Mechanics and Mechanical Engineering
Vol. 21, No. 4 (2017) 1021–1032

Numerical Analysis of the Foods Nature Effect on the Mechanical Behavior of Dental Implants

M. Sifi
B. Serier
A. Merdji
Laboratory of Physical Mechanics of Materials
Faculty of Engineering
Sidi Bel Abbes, 22000 Algeria
miloudsifi@yahoo.fr

A. Benaissa
Faculty of Science and Technology
Mascara University, Algeria

R. Mootanah
Medical Engineering Research Group
Faculty of Science and Technology
Anglia Ruskin University Bishop Hall Lane
Chelmsford, Essex, UK

Received (24 August 2017)
Revised (19 September 2017)
Accepted (23 October 2017)

This study focuses on a three-dimensional numerical analysis by the finite element method, the mechanical behavior of the dental prosthesis implant composed of a single implant. The effect of the nature of food on the level and distribution of the Von Mises equivalent stress generated in the bone and the elements that constitute this prosthesis have been highlighted. It has been shown that this level is particularly important that the Crushed masticated foods are rigid. This work was carried out to answer questions whose purpose was to analyze the risk of overload in the mandibular region. Loads transfer mechanisms and the possible failure of osseointegrated implants, the shape of the implant, the geometrical and mechanical properties of the placement site and bone resorption of the crest. A proper estimation of these effects allows the correct design of the implant.

Keywords: implant, abutment, bone, constraints, distribution, modeling, prosthesis, effort.

1. Introduction

Dental implantology is currently the most innovative and interesting therapeutic approach in dentistry, thanks to the constant improvement of implants and surgical and prosthetic procedures. It was in the 1960s that implantology gained its nobility thanks to the work of a Swedish team coordinated by Professor Bränemark and a Swiss team led by Professor Schroeder who developed the technique of implants Osteo-integrated systems from which all global firms are currently. Their works were published in the 70's and are the source of the revival of implantology. Since then, several hundred thousand implants have been successfully implanted in the world [1]. Success is obtained firstly with very precise radiological investigations (scanner) and also through the application of rigorous method. The replacement of a natural root damaged by an artificial anchor relieved several hundred thousand patients. This relief is seen on one aesthetic side and on one biomechanical side. During the process of chewing the implant transmits to the bone (the weakest link in the chain tooth) efforts that can harm dental implantology. These efforts can be a source of pain or presented risk of damage. The performance, reliability and durability of dental implantology depend on the stresses induced in the bone during mastication and also on bone quality. Several research studies have been carried out for the analysis of the static, dynamic and fatigue mechanical behavior of several types of dental prostheses and implants. Among the most recent works, Abdul Rahman and colleagues have analyzed the distribution and intensity of the stresses generated at the bone-implant contact point by the finite element method, and have shown the value of the implants dental preparations based on polyether-ether-ketone polymer [2]. Merdji and al. analyzed the distribution and level of induced stresses in the constituents of the dental prosthesis subjected to static loading. A load applied to the surface of the crown causes a high stress concentration in the upper part of the attachment zone of the tooth in contact with the cortical bone [3].

Vedovatto and al. performed a biomechanical analysis of hybrid prostheses. The purpose of this study is to evaluate the models and the concentration of stresses induced on the peri-implant zone [4]. Bruno Ramos Chrcanovica and al. have studied the mechanical behavior of the implant using a finite element method based on a mathematical model for bone modeling [5]. Schwitalla AD and al. analyzed the biomechanical effects and mechanical behavior of a dental implant based on the polyether-ether-ketone polymer (PEEK). This study led to the identification of stress distribution at the bone-implant interface [6].

Djebar and al. have shown numerically by the finite element method that the stresses generated in the bone during static mastication vary along this living element [7].

