foundation [14], which at the primary stage of edentulism increases very quickly due to a strong atrophy of foundation.

In the warranty period, most of the costs related to the necessity of repairing or replacing complete denture is actually incurred by the dentist. Possible producer warranty is only related to insignificant costs of attachments. The most expensive are repair resulting from denture material damages around the nests, as well as cracks in dentures. It is then necessary to remove a damaged nest or a fragment of a denture and filling the place with autopolymerizing acrylate. In patient's mouth, matrix and matrix nest are placed onto the patrix, that are to be placed in the denture, and the denture is then adapted in patient's mouth. After acrylate autopolymerizing it is necessary to finish and polish the denture. Taking into account the remarkable number of damages occurring in the warranty period, it is completely reasonable that the dentist who is exposed to additional costs of repairs, tries to secure himself by means of increased denture price. Nevertheless, patients decide to choose this type of treatment, either unconscious of further costs, or accepting them due to the lack of offered other affordable solutions that would be free of such drawbacks.

Attachments, fulfilling their basic retention function also have to make it possible to use the support on the mucous membrane during distribution of occlusal loadings. Manufacturers advertise own solutions as advanced as far as compatibility with mucous membrane resiliency is concerned. Nevertheless, a remarkable number of mechanical failures shows that the loads of implantological supports have not been identified well enough yet. Moreover, it is worth mentioning here that in case of upper dentures or locating implants in molar zones of edentulous mandible ridges there is to be observed a significant increase of clinical failures based on implant lost. Similarly, a success in retaining implants located in the front mandible section significantly depends on conditions of the bone foundation. Special caution should be maintained in case of implementing solutions in relatively unfavorable conditions of bone foundation, where it is only possible to introduce narrow implants having relatively low diameter within the range of 1.8-2.0 mm [15-18]. Although, it has been proven that bone-integration takes place, even in cases of the lowest diameters of 1.8 mm [19]. On the other hand, in cases recognized as clinical successes, overloading effects becomes visible in the form of commonly recorded „funnel-shapes" losses around implant neck, even in cases of larger diameters.

The aim of this study was to evaluate the overdenture cooperation with two mini-implants retained by typical commercial attachments. Analyses have been carried out by means of a FEM numerical research. There was analyzed transmission of mastication loads in the direction of attachments and then in the direction of bone tissue around implant. As the zero-hypothesis for this study assumed was the statement that typical attachments in overdentures do not make it possible to achieve a safe level of bone loading around neck of narrow mini-implant.

2. Methods

2.1. FEM modeling of loading attachments that fix denture to implants

Mechanical effects of denture cooperation with implants were tested in a typical mode of locating implants in the anterior part of mandibular bone. For the purposes of construction of numerical three-dimensional model and FEM calculations there was used the Algor software. For analysis there was chosen the case of osseous foundation, which creates largest problems in clinical practice, with characteristic strongly atrophied edentulous processes. Assumed was a slight inclinations of ridges slopes, which increases implants loads due to the small denture supporting area. In the model there has been reflected only a fragment of the mandible bone arch, which constitutes the area of denture support. On the whole length of the arch it has been assumed a fixed shape of processes and a constant layers system, as shown on the cross section on Fig. 2. In the geometrical model of the denture simplified were the irregularities of artificial teeth shape, which are not the object of the analysis and unnecessarily increase the size of numerical model. There was assumed a complete adherence between the mucous membrane and the denture. The whole model was fixed at the bottom of the mandible bone.

In order to simplify calculation procedures there was assumed for all system structures linear elastic mechanical characteristics [20-21]. Assumed was also average membrane elasticity, described by Young modulus E = 3 MPa, and its incompressibility in particular range was reflected by a high Poisson's coefficient ν = 0.49. For cortical bone there was assumed Young modulus E = 17 000 MPa; whereas for cancellous bone E = 600 MPa; at Poisson`s coefficients equal in both cases ν = 0.3. Denture material characteristic was described by E = 2000 MPa and ν = 0.3.

