ISSN 1392–1207. MECHANIKA. 2014 Volume 20(5): 460–465

Numerical analysis of stresses in the dental implants: case of three implants

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crossref http://dx.doi.org/10.5755/j01.mech.20.5.6664

1. Introduction

Dental prostheses have become a significant aspect of tooth replacement in prosthodontic treatment [1]-[3]. High implant success rates of the order of 78-100% have been published, with more than 15 years of observation time [4]-[6].

A dental implant refers to an artificial dental root planted in the jawbone in place of a lost natural tooth. Since the osseointegration concept of directly fusing organic tissues with metals was introduced by Branemark in 1952, single tooth implants and completely edentulous implants have become the most commonly practiced methods [7], [8]. In an implant, a part planted inside of the jawbone for the purpose of providing physical support is referred to as the fixture. A screw is used to connect this artificial dental root with an abutment which is attached to an artificial tooth. This is a popular method at the present time as it enables one to recover to the dental state prior to the loss and to achieve outstanding results in both functional and esthetic qualities. However, as this method is associated with planting into the jawbone, a continual usage of the artificial tooth induces repetitive loads to be exerted due to the masticatory movements.

Various dental implant designs have been advocated to reduce the bone loss of crestal regions and the osseointegrated interfaces. The assumption is that these designs can decrease biomechanical stress/strain and, thus, decrease bone loss. Overloading may induce bone microdamage which can trigger osteoclastogenesis [8]. Sequentially, epithelial, connective tissues, and microorganisms can migrate into the defective area causing severe bone loss which decreases the height of supports to the implants and increas the risk of the implant failure [9].

There are three major design profiles in the fixture: threaded, stepped body, and tapered body designs. These designs have been proposed to improve the biomechanical behavior of oral implants. The use of the threaded implant may enlarge the contact area between the implant and bone, increase implant mobility, and help dissipating interfacial stresses [9]. Likewise, the stepped fixture is suggested to create favorable load distribution due to its mimicking nature of root form [10]. Another design concept is to redirect stresses using tapered shape of a fixture body. This type of implant was reported to raise implant survival rates. Due to the possibility of shielding the stress away from the crestal cortical bone while transferring it onto the trabecular bone [11].

In our time dental prosthetic-implant systems are widely used for treatment of partial and total edentulism. This wide diffusion has been promoted by numerous studies which have demonstrated the "biologic" effectiveness of the used materials (in particular Titanium and some of its alloys) [12, 13]. In spite of this diffusion some aspects have not been deeply investigated, like the mechanical resistance properties of implants and the stability of the connection between implants and prosthesis elements [14, 15].

The objective of this study is to analyze the level of stresses induced in the bone between three implants during mastication of food. The aim is to see if such implementation is not conducive to the weakening of the bones. To do this, we are interested especially in the effects of interaction between implants on the stress distribution in the bone and the implants

2. Geometric model

The three-dimensional model used in this study is composed of four elements: abutment, implant, cortical bone, osspongieux. This is the dental prosthesis whose

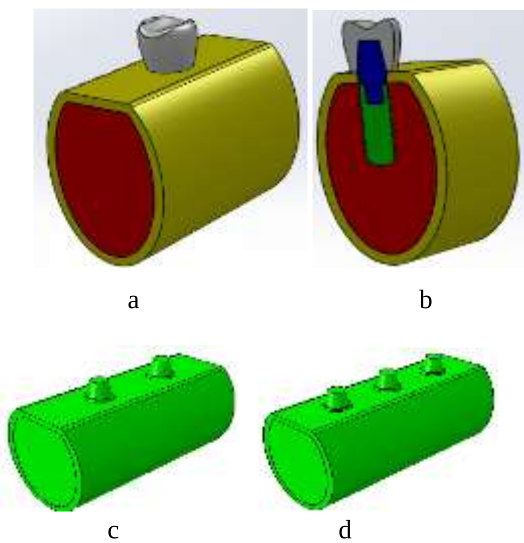
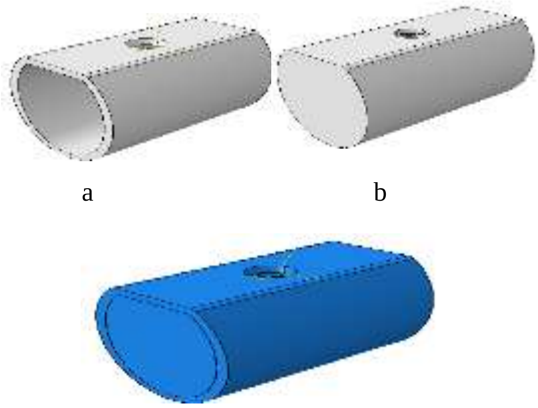