Using the same numerical method, Merdji and al. showed that the introduction of an elastomeric material at the abutment-implant interface allows the relaxation of stresses in the bone [8]. Based on the same method of analysis, Achour T. and al. have shown that the presence of a stress absorber (elastomer) between the implant and the abutement leads to a reduction of the stresses in the bone during a dynamic mastication [9]. Saidin S. and al. studied the effect of implant-pillar connections on the distribution of micromovement stresses and the factors that influence load transfer at the implant bone interface [10].

Ali B. and al. evaluated the effects of chewing overload on the mechanical behavior of dental implants [11].
Lucia Himmlova, MD, Tatjana Dostalova and al. using a mathematical simulation have analyzed the stress distribution around an implant and have shown that the length and diameter of this element determine the level and distribution of these stresses [12].
Several questions still arise from a scientific point of view concerning the nature of the immediate behavior and the evolution of the bone-implant interface when an implant is loaded under a fixed or removable prosthesis. Through this work, we tried to answer some of these questions in order to propose a new implantology technique that allows the correct design of the implant.

2. Materials and methods

2.1. *Geometrical model*

Sub- The three-dimensional geometric model of the dental structure, illustrated in Fig. 1, is analyzed by the finite element method. This model is a dental implant located in the lower jaw, in the region of the second premolar. In this study, trabecular bone (spongy) was modeled as a solid structure of 24.2 mm height and 36.2 mm width in a 2 mm layer of cortical bone. A titanium alloy screw (or implant) of 4 mm diameter and 10 mm long embedded in the jaw, receives an abutment of the same materials and 8 mm height. FIG. 2 shows the elements of the dental structure studied.

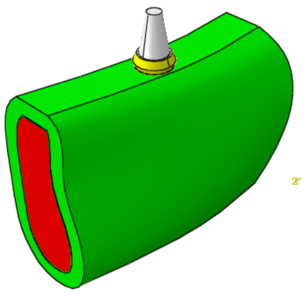

Figure 1 Model of the analyzed dental prosthesis

2.2. *Material properties*

The materials composing the analyzed dental prosthesis are: The implant and abutment which are made of titanium alloy (Ti6Al4V). The jaw consists of the spongy bone surrounded by the cortical bone. All materials assumed to exhibit linear and homogeneous elastic behavior. The behavior of the cortical bone is supposed to be an anisotropic material. The adopted material properties were specified in terms of Young's modulus, and the Poisson's coefficient.
The properties of the materials used in this study are summarized in Tab. 1.

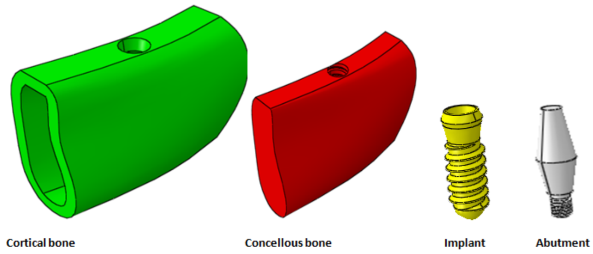

Figure 2 Representation of the dental prosthesis and its components

Table 1 Mechanical properties of materials used for dental prosthesis [13, 14]

Parts	Materials	Elastic modulus E [GPa]	Poisson's ratio ν	Density ρ [kg/m^3]	Compressive strength [MPa]
Jaw bone	Cortical bone	$E_x = E_y = 11.5$ $E_z = 17$ $G_{xy} = 3.6$ $G_{xz} = G_{yz} = 3.3$	$\nu_{xy} = 0.51$ $\nu_{xz} = 0.31$ $\nu_{yz} = 0.31$	1100	133
	Cancellous Bone	3	0,29	270	11
Implants	Titanium	110	0.32	4428.8	462
Abutments	Titanium	110	0.32	4428.8	462

2.3. *Interface and boundary conditions*

Normal masticatory forces depend on the nature of the foods absorbed, for puree, creams and other soft foods they are a few Newtons, for carrots or hard meat of about 70 to 150 N, and they exceed 200 N even for very hard foods.

The stiffness of these foods and the number of mastication cycles can considerably influence the functional forces. These forces normally apply for a relatively short period of time [15].