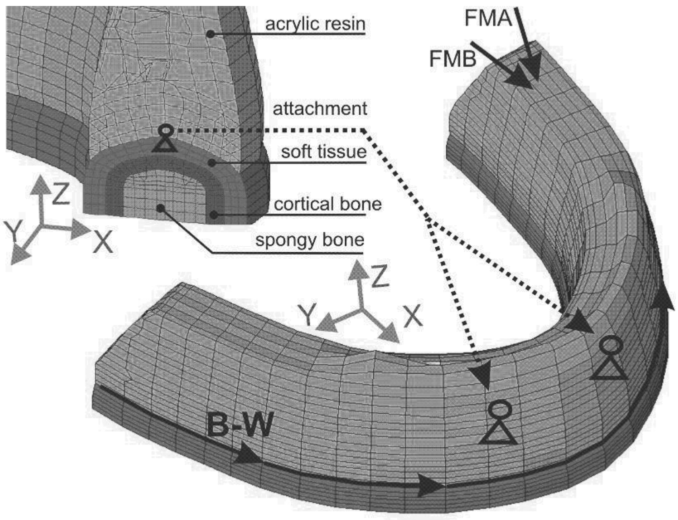

Fig. 2. FEM model analysis conditions

Typical commercial attachments, presented by their producers as biomechanically compatible as far as their advanced character regarding resiliency with mucous membrane is concerned can be divided regarding mechanical characteristics into two types. The most popular are attachments, in which there is possible rotation around supporting point (type marked with „K"). In the second type of attachments there is an additional possibility of denture settling along implants axis (type marked with „R").

In places where the denture is fixed to implants there was introduced a simple system of constrains, which limit freedom of denture displacements according to their functioning principles. Searched attachments loading constituted reaction values in the assumed constrains that were caused by particular cases of occlusal loads.

There was assumed denture loading with occlusal forces of 100 N. Mastication forces belong to loadings showing stochastic character. In the analyzed type of dentures, maximum loads recorded in molar zone might remarkably exceed 200 N. On the other hand, it is assumed that forces within the range of 50-100 N are sufficient to comminution of most of the food. Mechanical problems accompanying wear of attachments are mainly related to wear and fatigue. Justified is therefore the assumption of loads reflecting normal mastication. There was assumed an oblique direction of occlusal forces resultant. Loading with oblique occlusal forces not only presses the denture to its foundation, but also additionally forces its horizontal movement, as a result of which increased are the horizontal components of forces loading attachments. There was assumed a force directed at the angle of 45 degrees towards the cheek in frontal plane (FMB). Then, there was assumed the second case of denture loading, this time at the angle of 45 degrees towards the front in sagittal plane (FMA).

2.2. FEM modeling of stresses in bone tissue around implants

The next stage of the study was determining of bone tissue loading around implant cooperating with the analyzed type of dentures. Implant was loaded with forces that normally accompany mastication, values of which were defined at the previous stage of examinations. There was analyzed a variant that has generated maximum values of disadvantageous lateral loadings of the implant (during previous stage it was the FMA case). Hence, the implant was loaded by the force of 70 N

For the FEM analysis there was assumed geometry of a narrow implant presented in Fig. 3. Minimal diameter value for mini-implants was assumed at the level of 1.8 mm. For the purposes of the carried out analysis bone area was limited to the cylindrical shape around the anchorage zone. On the cross-section marked were the analyzed implant characteristics. Between post and the bone there was assumed an adherence together with cortical bone thickness of 2.0 mm. Model FEM analysis was carried out in the linear-elastic range. The assumed cortical bone Younga modulus equaled 17 000 MPa, whereas for spongy bone E = 600 MPa; at Poisson's coefficient in both of the cases at the level of ν = 0.3. For the implant itself, there were assumed characteristics typical for titanium alloys E = 140 000 MPa; ν = 0.3. Model was fixed on the lateral and lower surface of the cylindrical bone area. Mucous membrane did not constitute the object of the analysis and therefore it was not taken into account.

