JO JOURNAL OF OSSEOINTEGRATION periodontics and prosthodontics

Numerical simulation of the implant system of a prosthesis and a dental bridge under dynamic loading

K. BOUZOUINA, Y. CHELAHI CHIKR, B. BOUTABOUT

LMPM, Department of Mechanical Engineering, University of Sidi Bel Abbes, Ben M'hidi city, Sidi Bel Abbes, Algeria

TO CITE THIS ARTICLE
Bouzouina K, Chelahi Chikr Y, Boutabout B. Numerical simulation of the implant system of a prosthesis and a dental bridge under dynamic loading. J Osseointegr 2023;15(1):11-16.

DOI 10.23805/JO.2023.15.01.09

KEYWORDS Bridge, Dentures, Cancellous bone, Cortical bone, Dynamic loads.

ABSTRACT

Aim The objective of this study is to analyze the effect of masticatory efforts on the intensity and distribution of the equivalent von Mises stress generated in the bone and in the elements that constitute the tooth structure.

Materials and methods Three-dimensional numerical analysis by the element method is concerned with a comparative study between two dental structures subjected to dynamic loads. Each of the dental systems is subjected to a mechanical load simulating the functioning of the tooth in three directions: corono-apical, disto-mesial and linguo-buccal. There are two solutions to replace one or more missing teeth. The first solution is to use three dentures that replace the premolar tooth and the two molar teeth. The second solution is to use a dental bridge system consisting of three crowns that aims to replace the missing first molar tooth by relying on two implants.

Results The results show that maximum stresses lead to a risk of deterioration of the cancellous bone first to reach the cortical bone and finally the loosening of the implant.

Conclusion A dental bridge may be the best option if the neighboring teeth have large fillings and need crowns in the future. And if the tooth or teeth have been lost for a long time, the gum and bone will be reduced and other procedures are needed instead of the dental implant. However, the downside of the dental bridge system is that it gradually leads to bone loss, because it does not stimulate chewing. In fact, the artificial tooth does not rest on the jawbone, which causes this inconvenience.

INTRODUCTION

The finite element method is currently establishing itself as an essential tool for the design and analysis of complex problems, it allows to model complex geometries given a large number of physical phenomena offering interesting perspectives compared to analytical models (1). In this work the geometric model of the tooth structure is analyzed by the finite element method using the ABAQUS calculation code (version 6.13, Dassault Systèmes, Paris, FR) (2). Taking into account the nature of the loading and the geometry, a three-dimensional modeling is used. The choice of this code was essentially motivated by its great computing capacities; it offers good number of choices to discretize a geometry namely elements: triangular with four nodes and ten nodes, quadrilateral with four nodes and eight nodes. And this part calls for a dynamic study of the dental prosthesis and the dental bridge system.

The aim of the present study is to analyze the effect of masticatory efforts on the intensity and distribution of the equivalent von Mises stress generated in bone and the elements that constitute the tooth structure.

MATERIALS AND METHODS

Models and properties of materials

In this study, two different types of prosthetic systems were compared:

- The dental prosthesis system with three implants carrying the two crowns of the molar teeth and a crown of premolar teeth, which is mainly made up of four components: mandibular bone (cancellous, cortical), implant plus abutment, crown and crown-holder.
- The bridge is an assembly of three dental crowns, which is supported on two implants. The crown presents an appearance, close to that of natural teeth. Depending on its materials of manufacture, it is strong, durable and has an aesthetic appearance. The first crown of the premolar tooth and the two crowns replace the molar teeth. The dental bridge system consists mainly of four components: mandibular bone (cancellous, cortical), Implant plus abutment, crown and crown holder.

The complete model, which includes the crown, crown holder, metal part (implant + abutment), cortical bone and cancellous bone, was assembled using SolidWorks (Dassault Systèmes, Paris, FR), then exported to the ABAQUS programme (version 6.13, Dassault Systèmes, Paris, FR) (Fig. 1).