Masticatory forces of the natural dentition and the implant varies over a wide range [16].

This part of study falls within this context and aims at analyzing the effect of the food nature on the mechanical behavior of the dental prosthesis. Foods are therefore defined by their Young modules. This is indirectly simulated by static forces of mastication. That is the most important forces are exerted to crush stiffer foods, such as for example nuts, almonds, hazelnuts etc.... and conversely. We have thought through this work to highlight the response of the bone and the implant during the crushing of such foods. The magnitude of static forces applied to the dental structure composed of a single implant is shown in Fig. 3 and selected respectively as follows (25 Mpa, 20 Mpa, 15 Mpa, 10 Mpa, 5 Mpa and 3 Mpa).

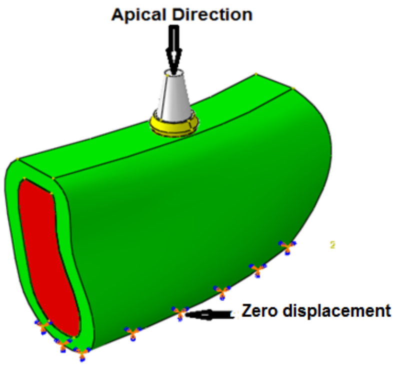

Figure 3 Loads applied to dental structure and boundary conditions

2.4. *Finite Element Modeling*

The mesh of the components consists of four-node tetrahedral linear elements as shown in Fig. 4, the uniform mesh of the geometry of this dental structure with an optimal mesh, which considerably increased the analysis time. Consequently, we have the mesh size that was optimal around the zones of interest; it was considered fundamental to refine the mesh at this interface in order to achieve an optimal precision. The mesh of the components is checked for use in an analysis of substantial stresses and deformations by finite elements

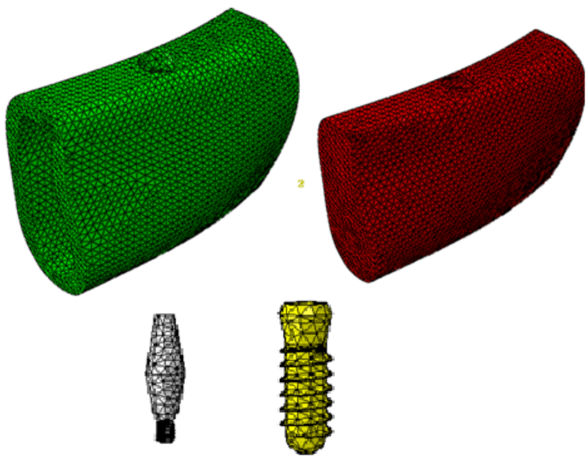

Figure 4 Meshing of the elements and the entire prosthesis

3. Results

Remember that this type of loading is applied to the dental structure in the so-called coronal-apical axial direction. In the other directions, the dental structure is not subjected to any effort.
The three-dimensional analysis of the Von Misses stress distribution in the dental structure is investigated under the effect of load applied in the vertical direction of the implant system in order to simulate the crushing effects of food.
Fig. 5 shows the distribution of the stresses in the main model. Such loading induces equivalent stresses in the various components of the implant system.

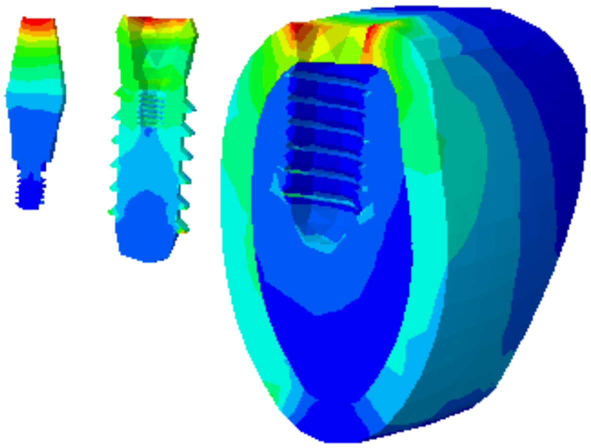

Figure 5 Distribution of the induced Von Mises equivalent stress in the dental structure

3.1. *Implant*

Fig. 6 shows the Von Mises stress distribution in the implant under the effect of the crushing of different foods. The zone of stress concentration is located on the upper face of the implant and more particularly in the junction between the abutment and the implant. The stress is intensively distributed in the region of application of the mechanical force. In the other parts of the implant, the stress is almost uniformly distributed and its level remains low.