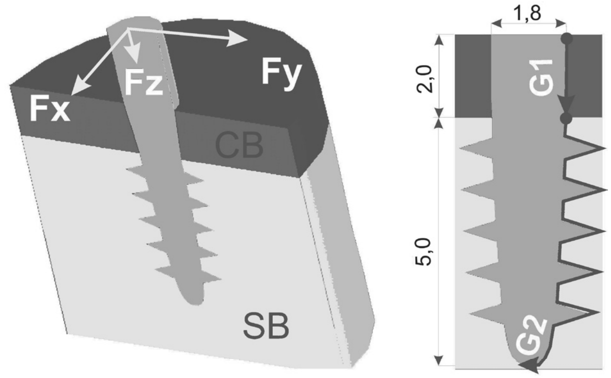

Fig. 3. Model cross-section with implant loading scheme and description of material groups: CB- cortical bone, SB- cancellous bone, Ti - implant. Paths G1 and G2 along which there are analyzed stresses in cortical and spongy bone

3. Description of achieved results

3.1. General remarks to modelling conditions

The principle of carrying out model analyses is eliminating of modeling assumptions that unnecessarily increase analysis robustness. Eliminated are elements, importance of which in the analyzed phenomenon is secondary or not important at all. Researchers strive here for achievement of the simplest model, which at the same time would make it possible to quantitatively determine analyzed phenomena [23].

In the model imaging of mandible tissues was limited to the area that supports the denture. Deformations of the whole of mandibular bone play a secondary role and do not influence significantly denture movements. Strains of soft mucous membrane denture foundation are incomparably higher in relation to bone, similarly as in relation to deformation of implantological supports together with the surrounding bone tissue. Hence, in the model it is not necessary to increase the denture supporting zone in order to determine distribution of mastication loads on mucous and implantological supporting zones.

Next analysis simplification was the assumption of linear-elastic mechanical characteristics. One can have the impression that the most questionable can be in this case such assumption in relation to mucous membrane. Although, it can be assumed that viscous flow in soft tissue together with elasticity in sequent mastication cycles result in total deformation, which for the purposes of this attachments loading analysis can be replaced with compressibility. Increase of attachments loading will not be determined for initial mastication cycles. Nevertheless, achieved will be the most interesting information on maximum reaction values on implantological supports that occur during maximum displacements, which reflect total mucous membrane deformation created by mastication load.

Assumption of a complete denture adherence on mucous surface is justified as in case of lost denture adherence, patient feeling the lack of denture stability reduced occlusal forces. Such assumption reflects to a remarkable extent a situation of a stable mastication.

In this work proposed was alternative approach to model boundary conditions, that makes possible determining of loadings on implantological supports without the necessity to construct relatively complex assemblies of attachments together with implantological construction. According to the rules of FEM analysis procedures, evaluation of loading in bone and strength analysis of implantological support, has been separated as a sole, next task. Model limited only to implant construction loaded by forces determined in the previous task, makes possible a more dense discretization at a lower need of computational capacity.

3.2. Transmission of occlusal forces

Values of forces bore by „K" and „R" attachments at the balancing and working side for analyzed variants of occlusal forces were presented in Fig. 4. For forces transversal to implant axis in horizontal plane „XY", that cause implant bending, there were given absolute forces resultant values. Values of the „Z" axis component were given separately as negative values resulting in loading of the bone and positive values causing pulling towards the top, i.e. opening of the attachment in the moment when there are reached values of forces limited by retention of attachment.

In Fig. 5 there were juxtaposed diagrams of denture displacements read in 9 check points along the front lower saddles margin (balanced-working "B-W" path was presented in Fig. 2). In presentation of displacements diagrams variant of lateral mastication forces (FMB) was chosen as the representative one. Displacement diagrams clearly show that denture mobility for both types of attachments does not differ a lot. Advertized by their producers ability of vertical settling in direction of implant axis („R") does not create any advantageous increase of flanks mobility, which would confirm better use of mucous supporting.