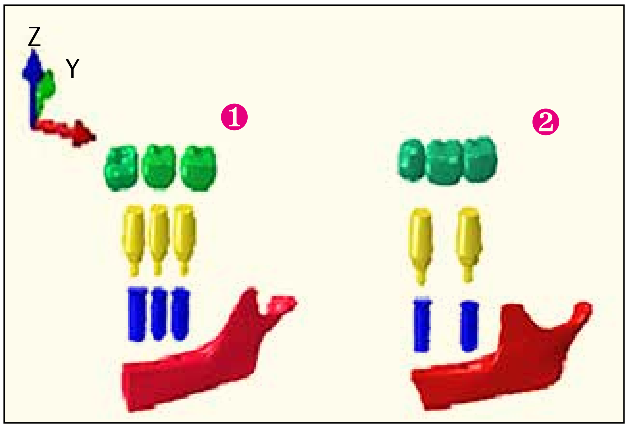

FIG. 1 Model created with anatomy similar to a mandibular molar region for dental prostheses (1) and a dental bridge system (2).

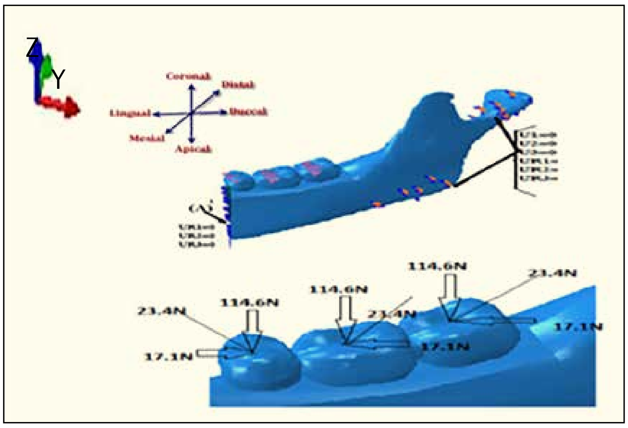

FIG. 2 Boundary conditions: zero displacement, corono-apical, linguo-buccal and disto-mesial loads (12).

It has been shown that the bone material is neither homogeneous nor isotropic (12) and should be modeled as a porous material with a complex microstructure. It is recognized that cortical bone has better carrying capacities than cancellous bone. However, Meijer et al. (13) assumed in isotropic, linear, elastic and homogeneous properties for this living material. In light of this, the bone materials and implant systems of our two models were considered isotropic and linear elastic. The material properties of the implant systems and the mandibular bone and crown of the present study are shown in Table 1.
In general, dental implants are subjected to complex physiological loads, but in many researches reviewed, dynamic loads directed at the occlusal angle are produced in the mandibular bone during the chewing of food (12).
In order to define the boundary conditions, three loads in the following directions: corono–apical, linguo-buccal and disto-mesial, define a 3D system of the same rank.
For the boundary conditions, three zones are presented:

- The lower plane of the mandibular bone, having zero displacements.
- The upper surface of the crown is subjected to a combined dynamic load of 114.6 N in the corono–apical direction, 23.4 N in the disto–mesial direction and 17.1 N in the lingual–buccal direction.
- Other surfaces are treated as free surfaces (zero load).

A combined dynamic load was applied to the central surface of the occlusal surface of the crown (Fig. 2). The boundary conditions have been applied to prevent any form of translational movement in our model.
For dynamic analysis, the loading time depends on the applied chewing. A temporal evolution of the load components per 5 seconds is demonstrated in figure 3.
The solid model resulting from the intersection of the implant and the jaw bone represents the hypothesis of complete osseointegration, which limits any relative displacement between the implant and the bone.

Interface states

The interfaces between the components of the prosthesis, respectively: the bridge, the prosthesis and the implant, as well as between cortical and cancellous bone are treated as perfectly bonded interfaces (5-7).

Finite element model

As shown in figure 4, the various components were meshed in linear elements tetrahedra with four nodes. Since the bone-implant interface is subjected to maximum stresses and strains under occlusal loading, it was considered fundamental to refine the mesh at this interface in order to achieve optimal precision. The mesh of the components is verified for use in a stress, and consequent, strain analysis

Components	Materials	Mechanical properties	Young modulus (E) (GPa)	Poisson ratio	Density (kg/m^3)	Limit breaking up (Mpa)
Crown	Feldspar porcelain (ceramic)	Elastic	61.2	0.3	500	2300
Framework	Alloy Cr - Co		200	0.3	/	/
Abutment	Titane		100	0.3	4428.80	800
Implant	Titane		100	0.3	4428.80	800
Mandibular bone	Cortical bone		14	0.3	1100	130
	Cancellous bone		1	0.3	270	

TABLE 1 Summary of components and their mechanical behavior for dental prosthesis and bridge (12).

