BIOMECHANICAL STUDY OF DISK IMPLANTS
Part II

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The presented work follows the first part [1], which is focused on the analysis of bone tissue in terms of dependence of bone tissue 'quality' and its subsequent behaviour based on the stress around the disk implant when biting.

This second part is focused on the stress-strain analysis (and tolerability) of disk implants as loaded during the masticating process.

The study includes two types of disk implants (single-disk and double-disk), three types of anchorage, four degrees (stages) of osseointegration in three quality degrees of the cancellous bone. The study, as expected, has shown that the problematic area of the implants is a transition between the implant body and the disk component, where the equivalent stress in the analyzed implants reaches 700 MPa.

Keywords: *disk implant, osseointegration, FEM, mandible, density*

1. Introduction

Disk implants have been developed for the application in the mandibles with low quality of the bone tissue; therefore the first part of the study was devoted to a detailed analysis of the behavior of the bone tissue around the applied disk implant. The second part is focused on the stress-strain analysis of the disk implant.

The main purpose of disk implants is the functional applicability in the bone tissue with a low quality where other types of implants fail. Disk implants are composed of one or more disks, different shapes, and pins for mounting to the implant body, see Fig. 1.

To ensure that the functionality of the implant in the mandible with low quality of the bone tissue is achieved, a large contact area of the disks with the cancellous bone tissue has to be obtained, but it is also necessary to achieve the interaction between the disk edge and the cortical layer of the mandible. Disk implants are inserted to the mandible from the side, where drills and cutters created a convenient bed. The implants are inserted during a single operation and may be subsequently loaded [2].

The development of these implants dates back to the last third of the last century when in 1972 French Dr. Jean-Marc Julliet established this type of the implant. In 1980 Dr. Gerard Scortecci introduced an improved technique to insert this implant; a significant progress has been observed in the medical instruments (cutters and drills). Today, there are several companies which distribute this implant around the world and are involved in its development. The most well known are Dr.Ihde Dental (Switzerland, Germany) [3], AirPerio (France) [4], and Victory (USA) [5].

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2. Materials and methods/experimental

The presented work is based on the biomechanical study of the mechanical interaction between the implant and the bone tissue. Two implants were solved with one and two disks for the three variants of the anchorage in the bone (see Fig. 1). In variant A, the mechanical interaction is between the implant disk, the inner and the outer cortical bone. In case of variant B, the interaction is only with the outer cortical bone, while in case of variant C the implant disc is smaller than the space between the outer and the inner cortical bone. This last variant represents the interaction with the cancellous bone only.

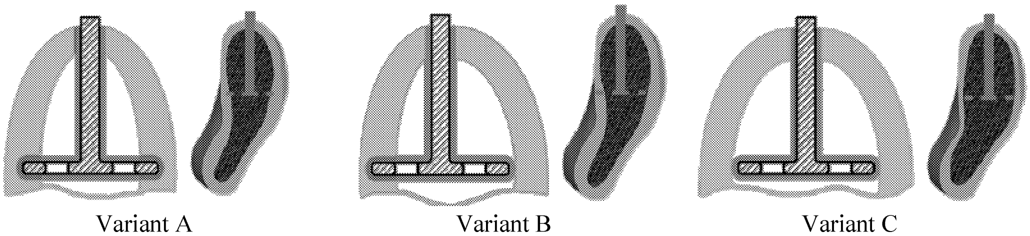

Fig.1: Variants of implant's anchorage

In this study, two states are considered in terms of the interaction between the implant and the bone. First the state where the complete implant-bone osseointegration [10] occurred followed by the state where the complete implant-bone osseointegration did not occur and therefore the mechanical iteration between the implant and the bone is not present. In clinical practice, there are cases where a transitional layer of a fibrous will be created between the implant and the bone [6]. Dentists consider this state as a failure; therefore it is not a subject of this study.