Range of denture flanks mobility that is ensured by both types of attachments makes it possible to achieve relatively low values of attachments loading only in case of vertical denture loadings. Under vertical occlusal loading of 100N (FMV) the lateral implant loading for ball attachment reach values of only 2.4 N. Although, in real conditions, under oblique occlusal forces both rotation freedom at attachments, and denture settling ability in the direction of implant axis do not eliminate bearing of significant values of component vertical occlusal forces. These are values remarkably exceeding half of the occlusal forces (55-66 N).

In many presented analyses of loading attachment systems based on FEM analyses, both numerical and laboratory, often, there is assumed only the vertical component of the occlusal forces. Results of this work clearly show that lack of the horizontal component remarkably limits the possibility to define the relation of model analyses to reality. In case when there is assumed dominant role of vertical occlusal loadings there is a significant underestimation of attachments loading. As a result, the design of implantological constructions is incorrect.

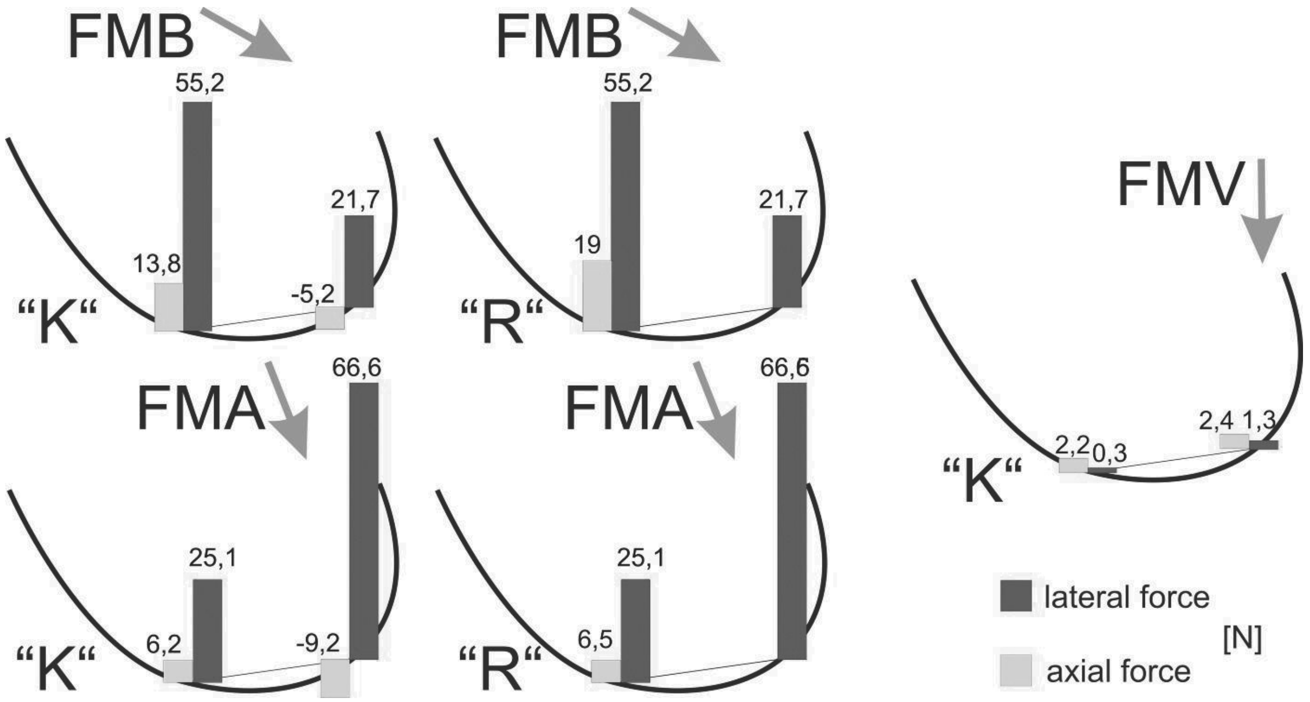

Fig. 4. Lateral and axial forces for "K" ball attachments and the so-called resilient „R" attachments loaded with oblique mastication forces (FMB and FMA). For comparison there are shown reactions with assumed only the vertical mastication forces component (FMV) for „K" type of attachments