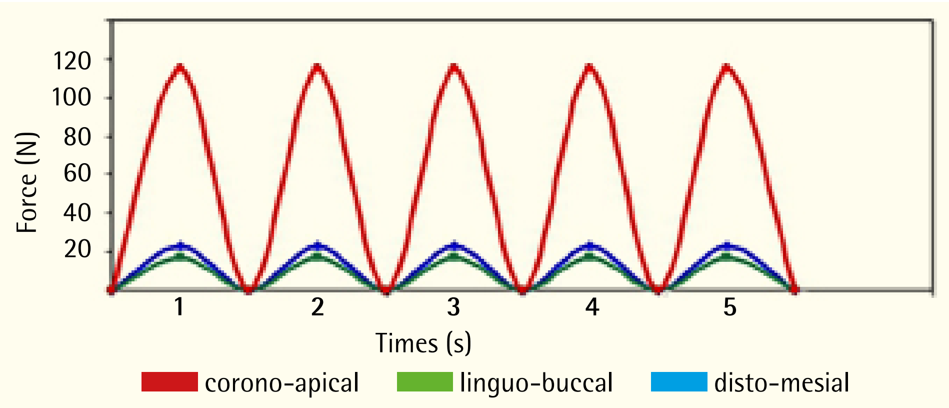

FIG. 3 Dynamic loading in 5 seconds (12).

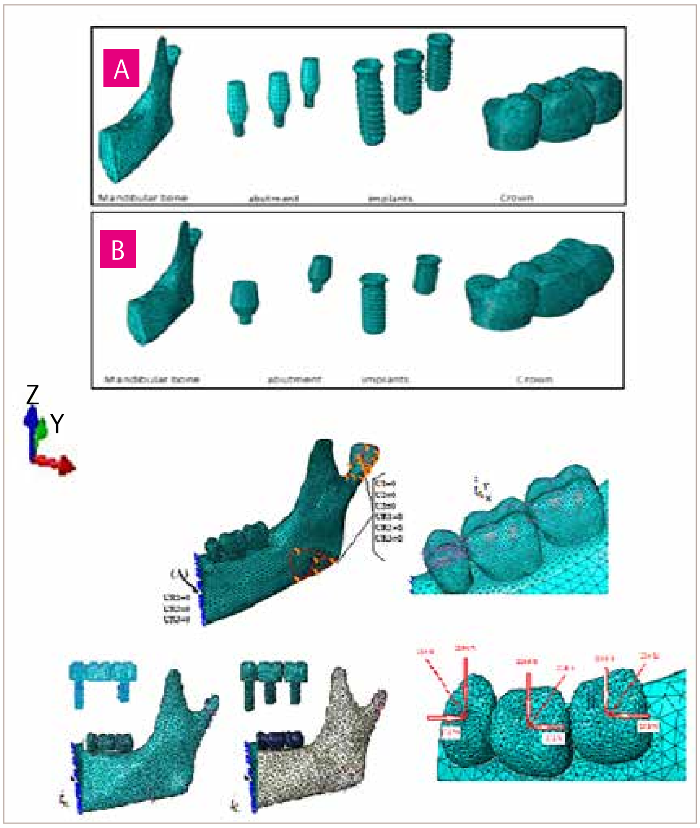

FIG. 4 Mesh using linear tetrahedral elements for a dental prosthesis (a) and a dental bridge system (b).

Components	Element size (mm)	Number of element	Number of nodes
Dental prosthesis system	0.25	1185198	2 666 695
The dental bridge system	0.25	706321	1 589 222,25

TABLE 2 Size and number of elements used for bone and implant systems.

Components	Von Mises stress (MPa) « Dental Prosthesis Model »	Von Mises stress (MPa) « Dental Bridge Model »
Cancellous bone	15.70	29.70
Cortical bone	81.90	99.80
Implant+ abutment	130.00	165.00
Framework	77. 10	155.00
Crown	65.50	100.00

TABLE 3 Maximum values of von Mises stresses for both models (prosthesis/bridge).

by finite elements (8-11). The mesh characteristics for each component are presented in Table 2.