Fig. 1 Implantology models analyzed: a, b - dental structure elements: c - two implants models: d - three implants models

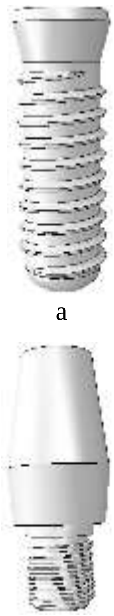
purpose is to analyse the level and distribution of stresses in the bone in the case of an implant using several implants. This study consists of the determination of stresses in the bone between implants during the chewing of food process. This process is simulated by dynamic efforts in three directions. The comparative analysis requires the study of implantologies consisting of a single implant, two implants and three implants models are represented in Fig. 1.

Bone is composed of spongy bone size: 24.2 mm height and 16.3 mm wide, this size is representative of the section of the lower jaw. Living Cetorgane made up of a spongy centre surrounded by 2 mm cortical bone (Fig. 2).



c

Fig. 2 Structure of the bones analyzed: *a* - cortical bone: *b* - spongy bone: *c* - structure bones



b

Fig. 3 Geometry of the implant and the abutment used in this study: *a* - the implant: *b* - the abutment

The implant is in the form of screw length of 12.3 mm and diameter of 4.2 mm (Fig. 3, a).

The abutment has the geometric characteristics of length $L = 8.9$ mm and diameter $d_1 = 2.8$ mm, $d_2 =$ $= 4.24$ mm (Fig. 3, b).

3. Used materials

Table

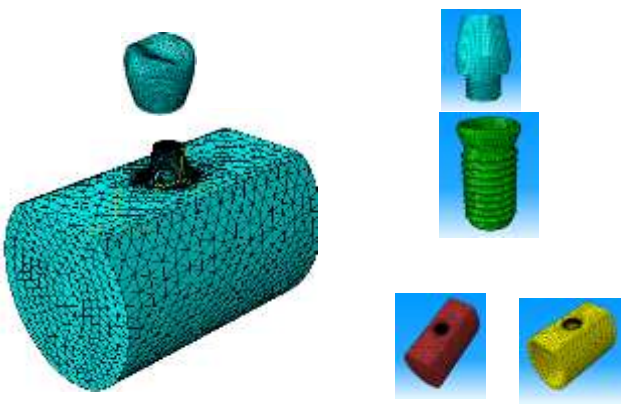
The mechanical properties of the materials used in this study are grouped.

Parts	Materials	Elastic modulus *E*, GPa	Poisson ratio *ν*	Tensile strength, MPa	Mass density, kg/m^3
Implant and abutment	Titanium Ti–6Al–4V	110	0.32	800	4428,8
Crown	Céramique feldspathique	61.2	0.19	500	2300
Cortical bone	Cortical bone (anisotrope)	$E_x = E_y = 11.5$ $E_z = 17$ $G_{xy} = 3.6$ $G_{xz} = G_{yz} = 3.3$	$\nu_{xy} = 0.51$ $\nu_{xz} = \nu_{yz} z =$ 0.31	130	1700
Cancellous bone	Cancellous bone	$E = 3$	$\nu = 0.3$	130	270

4. Material and method

The finite element modeling has been integrated into the biomechanical research for its ability to reproduce the behavior of a bone, joint or an implant, and serves as an alternative to the experiments in vitro, expensive and sometimes difficult to implement. The method involves a discretizing a continuous structure in a finite number of simple subsets forming a mesh, and allows to approach the mechanical response of this structure to a solicitation. It leads to the analysis of essential quantities that cannot be obtained by experiments: displacement, deformations and stresses, at any point of the tooth structure. Software design and computer-aided calculations are very numerous on the market. The most used are Catia, ABAQUS, Nastran and SolidWorks. All these software allow the design of industrial products, the analysis and resolution of complex problems. ABAQUS software has a powerful automatic mesh that can analyze the geometry and generate the most suited to the studied structures mesh. The analysis of the mechanical behavior of the denture requires the use of tetrahedral elements, type C3D4.