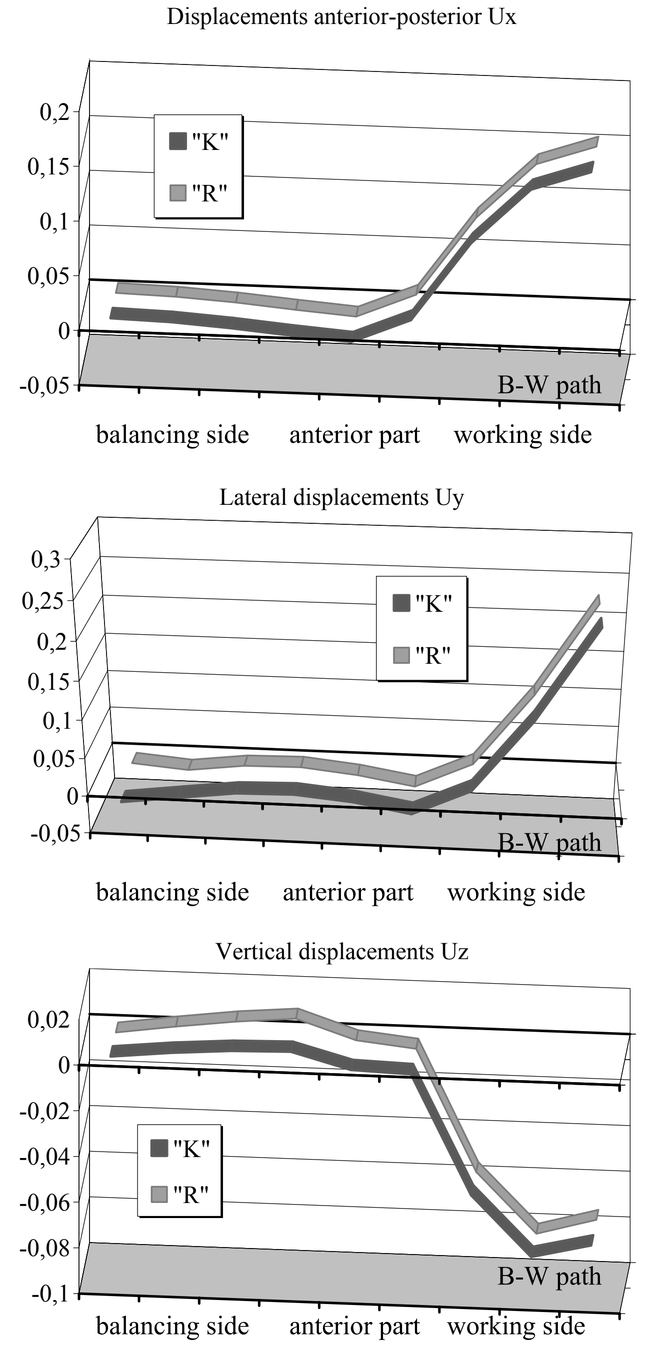

Fig. 5. Denture mobility for "K" and "R" attachments under FMB mastication forces along "B-W" path from balancing to working side.