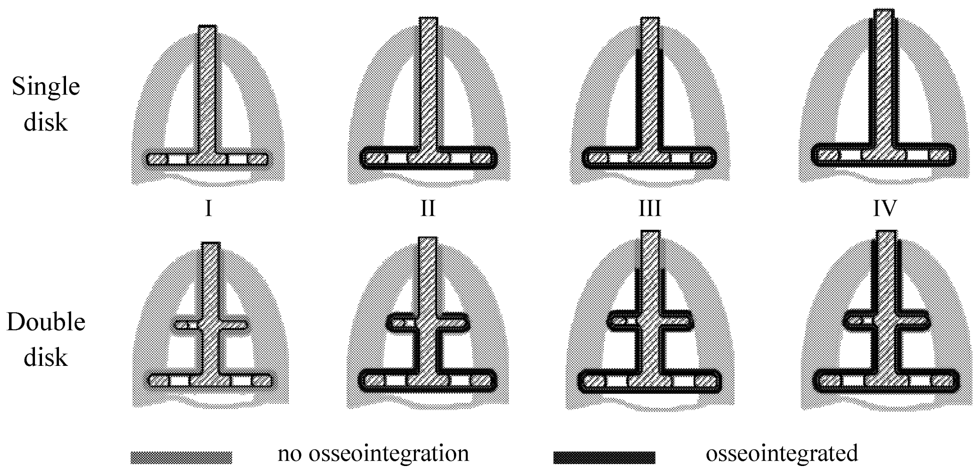

Fig.2: Variants of the anchorage in the mandible

This study takes into consideration four stages of osseointegration (see Fig. 2). The light grey line represents the outline of the area where the osseointegration did not occur and the dark grey line represents the outline where the osseointegration occurred.

3. Solution method

Based on the analysis of the shape, the material properties of the system components, the character of the system constraints (elements), the experience with similar problems solved, and the workplace equipment, the finite element method (i.e. numerical calculation method) has been chosen as the effective method of the computational modeling.

A computational model respecting the subsequent numerical solution of the finite element method includes four relatively independent parts: model of geometry, materials, loads, and constraints.

4. Model of geometry and constraints

The problem solved in this work is the mechanical interaction between the disk implant and mandible bone tissue. The shape, material characteristics, and constraint properties of the implant affect strain and stress fields only in their close vicinity.

The geometry model of the bone is created as a 20 mm-long section of the mandible. More precisely, this section represents the first molar region. Mandible geometry was obtained from the real mandible shape using the optical scanner ATOS Standard. The cortical bone thickness was modeled on the basis of CT images.

Dimensions and shape of the implant are based on the catalogues of companies Ihde [3], AirPerio [4] and Victory [5] – see Fig. 3.