The domain is represented by number finite elements of simple form. Nodes are the peaks of the elements. Elements provide the coverage of the area with a maximum recovery. The total numbers the vertices of 575125 elements. In Fig. 4 is represented the mesh crawled denture and its constituents. The mesh has been refined to have credible results.



a b

Fig. 4 Mesh overall dental prosthesis and its onstituents: *a* - prosthesis dental: *b* - elements of dental structure

5. Loading conditions

The effects of interaction of charge cycles in a time of 5 seconds, as well as the area of application, have been selected as follows:

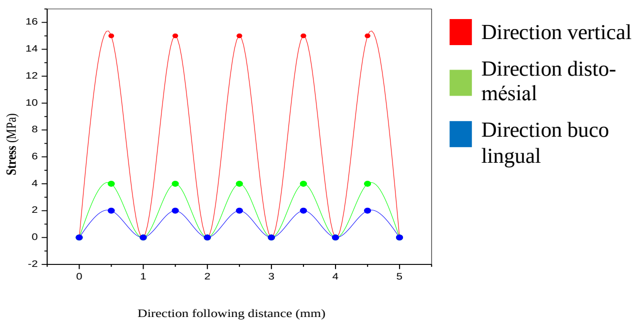


Fig. 5 Dynamic loading applied to the tooth structure

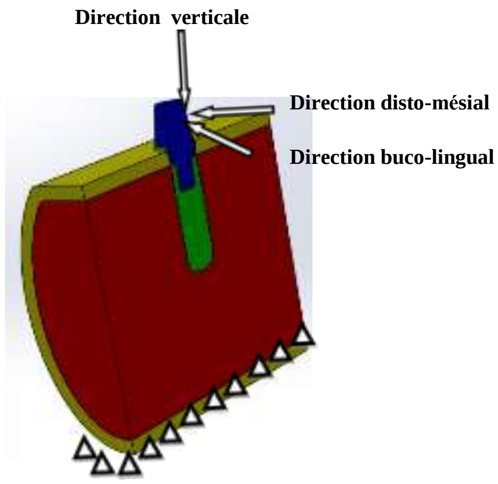


Fig. 6 Simulation of the masticatory and boundary conditions efforts

Three dynamic forces of intensity 4, 2 and 10 MPa on the occlusal surface system of implant following the vertical directions, disto-mesial and bucco lingual respectivement (Fig. 5).

Other surfaces are treated as free surfaces (zero effort).

Fig. 6 shows a section of the tooth structure meeting, and the elements constituting the boundary conditions imposed on the prosthesis.

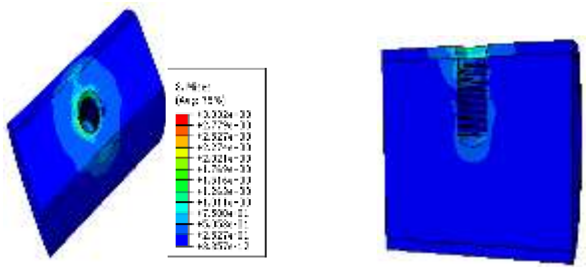
The model is fixed at its base, that is to say, no movement and rotation is permittedat the base of the cylindrical support. The three translations along the three axes U_x, U_y,U_z rotation and w_x, w_y, w_z are stationary.

6. Analysis and results

This study has aimed the three-dimensional analysis by the method of finite elements the level and distribution of stress equivalent of Von Mises induced in bone, the lower element of dental prosthesis, depending on the number of implants constituting the denture.

6.1. Cases of implant

Stresses induced in the bones of a settlement consisting of a single implant are shown in Fig. 7. The latter shows that it is in its part in contact with the implant that the bone is more strongly mechanically applied (Fig. 7, a and b). The distribution of the Von Mises stresses in the bone in the near vicinity of this area is not homogeneous. Indeed, they fuck intensity as and or move away from the more extensively solicited area.



a b

Fig. 7 Distribution of Von Mises stresses in the cortical and cancellous bone in a tooth structure to an implant: a, b - cortical and cancellous bone cases implant

