



Effect of the combined efforts on stresses distribution in the dental prosthesis

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ABSTRACT

This study focused on the numerical analysis by the finite element method the distribution of the equivalent stresses and its level in the three elements of the dental prosthesis (abutment, implant and bone) subjected to combined efforts simulating the operation of the tooth. This distribution was made in the three zones (distal, median and proximal) of these components.

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Introduction

Primary stability has been regarded as a prerequisite for osseointegration of dental implants [1,2], especially when early or immediate loading protocols are considered as treatment modalities in dental implantology [3]. The primary function of a dental implant is to act as an abutment for a prosthetic device, similar to a natural tooth root and crown. Then the osseointegration between the dental implant and supporting bone is occurred, the artificial crown (prosthesis) supports the daily loads of the patient during the occlusion [4]. W. Winter, S.M. Heckmann and H.P. Weber [5] showed that one can calculate the non-linear relationship between the tightening torque and the rotation angle. The final couples of displacement, which depend on curative time, are described by a curative function depending on time. Oguz Kayabasi, Emir Yuzbasioglu and Fehmi Erzincanli [6], studied the dynamic, static and fatigue behaviours of the implant. In fact, dynamic loads were applied during five minutes to occlusive surface. For the fatigue damage analysis of the implant, they used the formula of Goodman, Soderberg and Gerber. Baris Simsek and Erkan Erkmen [7] studied the evaluation of the tensile and compressive stresses for the cortical bone and cancellous under conditions of load according to the distance inter-implants, the 1.0cm of inter-implant distance is the

optimum distance for two fixtures implantation. Alessandro Pegoretti and Claudio Migliaresi [8] calculated the long-term effects of aging in water on the physical properties of a new class of commercially available dental polymer composites reinforced by glass fibres. Jianying Li and others [9] developed a new bone model which can simulate both underload and overload resorptions that often occur in dental implant treatments. Lindsey R. Van Schoiack and Jean C. Wu [10] studied the effect of the bone density on the mechanical damping behaviour of dental implants. However, Mr. Sevimay and others [11] made a study of the effect of 4 different bone qualities on stress distribution in an implant-supported mandibular crown, using 3-dimensional (3D) finite element (FE) analysis. Mr. J Morgan and D. F. Jamest [12] indicated that the distributions of force, bending moment and torque are determined by structural analysis for an osseointegrated dental implant system. The system is a dental prosthesis rigidly connected to bone by implants. The immediate result of the structural analysis is that the bending moment due to the vertical component of the applied load a moment which has previously been neglected can produce stresses on the implant which are of magnitude larger than the direct axial stresses. The finite element analyses of Dincer Bozkaya and others [13] led to the evaluation of the characteristics of load transfer of five different implants in the compact bone to different loads. Dinaer Bozkaya and Sinan Muftu [14] analyzed the mechanisms of fitting with conical tightening in dental implants; the validity

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and the applicability of the analytical solution were studied by comparing them with the model designed in finite elements for a range of problem parameters. Morgan et al. [15] reported that fractures occur due to fatigue under a physiologic load surrounding the implant fixture that causes marginal bone resorption, and Rangert et al. [16] reported that fractures are related to bending overload brought about due to compound factors such as cantilever load, bruxism, and overload. Balshi [17] listed the causes of fracture as defects in implant design or material, non-passive fit of the prosthesis, and biomechanical overload as a common case. Piatteli et al. [18] and Lee et al. [19] reported that implant fractures develop due to fatigue or traumatic overload.

Hao-Sheng Chang et al. [20] investigates the stress distributions in an implant, abutment, and crown restoration with different implant systems, in various bone qualities, and with different loading protocols using a three-dimensional finite element model.

The aim of this study is the analysis to analyze the level and the distribution of the equivalent stress in the three components (abutment, implant and bone) of the dental prosthesis under the combined mechanical efforts simulating the process of the tooth.

Geometrical model

The three-dimensional geometrical model of the dental structure, illustrated in Fig. 1, is analyzed by the finite element method using ABAQUS code version 6.11.

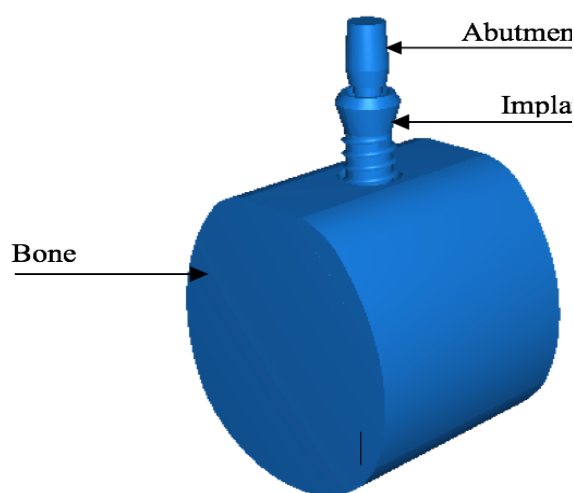


Fig. 1. Three-dimensional model of the structure.