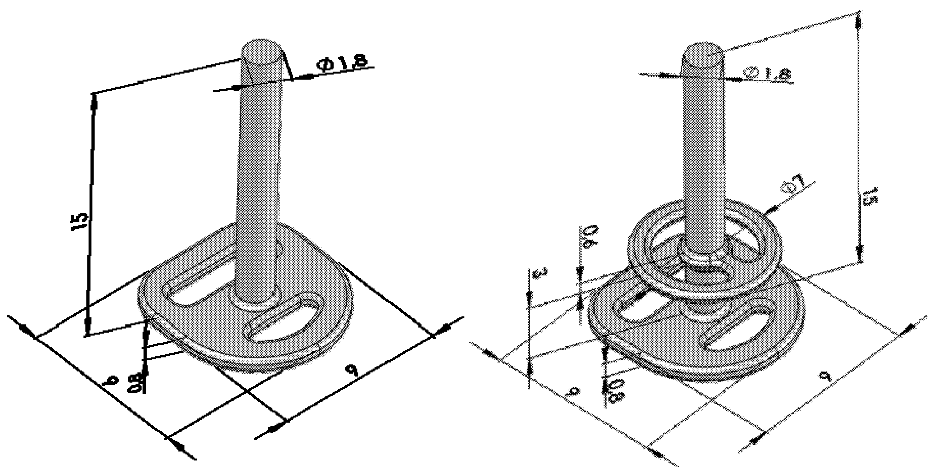

Fig.3: Geometry model of disk implants

5. Material models

The parts forming the real system are from different materials. Most disk implants of previously mentioned producers are from the titanium alloy Ti6Al4V; therefore the material of the implants in the presented study is the Ti6AL4V. In terms of the level of the solved problem, the appropriate and validated model of mechanical properties is homogenous, isotropic and linearly elastic model, which is explicitly described by two material characteristics: Young's modulus (E) and Poisson's ratio (μ). For this model, based on the analysis of the objectives of this study, titanium alloy Ti6AL4V has been used.

The bone – i.e. a part of the mandible – is composed of the cortical and cancellous tissue; a description of mechanical properties of the cortical but mainly the cancellous bone tissue is much more complex. The use of a higher level model of the cancellous bone tissue hinders on the absence of verified material properties. This was the reason why for the cortical as well as the cancellous bone tissue, the Hooke material model has been used. In the case of cancellous bone tissue, the solution has been carried out for three values of the material characteristics for different quality of cancellous bone tissue, see Tab. 1.

Material	E [MPa]	μ [–]
Cancellous bone	100, 200, 300	0.3
Cortical bone [7]	13 700	0.3
Titanium alloy [7]	116 000	0.34

Tab.1: Mechanical properties

6. Model of loads and constraints

During mastication, the tooth is loaded in a general direction. After a decomposition of the general loading to the coronoapical (CP), buccolingual (BL) and mesiodistal (ML) directions, the largest component is in the coronoapical direction. All three directions are included in the study. The value of dominant component, 190 [N], was taken from literature [8], [9]. Values in the direction BL and MD are much smaller, 17 and 21 [N] respectively, and were taken from [8].

In the end section of the bone model (the side of the TP joint), displacements in all direction s are prohibited in all points.

Two states are considered for the contact between the implant and the bone, as has been previously mentioned. The state where the complete implant-bone osseointegration occurred and the state where the complete implant-bone osseointegration did not occur (see Fig. 2).

In case of the complete osseointegration, the constraint between the implant and the bone tissue is rigid. If no osseointegration occurred, the connection between the implant and the bone is applied by the contact-type constraint. The variant states of osseointegration in the individual areas of the implant and the bone tissue contact are shown in Fig. 2.

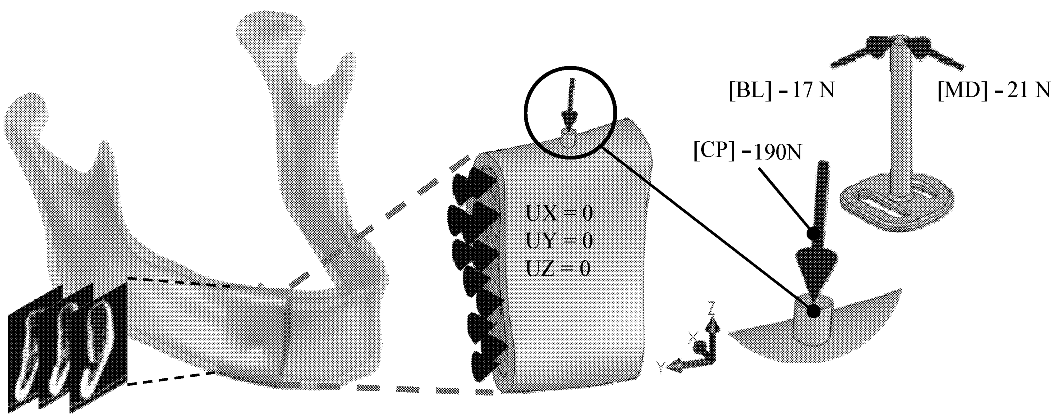

Fig.4: Segment solution of the mandible with the implant

7. Computational – Finite Element Model

To create a computational model for a computational solution by means of the finite element method, it is necessary to respect rules and the boundary conditions of the system. In our case, it is the system Ansys 11.