RESULTS AND DISCUSSION

Maximum von Mises stress value is reported in table 3.

Distribution of von Mises stress under dynamic loading of a dental prosthesis and dental bridge

In this study, the distributions of the overall state of the stresses for each of the components of the two models were studied by considering the combined axial and horizontal loads in the corono-apical, disto-mesial and lingo-buccal directions. Qualitative and quantitative analysis were performed, based on a progressive visual color scale, ranging from dark blue to red.

a) Stresses in the bone

We are only interested in the three-dimensional analysis of the distribution of von Mises stress in bone under the effect of different cyclic loads applied along the three axes of the implant system. This dynamic loading applied to the occlusal surface induces equivalent stresses in the bone strongly located on the bottom of this component and on part of its upper surface. This stress distribution is due to the compressive forces exerted. For better visualization in cortical and cancellous bone, the stress distributions in this region

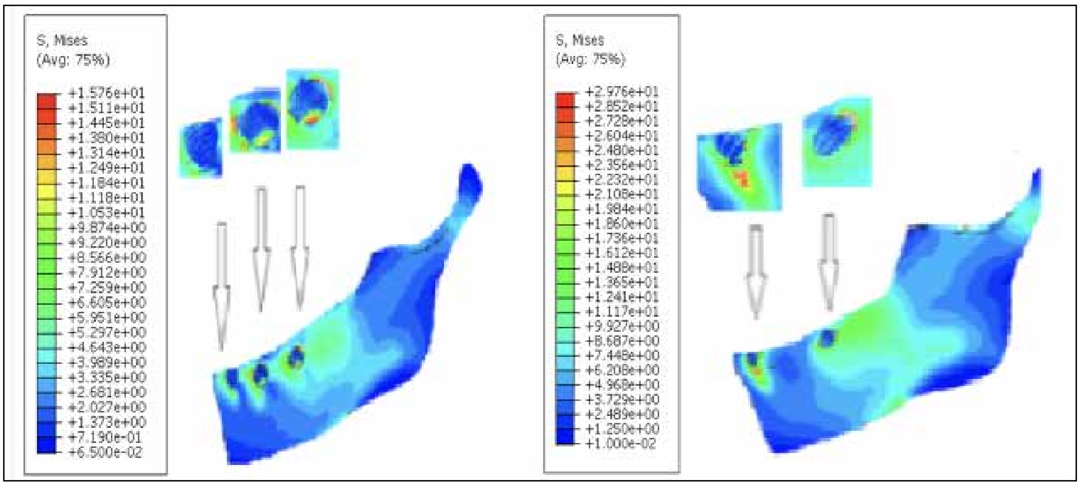

FIG. 5 Contour of von Mises stresses of cancellous bone for the dental prosthesis (a) and the dental bridge system (b) at t = 5 sec.