Complete rotation freedom in attachments, in dentures cooperating with two implants might be used. Better results are awaited in case of single implant retained dentures [24], which in practice function not worse than two-implant retained dentures [25,26]. System of two attachments blocks movement in horizontal plane horizontal plane. The actual denture mobility is limited to rotation along the axis determined by attachments points. Dentures saddles can only settle in hinge movement, similarly to the case of bar-attachments. Horizontal component of occlusal forces generates torque on supports, that gives remarkable values of horizontal reactions bending the implant. Attachments having pivot mobility behave in a similar way. Advertized by their producers relief effects can only be awaited in case of an even vertical settling of the prosthesis. Attachments will be able to function in the advertized biomechanically compatible manner only in a special case of occlusal loadings on incisors. Under force influence on incisors, due to its location between implantological supports, possible is an even vertical settling of the prosthesis. Although, occlusal loadings on incisors in case of soft tissue supported dentures are insignificant, and incisors are as standard procedure excluded from occlusion. During mastication it is very hard to count on influence of biomechanical compatibility in this case. Even balanced bilateral occlusal pressure in molar zone does not create sole vertical settling of the denture. Hence, denture mobility and lateral implants loadings do not much different than ball-attachments solutions.

Influence of the way, in which attachments are loaded by simulated occlusal forces on the evaluation of the tested attachments are also confirmed by carried out elasto-optical experiment [27]. Oblique forces on molar are transmitted onto foundation in a completely different way than vertical forces [27]. In case of vertical forces, loading is transmitted on mucous membrane in posterior areas. Oblique forces create high loading in bone tissue around the post at the working side.

Similarly to FEM analyses in work [28] lateral loadings in attachments, increase from the value of app. 3.5 MPa in case of vertical loadings, to more than 25 MPa in case of loadings acting at the angle of 60 degrees to implant axis. Although, the discussed [28] significant influence of analyzed types of attachments on bone loading is rather questionable. Achieved differences between 25.3 and 28.1 MPa might result from changeable distribution of lateral loadings for various types of attachments, which leads to insignificant variance in direction of the resultant of all those forces and torque the bending implant. As the results, differences in bone loading in comparative studies mainly depend on the arm of lateral forces, implant and attachment construction characteristics or implant diameter. Such comparisons result in disinformation as far as evaluation of attachments function is concerned. There are compared loadings of prosthesis construction and bone, which are secondary values dependant not only on characteristics of the attachments. Hence, results of such comparative tests should not be perceived as such in relation to loadings bore by the attachments themselves.

In this work there has been achieved an unequivocal and transparent evaluation of cooperation between the denture and particular type of attachments. Universal character of the analysis results from assumed constrains replacing in the model complete assemblies of attachments that are in an unambiguous way related to rules of their functioning.

Significant values of lateral forces constitute explanation of common problems and failures caused by mechanical aspects. A term of biomechanical compatibility that has been introduced to common consciousness by manufacturers, in the light of unambiguous results of this analysis, should be perceived only as a marketing measure. In the advertisement there is used a phenomenon, independent from the type of attachments, that almost 100% of implants introduced in anterior part of mandible characterized by sufficient bone conditions are successfully retained.

Atrophic processes in bone tissue around the implant mainly depend on implant bending, so in fact on lateral loadings [27-31].

Effects of forces acting on a mini implant of a diameter of 2.0 mm are shown in Figs. 6-9. Level of stresses in implant on fig. 6 is high. At the margin there is a visible area where stresses reached yielding level of 700-880 MPa for cold forged titanium alloys Ti6Al4V [32]. This area is small and does not create a danger of instantaneous implant break. Nevertheless, construction works without a safety margin. This fact creates high requirements regarding the quality of the alloy and used technology. Any, even insignificant defects in implant surface finishing contribute to decrease of life-time [33]. Distribution of equivalent stresses in cortical and cancellous bone are shown in Fig. 7. In Fig. 8 there are presented diagrams of equivalent stresses, as well as minimal and maximal principal stresses along G1 path at the side of the bone loaded by the bent post. In Fig. 9 there were presented stresses profiles in cancellous bone along G2 path. Especially dangerously high stresses values can be observed in implant introduction area in cortical bone. Values in parts of the bone exceeded cortical tissue strength parameters. There is marked on the diagram an average shear strength of 68 MPa [34]. Equivalent stresses reach higher value up to the depth of 0.5 mm. It should be taken into account that stresses in bone tissue should not even exceed much lower values if the risk of tissue atrophy being an effect of cycling overloading is to be minimized. Which are in case of tangent stresses on the level of 30-35 MPa [30].