The meshing was carried out using elements SOLID187 and SOLID186 and for implementing the contact-type constraint, these were CONTA174 and TARGE170 which belong to the standard libraries of the system Ansys 11 [11].

Maximum attention was paid to the meshing (see Fig. 5) as the number of elements and nodes was different in the individual variants. In case of elements the number ranged between 100 and 260 thousand, and in case of nodes this number ranged between 400 and 600 thousand. Contact surfaces were bounded with 10 to 30 thousand contact element pairs.

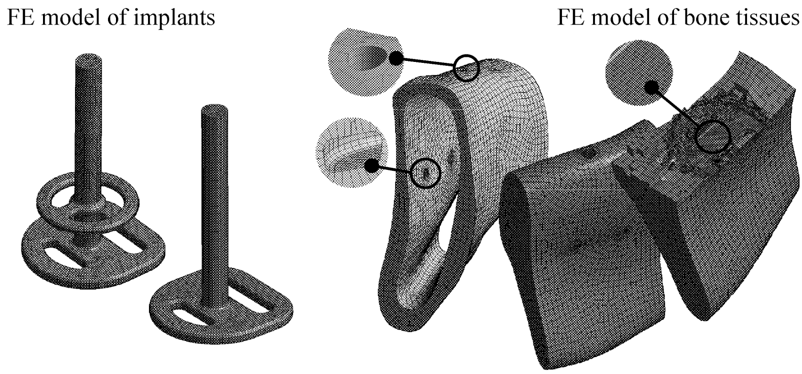

Fig.5: Discretisation

8. Solution

To assess the mechanical interaction of the implant with the bone, 24 computational models were created for two different types of the implants, four stages of the osseointegration and three variants of the implant's anchorage in the bone.

To assess the impact quality of the cancellous bone tissue, the solution was made for three values of modulus of elasticity of the cancellous bone; 100, 200 and 300 MPa respectively.

The used hardware and solver settings were the same as when solving the problems in the first part of study. Hardware parameters and solver settings are described in detail [1].

9. Presentation and analysis of results

The failure of the implant in the human body is always unpleasant and causes many losses not only of economical character but also institutional and personal losses, such as loss of good reputation, prestige and trust. Issues related to successful implantation are usually complex and require a profound analysis which usually identifies the possible causes. Provided that the possible cause is from the area of biomechanics, the analysis is very difficult because it is not easy to express biomechanical limit states.

When predicting the limit states, it is suitable to carry out the check-ups of all possible limit states which can be performed, especially those which are followed by other possible limit states, such as limit state of elasticity, which is a focus of this study.

In case of mechanical interaction between the implant and the mandible during chewing, a general tri-axial stress-strain state arises in both bodies. To assess the limit state of elasticity, the equivalent stress was determined on the basis of the yield criterion von Mises.

9.1. Influence of implant anchorage in the mandible

Figure 6 shows isosurfaces of intervals of the equivalent stress for various variants of the anchorage and one/double-disk implant. The modulus of elasticity applied on the cancellous bone was 100 MPa. Equivalent stress differences of the various options can be well due to the same scale of the stress. The maximum value of the equivalent stress is for all variants of the anchorage in the transition between the disk and the implant body. In this area, high concentration of equivalent stress is also apparent. The greatest value and the largest area with high value of the equivalent stress are with variant B while with C, the value of the extreme equivalent stress is the lowest; however this variant is not allowable in terms of large strain of the bone tissue. In this variant, the principle of the disk implants – mechanical interaction of the implant with the cortical bone tissue – is not realized. The most favourable anchorage among the rated ones is variant A. A similar character can be ascribed to the analysis of extreme equivalent stress of double-disk implants but the stress values are 15 % lower.