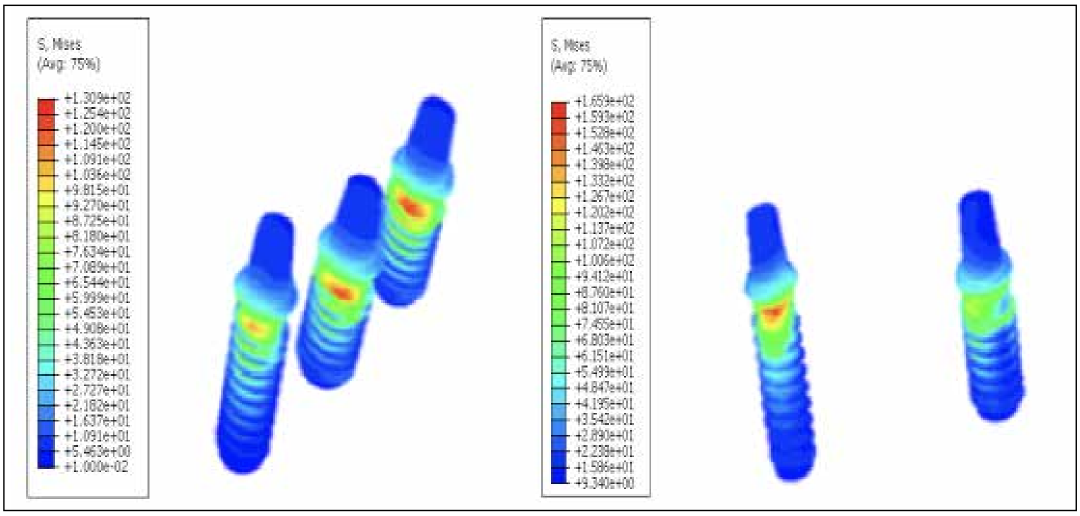

FIG. 6 Contour of von Mises stresses of the implant-abutment part for the dental prosthesis (a) and the dental bridge system (b) at t = 5 sec.

have been shown separately.

b) Contour of the stress of the cancellous bone

Figure 5 illustrates the distribution of von Mises stress in cancellous bone. It can be seen that the contact area of the cancellous bone with the apex of the implant, also experienced a stress level of 15.76 MPA for the prosthesis and 29.76MPa for the bridge. The appearance of a stress field in this region is due to the force reaction which opposes the axial force applied to the occlusal surface. In addition, these stresses tend to gradually decrease in the bone as they move away from the area of the bone-implant junction.

Stress contour in tooth structure components

a) Contour of the stresses of the abutment–implant

Figure 6 shows the distribution of von Mises stress in the implant-abutment metal part under the effect of dynamic stresses applied along three axes of the implant system. It is observed that the stress concentration zones are located on the external faces of the implants and more particularly at the level of the surface of the junction between the bone and the neck of the implant and this is valid for both prosthesis and dental bridge models. In the other parts of the implant the stress is almost evenly distributed. However, it can be seen that the maximum of these stresses was generated in the dental bridge system.

b) Contour of the stress of the Framework

Figure 7 shows the distribution of von Mises stresses within the frameworks of the two dental implant systems. For the dental prosthesis, maximum stresses are concentrated in the abutment-framework connection area at the point of application of the occlusal force and this for the dental prosthesis. However, for the bridge placed on dental implants, the most intense stresses are found at the level of the surface separating the two crowns, which replace the two molars. This increase in stress is due to the bending moment caused by the axial force applied to the crown.

c) Contour of the stress of crown

The maximum von Mises stress is concentrated on the upper occlusal surface of the three crowns of the dental prosthesis, which replace the premolar and the two molars in Fig. 8 (a). However, for the dental bridge system, the most intense stresses are found between the two crowns of the dental prosthesis, which replace the molar teeth. This stress concentration is due to the bending moments caused by the axial forces as shown in Figure 8 (b), which also shows that these stresses tend to gradually decrease

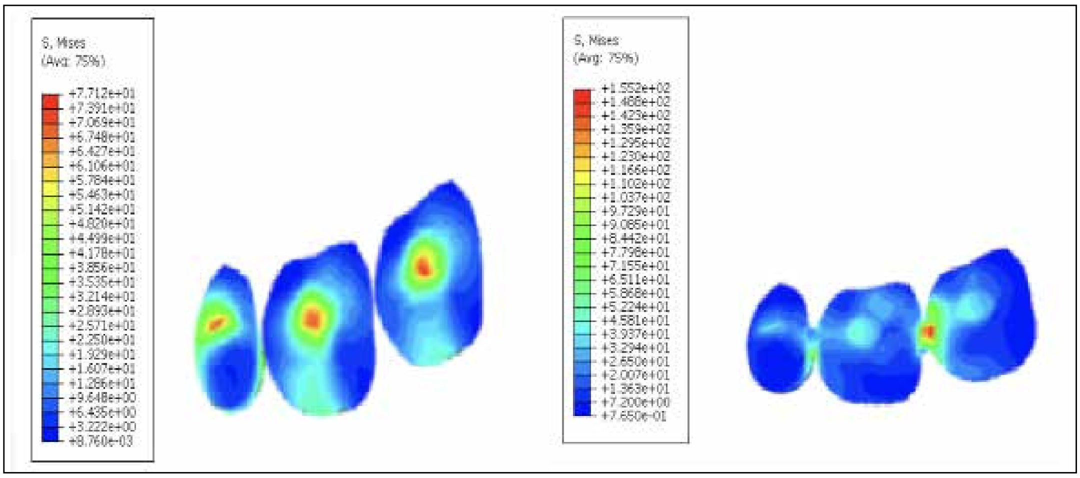

FIG. 7 Contour of the von Mises stresses of the crown gate for the dental prosthesis (a) and the dental bridge system (b) at t = 5 sec.