3.2. *Abutment*

Fig. 7 shows the distribution of the stresses in the abutment. The stress distribution in this component was simulated under the effect of a mono-axial mechanical loading applied along the vertical axis of the system. The obtained results show that the maximum of these stresses is concentrated in the base of the external surface that is to say on the upper part.. These results confirm from a biomechanical point of view that the abutment is the geometrically weakest component of the implant-prosthesis system because it constitutes a main critical zone of transfer of charge to the implant and the bone [17].

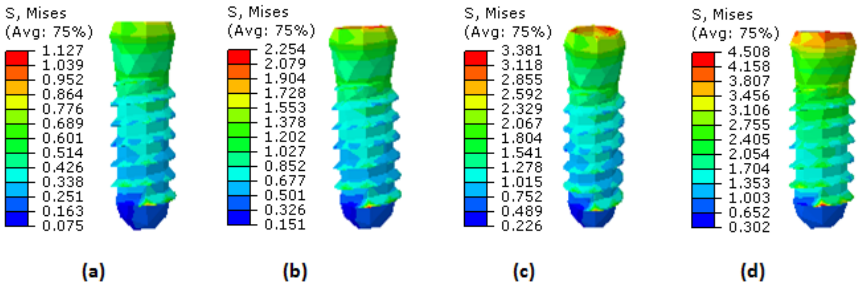

Figure 6 Level and distribution of the equivalent stress of Von Mises induced in the implant

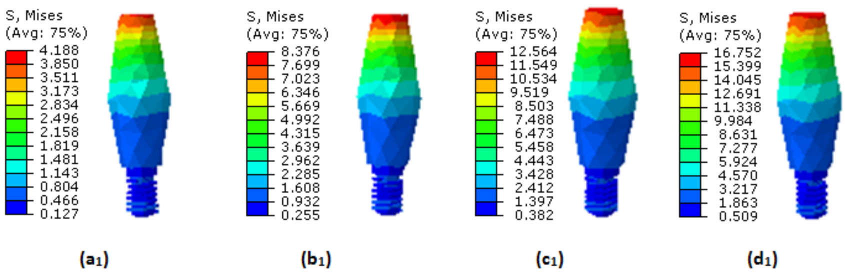

Figure 7 Level and distribution of the equivalent stress of Von Mises induced in the abutment