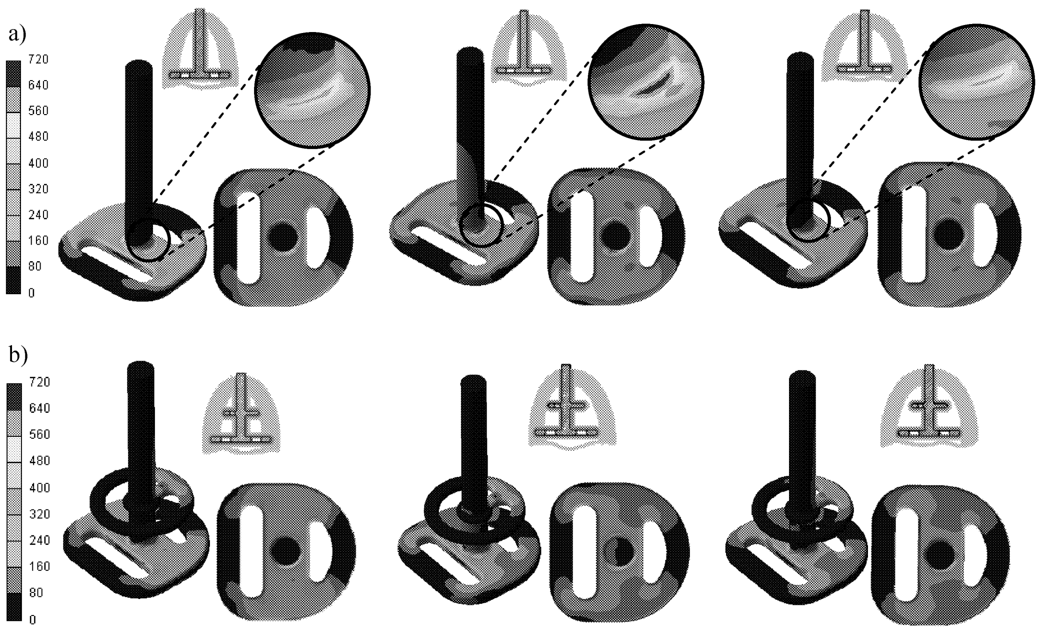

Fig.6: Influence of anchorage on the size of equivalent stress of: (a) one-disk implant, (b) double-disk implant

9.2. Influence of osseointegration stage on the stress in the implant

As for the load, the healing stage affects the stress most as shown in Fig. 7. The stress is significantly lower during the complete osseointegration stage than during the stage when the implant is not integrated into the bone; i.e. after implantation. The double-disk implant anchorage, variant A, is shown in Fig. 7. In the first stage of osseointegration, the equivalent stress decreases by 10.1 %, then by 28.8 % compared with the previous stage, and finally by 58.4 % when the cortical bone grows onto the implant body.

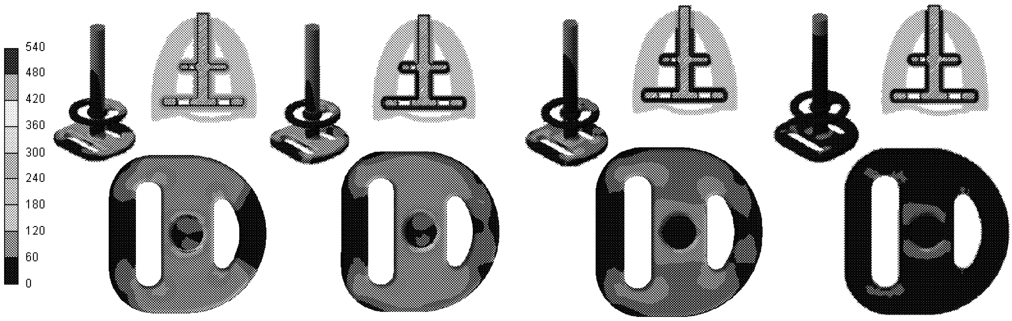

Fig.7: Influence of osseointegration on the size of the equivalent stress in the implant

Values of the equivalent stress for all the solved cases are shown in the charts in Figs. 8–10. For all variants, a dangerous area is in the transition between the neck and the disk of the implant. The differences between the various stages of osseointegration I–IV, and the variants of anchorage A, B, C are obvious from the charts. The differences between the one-disk implant and the double – disk implant are obvious as well. For all other parameters the highest equivalent stresses are in variant B. The lowest stresses are in variant C where the implant disk and the cortical bone are not integrated. This variant is unacceptable because of large stress of the cancellous bone tissue [1].