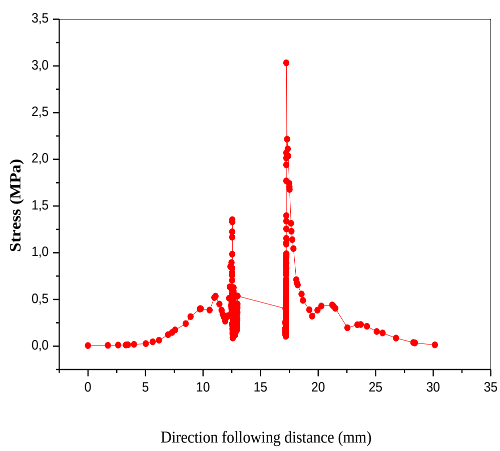


Fig. 8 Variation of stress of Von-Mises induced in bone implant-implant distance

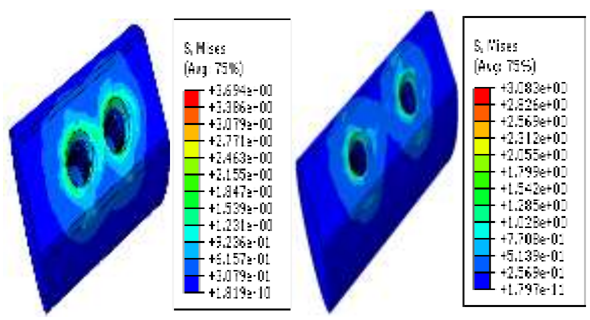
The results shown in this figure are consistent with those shown in Fig. 8. In fact, the stress induced in the bone believes peaked and then tends towropes initial level. The maximum current is reached in the zone of contact with the implant.

7. Interaction effect

The objective of this study is to analyze the level and distribution of stresses in the bone during the implant-tation of several implants close to one another. The aim of this study is the proposal of a new technique of implant-logy which consists in the implementation of three im-plants to support two teeth. We analyze if such a technique does not damage to the bone. This is the objective of this study. This work is to analyze the intensity of Von Mises equivalent stress induced in bone in its part located between the implants. Two types of implant have been stu-died. This intensity was analyzed not only based on the number of implants, but also of the distance separating them.

7.1. Cases of two implants

In this part of the work stresses induced in the bone level between two implants depending on their distance. The results are shown in Figs. 9 and last 10. These show that the equivalent stress level is most significant in the area of the bone at the close of the implant, part neighborhood into intimate contact with the implant. Implantation of a second implant in the vicinity very Pocket first led to an increase in the level of stress in the bone between these two components. The extent of the area under stress is more pronounced on the lateral part of this element (Fig. 9). Two implants in the neighborhood very close to one another induced in bone between these two components of the denture from the constraints of Von Mises of high amplitudes. (Fig. 9). it is in its upper area that the bone is more extensively solicited. Implant-implant interaction effect is little marked when two implants are located far from one another. The corresponding constraints to such a provision are of a level comparable to that of the constraints caused by a single implant.



a b

Fig. 9 The stress distribution of Von Mises in the cortical and cancellous bone in dental structure two implants: a - distance between two implants 0.5 mm: b - distance between two implants 10 mm

In the Fig. 10 is represented the variation of equivalent Van Mises stress induced in the bone the distance separating two implants of a dental structure. Implantology using two implants implanted one next to the other induced higher stresses when they are located at distance from the other. This increase is mainly due to the interaction of their stress around each implant field.

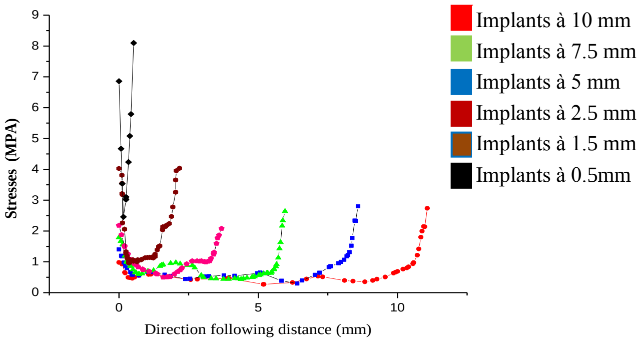


Fig. 10 Variation of Von Mises stress induced in the bone-implant distance function implant