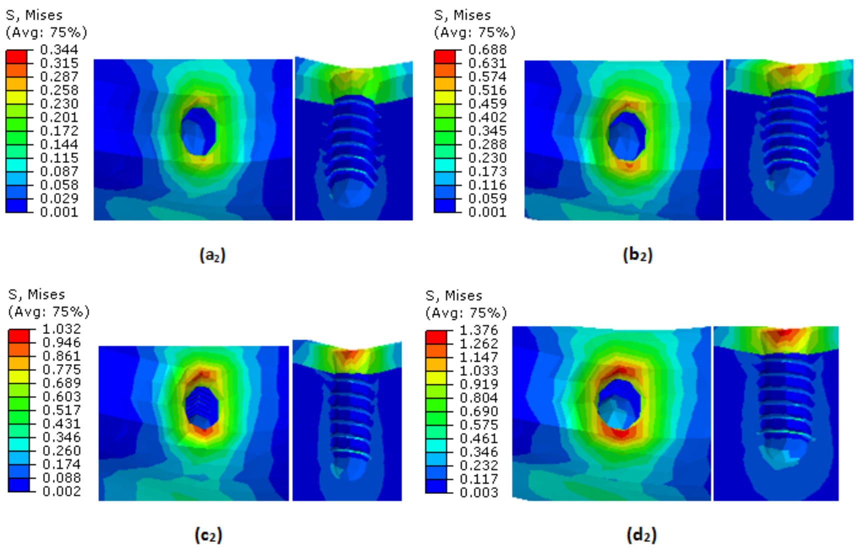

Figure 8 Level and distribution of induced equivalent stress in bone

3.3. *Jaw bone*

We are interested only in the three-dimensional analysis of the Von Misses stress distribution in bone under the effect of a loading applied in the vertical direction of the implant system. Such loading induces equivalent stresses in the bone strongly located on a part of its upper surface. For better visualization, the stress distributions in these bone regions are presented separately. In cortical bone, peak values of the equivalent Von Mises stress was mainly around the implant region neck (Fig. 8). This suggests that emphasis should be given on the contact of the implant with the cortical layer of the bone due to its low modulus of elasticity.

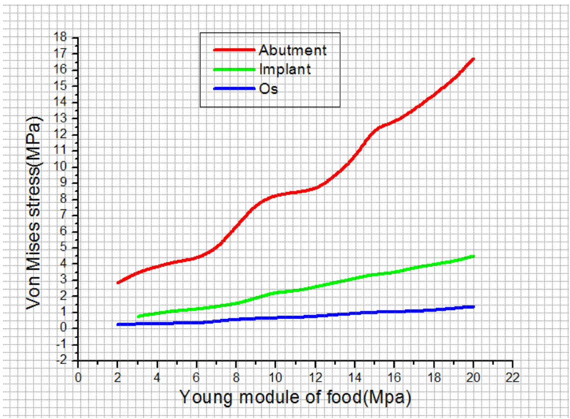

Figure 9 Distribution of the induced equivalent stress in the dental structure as a function of the Young's modulus of the food

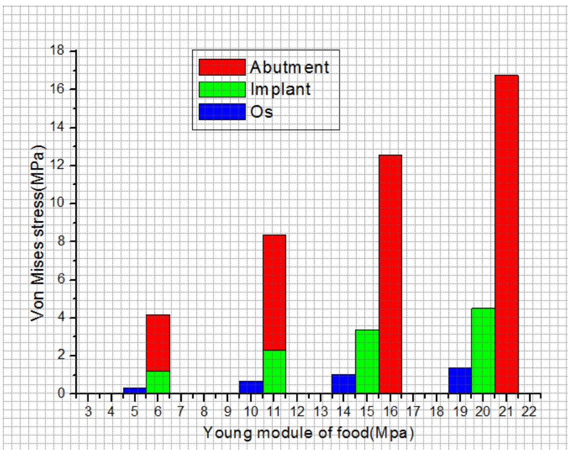

Figure 10 Von Mises stress comparison histograms for each component of the dental structure

The founded Von Mises stresses for the various components of the dental structure from the point of coronal apical application are illustrated in Figs. 9 and 10, analysis of these figures shows that the level of these constraints increases with increasing hardness of the food that is to say, the food of the Young's modulus.

4. Discussion

A three-dimensional finite-element analysis of distribution of the equivalent stresses of Von Mises in each of the components of the dental prosthesis as a function of the Young's modulus of food is shown in Figs. 6, 7, 8, 9 and 10.

A load applied to the abutment surface causes a high stress concentration in its upper part. This zone is intensively stressed because its mechanical properties are the highest. Moreover, it is the zone undergoing the maximum of crushing forces. This does not eliminate the existence of relatively low stress in the apical area in contact with the apex of the implant, justified by the compression loads on the implant systems [18–19].

In this study, stress concentration occurred only in one side of the neck and not around as found in previous studies [20]. Lidia and al. [21] have described that the conventional cylindrical geometry implant induces relatively high stresses on the bone along the implant body while concentrating them near the neck. These findings are in fact consistent with our findings. However, this situation can cause pathological bone loss in the cervical region of the implant by atrophy and near its tip due to excessive load. In addition, the new implant provides low stress distribution from the top of the implant to the apical region.