The quality of cancellous bone tissue affects significantly the stress of implant, which reflects the value of the modulus of elasticity in this study. With the increasing quality of bone tissue, the stress level decreases. The disk of the implant is in the mechanical interaction with the stiffer material, the ratio values of the modulus of elasticity in the cancellous and the cortical bone decrease, deflection of the disk decreases, and the stress concentrators also decrease. The stress of the disk after decomposition is more even, and safety due to the mechanical failure increases.

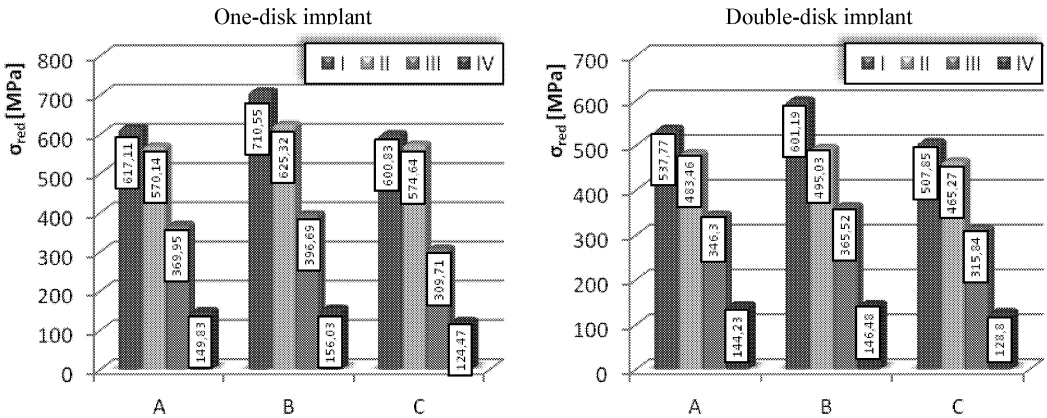

Fig.8: Maximum values of the equivalent stress for different stages of osseointegration and the anchorage for the modulus of elasticity of the cancellous bone 100 MPa

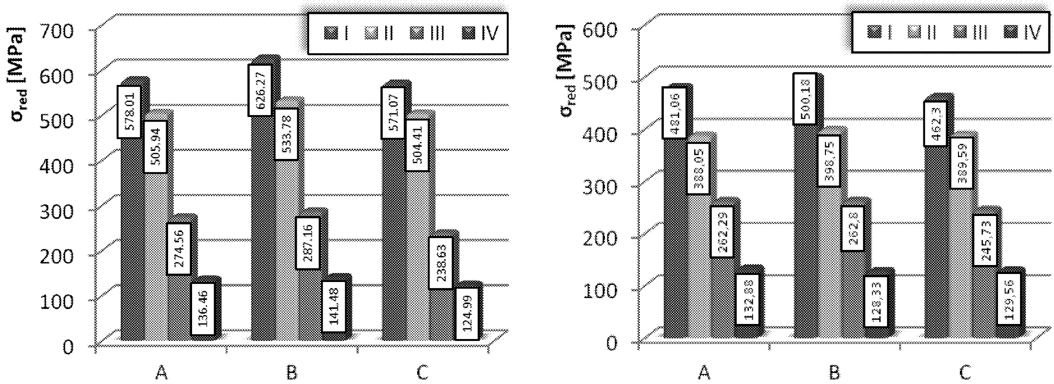

Fig.9: Maximum values of the equivalent stress for different stages of osseointegration and the anchorage for the modulus of elasticity of the cancellous bone 200 MPa