7.2. Case of three implants

In this case the equivalent stress Von Mises was analyzed in the bones of a composed of three implants implantology. We analyze this stress level created in the bone in the vicinity of a central implant depending on the distance to two other implants located on part and sides of this central implant (Fig. 11). This interaction causes an increase of this constraint from the cited cases. A reduction of the distance between the central implant to the two others located at the ends of the dental structure entails an interaction of this greater stress field (Fig. 11, b). One such interaction results in the bones of the strongest constraints. A more significant trend of two external implants to that located on the central part of the induced bone in this component of the dental structure, slightly stronger constraints as shown in Fig. 11, c. Implantation in the bones of three implants in the close vicinity of the other results a strong interaction of the fields of constraints in this component around each implant as shown in Fig. 11, d. In this case, extended high stress area is much larger. These constraints are seeking the bones in its upper and lateral parts. The level and the stress distribution in bone around the central implant do not reflect those resulting from a dental structure consisting of one or two implant (Fig. 11, *f*) the results shown in this figure show that the implantology using three implants induces bone of Von Mises equivalent constraints more significant than those composed of one or two implants. It is in living tissue around the central implant that constraints are highly loca-lized. Our results show that a dental structure composed of three implants weakens the fabric alive by interaction ef-fect of the stress fields in this element around each implant.

The stress level equivalent of Von Mises induced in the bone around the central implant the distance that separates the two other implants located on part of it is shown in Fig. 12. The latter shows that a trend of external implants to the Central implant causes bone of increasingly high-stress. The interaction of the stress fields induced in the bone in the near vicinity of each implant is the cause of this increase in the level of stress.

Fig. 13 shows the results of a comparative analysis between the stress induced in bone belonging to a two implants dental structure and resulting from prosthesis to three implants. Implantation in the bones of three implants in this component of larger than equivalent Von Mises stresses induced by the implementation of two results, regardless the distance separating these elements.

Remember that low levels of the stress recorded in the bone are mainly due to the numbers of constituents of the dental structure analyzed in this work. They are the number of four (abutment-implant-bone), instead of six (Crown-door Crown-abutment-implant-bone).

The proposal of a new technique of Dental implantology consisting of three implants to support two teeth can be fatal for the bone. Indeed it is a source of additional stress in the bone by interaction effect.

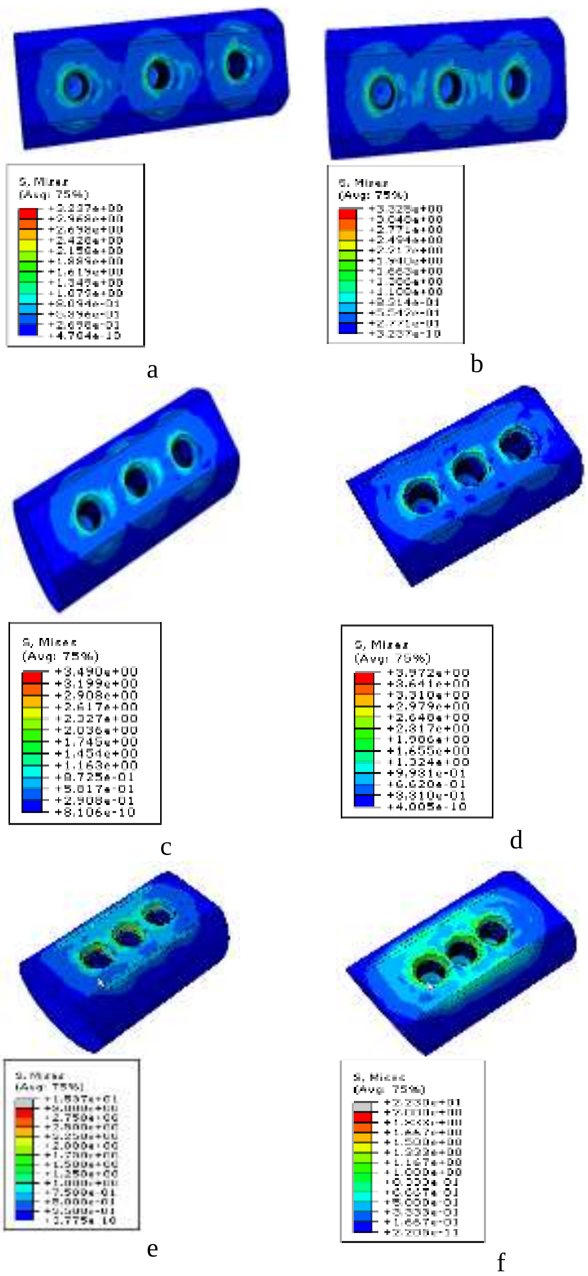


Fig. 11 Distribution of Von Mises stresses in cortical and cancellous bone subjected to dynamic loading: a - distance between two implants 10 mm: b - distance between two implants 7.5 mm: c - distance between two implants 5 mm: d - distance between two implants 2.5 mm: e - distance between two implants 1.5 mm: f - distance between two implants 0.5 mm