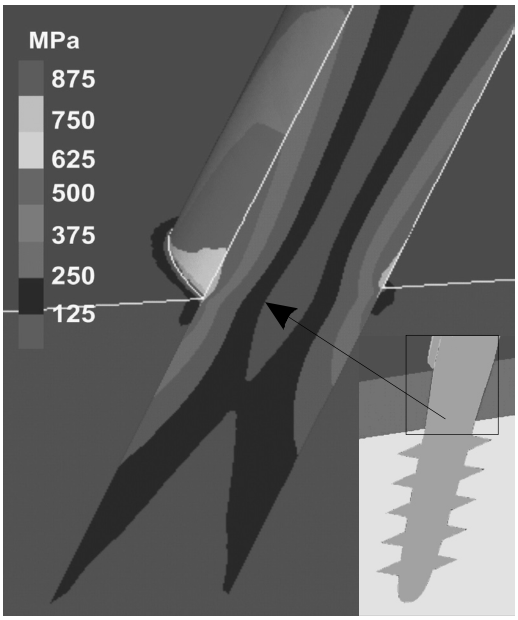

Fig. 6. Distribution of equivalent stresses (H-M) in implant having diameter of d = 1.8 mm for the variant of loading with a horizontal force of 70N

Also in cancellous bone strains values reach significant level, which in many cases would exceed the strength. Hence, in practice successful implants maintenance depends on the strength parameters of the tissue in the not-overloaded areas that have to be sufficient for loading transmission.

Analyses results are in line with observed in practice “funnel-shaped” cortical bone defects surrounding implant neck. A loss of tissue not larger than 0.5 mm during the first year of denture wearing is recognized as clinical success. Area of the overloading zone (values higher than 30 MPa) is covered by a similar range. Hence, these results have a good relation to reality. During further years of denture wearing acceptable are further atrophic shifts within the range of 0.1-0.2 mm/year. If such assumption is made, it is very hard to guarantee implant endurance in a period longer than 10 years. Acceptance of such significant atrophy in a long-term forecast denotes gradual exposure of implant thread. Bending implant in such a a situation generates significant strains around geometrical notch, which is constituted by the exposed thread. In the described situation fatigue processes very often lead to implant break, especially in case of mini-implants.

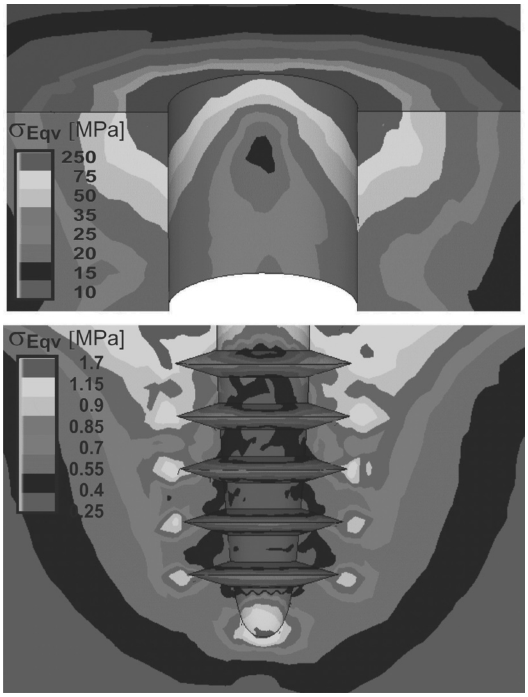

Fig. 7. Distribution of equivalent stresses (H-M) in cortical and spongy bone around the implant having diameter of d = 1.8 mm for the variant of loading with a horizontal force of 70N