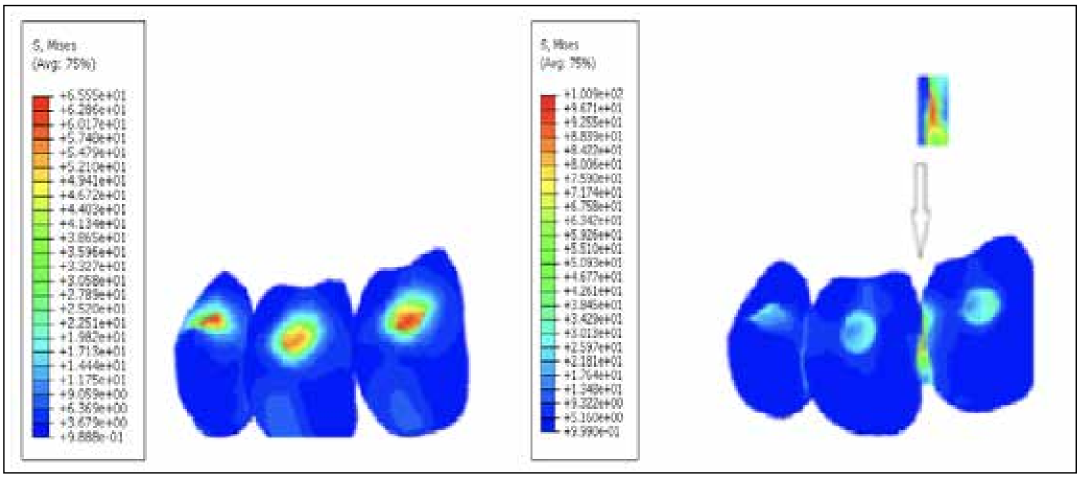

FIG. 8 Contour of the von Mises stresses of the crown for the dental prosthesis (a) and the dental bridge system (b) at t = 5 sec.

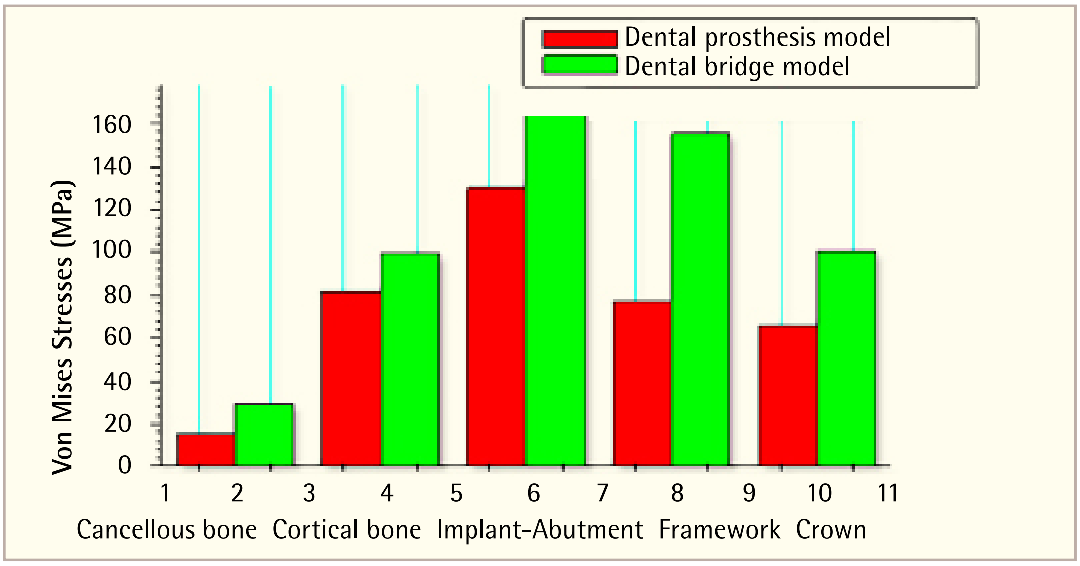

FIG. 9 Histogram of the maximum von Mises stress of the two dental structures.

away from these regions. The geometry of the dental bridge system is an important parameter which influences the load transfer to the different elements. The stress field is distributed in the three crowns of the dental prosthesis with a gradual and homogeneous manner, the stress reaches the maximum value in the center of the crown then it decreases as one moves away of this region. While the dental bridge system presents the most important stress at the level of the contact surface of the two crowns which replace the two molars.