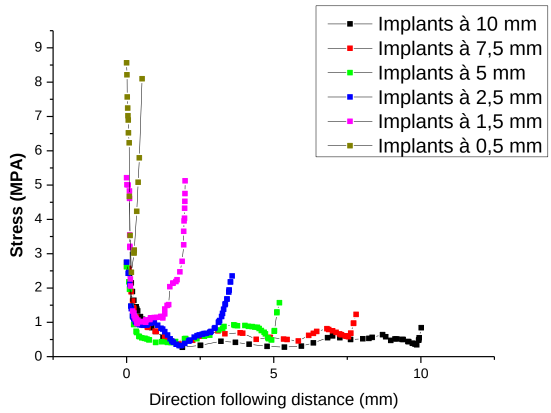


Fig. 12 Variation of Von Mises Stress induced in the bone-implant distance function implant

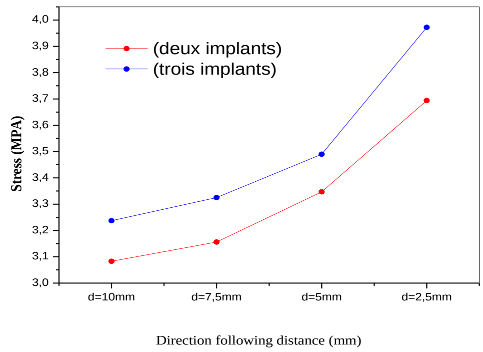


Fig. 13 Variation of Von Mises stress induced in depending on the distance between implant

8. Conclusions

The results obtained in this work show that:

1. The dental implant using implant induced during mastication of food simulated in this case by 3-d efforts, in the living tissue of the constraints on its upper part.

2. Denture consisting of two implants causes bone of constraints more intense than those resulting from a dental structure consisting of a single implant - the distance determines the level of stresses in the bone.

3. Implantation of an implant in the close vicinity of another spawns in the bones of the most important constraints.

4. The distance between three implants determines the intensity and distribution of the Von Mises equivalent constraint in the bone in the near vicinity of the central implant.

5. Implantation in the bones of three implants in the vicinity very close to generate as a result of the efforts of mastication, pressures greater than those induced by two implants.

6. The extent of the area of bone under constraints is closely linked to inter distance implant-implant. The reduction of this distance causes a greater spread of this area.

7. Establishment in the bones of three implants is the result of stress level and distribution different from that using a one or two implants.

8. The intensity of the equivalent stress generated in the bone near the central implant depends on the dis-

tance separating the implant to the other two located at both ends.

9. Regardless of the distance separating the implant, implantation in the bones of three implants generate pressures greater than two implants.

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ĮTEMPIŲ DANTŲ IMPLANTUOSE SKAITMENINĖ ANALIZĖ: TRIJŲ IMPLANTŲ ATVEJIS

R e z i u m ė

Šio tyrimo tikslas yra ekvivalentinių Von Mises įtempių kauluose, sukeltų dinaminių jėgų kramtant baigtinių elementų, skaitmeninė analizė. Tikslu pasiūlyti naują dantų implantologijos metodiką, ribinės sąlygos užduotos priklausomai nuo implantologijos pobūdžio t.y. implantų skaičiaus ir juos skiriančių tarpų.

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NUMERICAL ANALYSIS OF STRESSES IN THE DENTAL IMPLANTS: CASE OF THREE IMPLANTS

S u m m a r y

The objective of this study is numerically analysis by finite element method the level and distribution of equivalent Von Mises stresses induced in bone during the masticatoire simile process by dynamic forces. These constraints are evaluated according to the nature of implantology, i.e. on the basis of the number of implants and the distance separating them with the aim to propose a new technique of Dental implantology.

Keywords: stress, bone, implant, abutment, dental implant, distribution, stress levels, dynamic, effort, interaction.

Received March 13, 2014
Accepted September 17, 2014