In this research, the model presented indicated the existence of a stress concentration at the same region of the neck, ie, the upper zone of the cortical layer. This is explained by:

1. The evidence that the surface between the implant and the cortical bone is much smaller than that between the implant and the Cancellous bone. In addition, cortical bone is approximately ten times more rigid than spongy bone.

2. The intimate contact between the cortical bone and the implant interface, which explains that the load applied to the implant, is directly transmitted to the cortical bone.

These are indeed the main reasons that the maximum stresses tend to increase in cortical bone. This justifies the fact that bone loss in this area is related to this stress concentration [22-23] and suggests that great importance must be given to the contact of the implant with the cortical layer of the bone.

In some major radiology studies, loaded implants had typical bone loss around the implant neck [24]. This agrees well with the results of our study based on the finite element method.

However, abutment represents the highest level of stress compared to other components of the implant system. This is also due to the high mechanical properties of the abutment but the modulus of elasticity of the cortical bone is higher than that of the cancellous bone, which is why the cortical bone is more resistant to deformation. These results illustrate our closeness to the actual behavior of the whole of a dental prosthesis operating inside the mouth.

5. Conclusion

The results of the model studied clearly show that the distribution and the stress level depend on the nature of the food. Within the limit of this study the following conclusions were sorted:

1. The maximum stresses are located on the upper faces of each component of the dental prosthesis for the model studied.

2. The equivalent stress distribution of Von Mises is not homogeneous; it varies along the bone from its upper to its lower part.

3. The level of stresses induced in the bone depends on the nature and hardness of the food.

4. The risk of embrittlement is even higher than the crushing forces are most important.

The results of this study allow us to affirm the validity and the compatibility of the prosthesis designed model and the performed modeling procedure, which is in line with the above objectives. This will also allow us to validate and refine our numerical model because indeed only clinical trials are proofs unanimously recognized by the scientific community. However, additional effort should be provided in the modeling of the implant unit.
Finally, we hope that the objective of this work has been achieved and that it can serve as a response tool in the field of dental implantology and allow the correct design of the implant.

References

[1] **Branemark, P. I.**: Osseointegrated implants in the treatment of the edentulous Jaw experience from a 10 year period, *Scand. J. Plast. Reconstrs. Surg.* 16, 130-132, **1977**.

[2] **Obeid, A. S., Alkhodary, M. A., Omran, M. H., Abdelwahab, E. M.**: The Basal Polymeric PEEK Dental Implant Restoring a Missing Molar: A Case Study Validated with Finite Element Analysis, *Journal of Advanced Dental and Medical Sciences*, 1, 2, 50–56, **2015**.

[3] **Merdji, A., Bouiadjra, B., Achour, T., Serier, B., Ould B., Chikh, Z. O.**: Feng Stress analysis in dental prosthesis, *Computational Materials Science*, 49, 126–133, **2010**.

[4] **Vedovatto, E., Mazaro, J. V. Q., Filho, H. G., de Carvalho, P. S. P., de Mello, C. C., Lemos, C. A. A.**: Biomechanical Analysis of Implant Assisted-Overdentures with Variations in the Attachments Systems, *Materials Sciences and Applications*, 6, 734–742, **2015**.

[5] **Chrcanovic, B. R., Albrektsson, T., Wennerberg, A.**: Tilted versus axially placed dental implants, *Journal of Oral Rehabilitation*, 41, 443–476, **2014**.

[6] **Schwitalla, A. D., Abou-Emara, M., Spintig, T., Lackmann, J., Müller, W. D.**: Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone, *Journal of Biomechanics*, 48, 1–7, **2015**.

[7] **Djebbar, N.**: Stress distribution in dental implant with elastomeric stress barrier, *Materials and Design*, 32, 282–290, **2011**.