In the model analyzed in this study, as well as in other results presented in branch literature, there are not taken into account any installation deviations. Attachments location in relation to implants is characterized by spread. Even insignificant location deviations constitute a source of additional lateral loadings on implants in rest condition. Deviations in attachments positioning creates a root-cause of mucous membrane injuries. They result in a constant mucous membrane stress, as well as in overloading of its particular areas. Deviation in attachment position introduces „favorable" directions of hinge movement that is realized by the denture. In that way it comes to a constant overloading of one area on soft foundation, in spite of the fact that in resting condition there are no stresses to be found. Problem of mucous membrane injuries in case of implant-retained dentures is very common. Due to the fact that, injuries require use of permanent relining, worth mentioning here are non-commercial attachments solutions, which are realized directly in silicone relining.

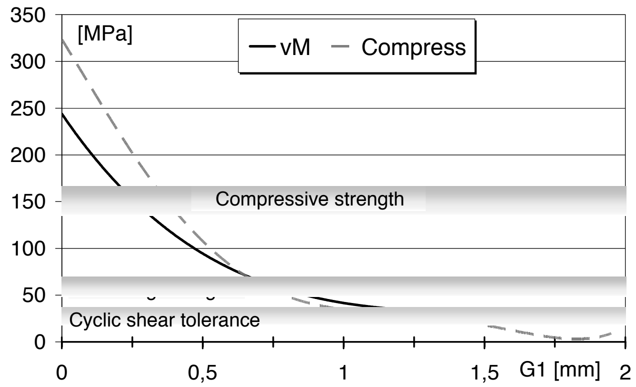

Fig. 8. Minimal stresses „compression" and equivalent stresses „vM" in cortical bone along G1 path

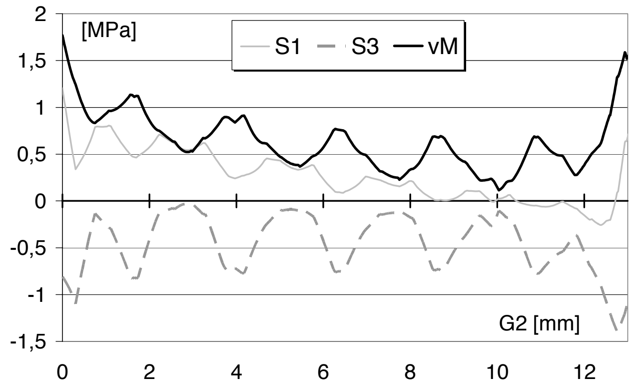

Fig. 9. Maximal „S1", minimal „S3" and equivalent stresses „vM" in cancellous bone along G2 path

This type of attachments demonstrate lateral compressibility, which ensures incomparably higher biomechanical compatibility than the currently available commercial attachments. According to mechanics principles, the less rigid is the support, the lower value is reached by the reaction force. In presented studies [29,35,36] and analyses of mastication loads distribution it has been shown that use of silicone attachments makes it possible to reduce implant loading drastically. Moreover, attention should be paid to the fact that this type of attachments ensure significantly higher level of tolerances for installation deviations. Lateral compressibility allows for eliminating of initial loading of the post in the important initial osteointegration period. Until now, one of the unused advantages of silicone attachments is the possibility of adjustment attachments compressibility characteristics to individual resiliency topography of mucous foundation.

4. Conclusions

On the basis of the carried out FEM analyses it can be said that there can be observed the area of overloaded bone around the neck of the implant in case of dentures retained on two mini-implants by means of commercial attachments. In order to eliminate overloading effects there should be used non-commercial silicone attachments, which deserve the name of "biomechanically compatible" due to their lateral compliance. This kind of attachments, remarkably decrease implants loading, which creates new possibilities of using in implants production materials that have lower elasticity modulus, that is better fitted to bones than titanium and its alloys.

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