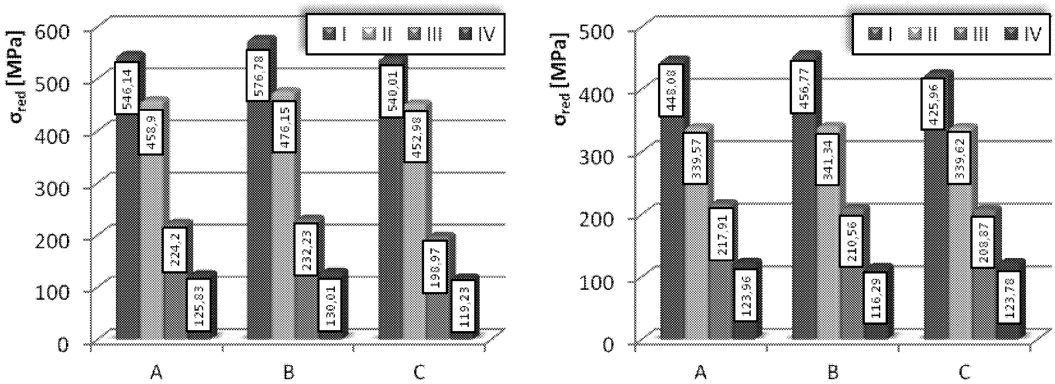

Fig.10: Maximum values of the equivalent stress for different stages of osseointegration and the anchorage for the modulus of elasticity of the cancellous bone 300 MPa

9.3. Influence of side forces load on the stress of the implant

Furthermore, this study is focused on the assessment of the model loading level. This assessment of the influence is related to the components of forces in the BL and MD directions, Fig. 11.

In the first three stages of osseointegration, for the load in the direction of BL and MD, the size and the location of the maximum equivalent stress are the same. The mechanical interaction of system elements and consequently the stress concentrator change significantly in 4th stage of osseointegration, which can be seen both in terms of the location of the area and also in terms of the maximum equivalent stress value.

If the implant is loaded by the components of forces in all directions (CP, BL, MD), or possibly only in the direction of the largest component, i.e. in the coronoapical direction, the value of the maximum equivalent stress remains the same, Fig. 12. In terms of the implant safety, the influence of load of the implant in the direction BL and MD is insignificant due to the limit state of elasticity.

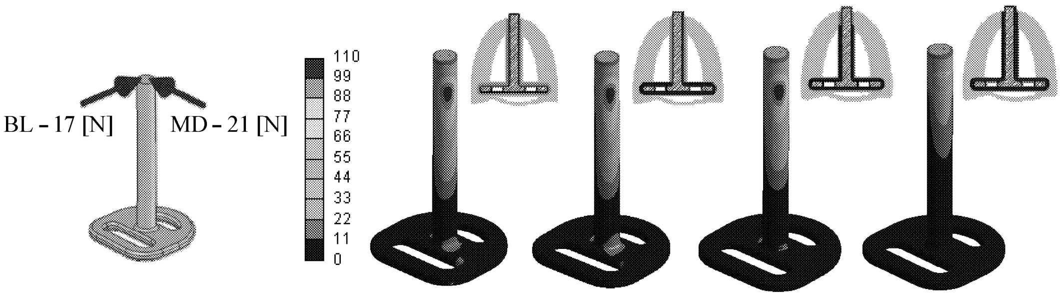

Fig.11: Influence of side forces load on the stress of the implant for 4 stages of the osseointegration

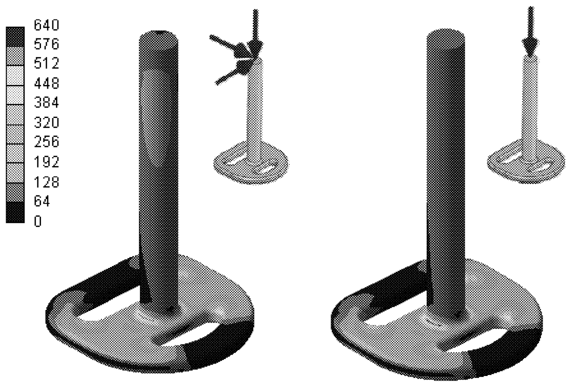

Fig.12: Comparison of the size of the equivalent stress in the implant for two cases of load