[8] **Merdji, A., Mootanah, R., Bachir Bouiadjra, B., Benaissa, A., Aminallah, L., Ould Chikh, B., Mukdadi, S.**: Stress analysis in single molar tooth. *Materials Science and Engineering*, C, 33, 691–698, **2013**.

[9] **Achour, T., Merdji, A., Bachir Bouiadjra, B., Serier, B., Djebbar, N.**: Stress distribution in dental implant with elastomeric stress barrier. *Material and Design,* 32, 282–290, **2011**.

[10] **Saidin, S., Abdul Kadir, M. R., Sulaiman, E., Abu Kasim, N. H.**: Effects of different implant- abutment connections on micromotion and stress distribution: Prediction of microgap formation, *Journal of Dentistry,* 40, 467–474, **2012**.

[11] **Benaissa, A., Chikh, E. B. O., Meddah, H. M., Merdji, A., Bouiadjra, B. A. B.**: Effects of overloading in mastication on the mechanical behavior of Dental Implants, *Materials and Design*, 47, 210–217, **2013**.

[12] **Himmlova, L., Dostalova, T.** and al.: Influence of implant length and diameter on stress distribution: A finite element analysis, *The Journal of Prosthet Dent.*, 91, 1, 20–25, **2004**.

[13] **Chen, K. K., Miyake, K., Terashita, M.**: Cervical strains induced by occlusal loading, *Journal of Dental Research*, 478–478, **1999**.

[14] **Shames, I. H., Dym, C. L.**: Energy and finite element methods in structural mechanics, *New York: McGraw-Hill*, **1985**.

[15] **Smukler, H.**: Equilibration occlusale en denture naturelle, *Paris: édition CdP*, 16–19, 51, 81–82, **1993**.

[16] **Boz-Kaya, D., Muftu, A.**: Evaluation of load transfer characteristics of five different implants in compact bone at different load levels by finite. *Journal of Prosthet Dent.*, 92, 6, 523–530, **2004**.

[17] **Assunc, W., Gomes, E. A., Bara, V., Delben, J. A., Tabata, L. F., de Sousa, E. A.**: Effect of superstructure materials and misfit on stress distribution in a single implant-supported prosthesis: a finite element analysis. *J Craniofac Surg* 21, 689–95, **2010**,.

[18] **Steigenga, J., Al-Shammari, K., Misch, C., Nociti, F.H., Jr., Wang, H. L.**: Effects of implant thread geometry on percentage of osseointegration and resistance to reverse torque in the tibia of rabbits, *J Periodontol,* 75, 1233–1241, **2004**.

[19] **Abu-Hammad, O. A., Harrison, A., Williams, D.**: The effect of a hidroxyapatiterein forced polyethylene stress distributor in a dental implant on compressive stress levels in surrounding bone, *Int J Oral Maxillofac Implants,* 15, 4, 559–64, **2000**.

[20] **Berkovitz, B. K. B.**: Periodontal ligament: structural and clinical correlates. *J Dent Res,* 31, 46–54, **2004**.

[21] **Nishida, E., Saito, M., Ishikawa, S., Sasaki, T., Noguchi, T., Shimizu, N., Teranaka, T.**: Transcriptome analysis of extracellular matrix genes regulating periodontal ligament development, *J. Dent. Res.,* 56, 2598–2605, **2006**.

[22] **Asmussen, E., Peutzfeldt, A., Sahafi, A.**: Finite element analysis of stresses in endo dontically treated, dowel–restored teeth, *J. Prosthet Dent.*, 94, 321–329, **2005**.

[23] **Bader, J. D., Shugars, D. A., Martin, J. A.**: Risk indicators for posterior tooth fracture, *Journal of the American Dental Association*, 135, 7, 883–892, **2017**.

[24] **Fill, T. S., Carey, J. P., Toogood, R. W., Major, P. W.**: Experimentally Determined Mechanical Properties of Periodontal Ligament: Critical Review of Current Literature, *Journal of Dental Biomechanics*, doi:10.4061/2011/312980, **2011**.