The histogram shows the maximum stresses of the mandibular bone and of the various components of the dental implant systems. Compared to dental prosthesis, the highest stresses are found in the components of the dental bridge system (Fig. 9).

CONCLUSION

The aim of this work is to determine the biomechanical stresses developed at the level of each dental structure and their consequences on the various components of the prosthesis and the surrounding bone under dynamic loading. These interactions are modeled in the form of contact forces.

The results obtained numerically by the finite element method permit the following conclusions:

- Regardless of the type of dynamic loading, it can be seen that the level of interfacial stress is relatively low compared to that of the stresses developed in cortical bone.
- The dynamic stress leads to von Mises stress in the denture and dental bridge system, the intensity of which is approximately twice that of the static stress.
- The stress induced, under the effect of dynamic loading, in the elements of the dental implant system and especially in the bone, is very intense, and can be fatal for the dental structure, but if the implant is designed with resistant material, then it can easily withstand the level of these stresses. The dental prosthesis has better rigidity while the dental bridge has better flexibility.

REFERENCES

1 Misch BM. A scientific rationale for dental implant design. In: CE M (ed). Contemporay Implant dentistry, 2nd ed. St. Louis: Mosby, 1999:329-343.

2 Kitamura E, Stegaroiu R, Nomura S, Miyakawa O. Biomechanical aspects of marginal bone resorption around osseointegrated implants: considerations based on a three-dimensional finite element analysis. Clin Oral Implants Res 2004; 15:401-412.

3 Bozkaya D, Muftu S, Muftu A. Evaluation of load transfer characteristics of five different implants in compact bone at different load levels by finite elements analysis. J Prosthet Dent 2004;92:523-530.

4 Oh TJ, Yoon J, Misch CE, Wang HL. The causes of early implant bone loss: myth or science? J Periodontol 2002;73:322-333.

5 Hermann JS, Cochran DL, Nummikoski PV, Buser D. Crestal bone changes around titanium implants. A radiographic evaluation of unloaded nonsubmerged and submerged implants in the canine mandible. J Periodontol 1997;68:1117-1130.

6 Hermann JS, Buser D, Schenk RK, Cochran DL. Crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged and submerged implants in the canine mandible. J Periodontol 2000;71:1412-1424.

7 Hammerle CH, Bragger U, Burgin W, Lang NP. The effect of subcrestal placement of the polished surface of ITI implants on marginal soft and hard tissues. Clin Oral Implants Res 1996;7:111-119.

8 Luo G, Sadegh AM, Alexander H, Jaffe W, Scott D, Cowin SC. The effect of surface roughness on the stress adaptation of trabecular architecture around a cylindrical implant. J. Biomech 1999;32:275-284.

9 Jung YC, Han CH, Lee KW. A 1-year radiographic evaluation of marginal bone around dental implants. Int J Oral Maxillofac Implants 1996;11:811-818.

10 Wiskott HW, Belser UC. Lack of integration of smooth titanium surfaces: a working hypothesis based on strains generated in the surrounding bone. Clin Oral Implants Res 1999; 10:429-444.

11 Norton MR. Marginal bone levels at single tooth implants with a conical fixture design. The influence of surface macro and microstructure. Clin Oral Implants Res 1998; 9:91-99.

12 Hansson S, Werke M. The implant thread as a retention element in cortical bone: the effect of thread size and thread profile: a finite element study. J Biomech 2003;36:1247-1258.

13 Djebbar N, Serier B, Bachir Bouiadjra B, Benbarek S, Drai A. Analysis of the effect of load direction on the stress distribution in dental implant. Materials & Design 2010; 31: 2097-2101.

14 Achour T, Merdji A, Bachir Bouiadjra B, Serier B, Djebbar N. Stress distribution in dental implant with elastomeric stress barrier. Materials and Design 2011; 32: 282–290.