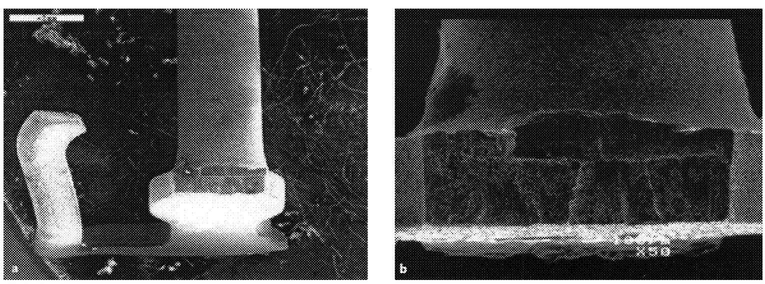

Fig.13: Broken disk implant [2]

10. Discussion

The literature or discussions with experts from the clinical practice describe the failures of the implant (Fig. 13) [2].

The stages, in which the implant is applied, are of complex character. Though we consider the diversity and wide range of aspects, which implants have to meet in terms of mechanical failure, the safety due to the limit state of stress and the fatigue damage of the implants is of crucial importance. When performing stress-strain analyses of dental implants, the authors of this article sporadically came across high stress of the implant in the areas of stress concentrators of bone-implant mechanical system, which is also the case of the implants presented in this study. For these implants, the authors only provided the necessary technical documentation created on the basis of produced and commercially available implants. The maximum value of the equivalent stress is 710.55 MPa (Fig. 8) for material Ti6AL4V, which is the most commonly used material for dental implants; this value represents 80 % of the yield strength (yield strength of the titanium Ti6AL4V is according to the literature in the range of 820–900 MPa [12]).

Considering the character of the masticating process, the maximum equivalent stress may be taken as the value of maximum stress of masticating cycle. Therefore it is advisable to carry out at least an approximate examination in terms of material fatigue. Considering the value of fatigue strength of titanium alloy of approx. 500 MPa [13] for the symmetric cycle and accepting the possibility of occurrence of dynamic factor, it can be concluded that during mastication the equivalent stress reaches the values of fatigue strength.

11. Conclusion

The second part of this biomechanical study of the dental disk implant was focused on the stress-strain analysis of the implant-bone system and the stress analysis of the implant. Attention was paid to the limit state of elasticity and partially to the limit state of fatigue failure.

1. The maximum value of the equivalent stress is in the area of transition between the implant disk and body. It is a critical area, which deserves an increased attention in the construction stage.
2. Clinically (in terms of implantology), among the anchorage variants, only variant A is permissible. Graphs in Figs. 8–10 enable us to imagine how the break of this condition would affect the maximum equivalent stress of the implant, the quality of bone tissue and the degree of osseointegration.
3. Graphs in Figs. 8-10 further allow us to evaluate the impact of osseointegration on the maximum value of the equivalent stress of the implant. Considering this criterion, substantial decrease of the maximum value of the stress (approximately 50 %) due to the osseointegration on the implant body can be observed.
4. The maximum values of the equivalent stresses of this study implant are prohibitively high.
5. The conclusions concerning the location of critical area are in compliance with [2]. This area is also referred to as the area of the most common failure of disk implants.

These conclusions were based on the biomechanical study. The problem of the interaction between the implant and the bone is a complex problem, where other aspects (clinical, biological, biochemical, etc.) are also significant and have to be taken into consideration when carrying out a complex assessment.

For coloured figures, see website http://biomechanika.fme.vutbr.cz/index.php?lang=en – Main Menu – Articles – 'Biomechanical study of disk implants'.

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