The bone was modelled as full structure (block of bone with size equal to the section of lower jaw: 24.23 mm height and 17.43 mm width). It is composed of a spongy center surrounded by 2 mm of cortical bone. The implant is presented in screw form of length 14 mm and diameter 4.1 mm. Abutment of conical form is adjusted to the implant. The abutment dimensions are: length $l = 7.2$ mm, lower diameter $d_1 = 2.6$ mm and great diameter $d_2 = 3.6$ mm [21].

Table 1 gives the elastic properties of the dental prosthesis components [21]. The behavior of the cortical bone is supposed orthotropic.

Load conditions

A tightening torque abutment/implant and implant/bone of 3500 N.mm and a friction coefficient of 0.28 were retained. Loading of the structure, in three-dimensional model, with forces of 115 N, 24 N and 18 N were applied on the structure according to the illustrated directions in Fig. 2. The level of these loadings simulates that exerted on an average adult tooth.

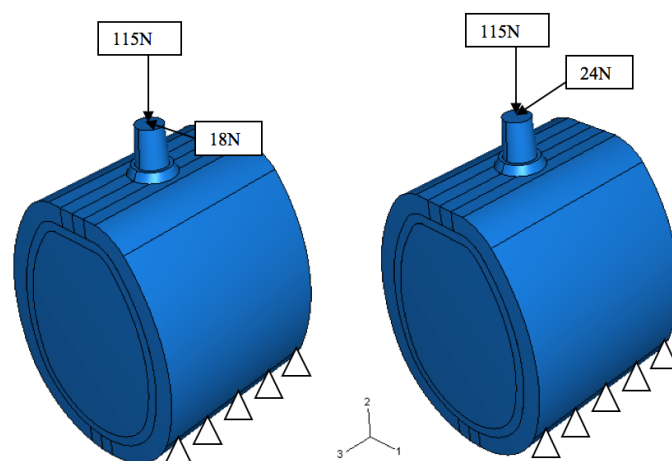


Fig. 2. Applied loads and boundary conditions of model.

Modelling contact

Interaction between the bone and implant during simulation of the implantation process is complex and requires definition of contact conditions. In the present study, contact is defined in ABAQUS software using surface-to-surface discretisation because it provides more accurate stress and pressure results than node-to-surface discretisation.

Table 1. gives the elastic properties of the dental prosthesis components [21].
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Material	Young's modulus E [MPa]	Poisson ratio (ν)
Implant (Titanium alloy Ti-6Al-4V)	110000	0.32
Abutment (Titanium alloy Ti-6Al-4V)	110000	0.32
Cortical Bone	$E_x = E_y = 11500, E_z = 17000$ $G_{xy} = 3600, G_{xz} = G_{yz} = 3300$	$\nu_{xy} = 0.51, \nu_{xz} = \nu_{yz} = 0.31$
Cancellous Bone	14700	0.3

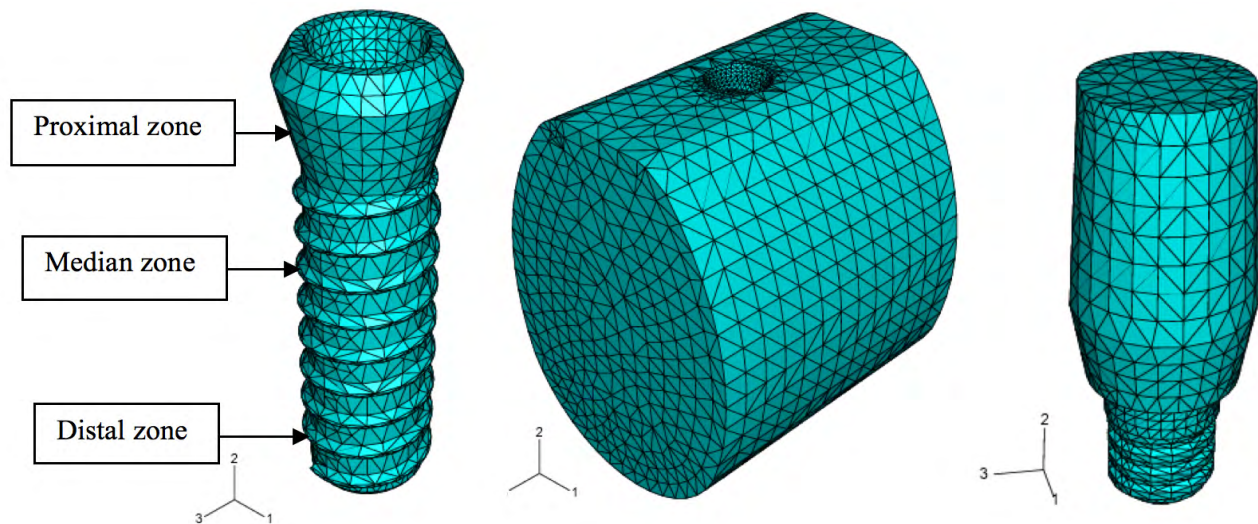


Fig. 3. Finite element model of the structure.

Results and discussions

Stress distribution in the bone-implant interface

Because of complexity of the forces exerted on the tooth, the distribution of the stresses on the dental prosthesis components was analyzed under the combined effect of loading normally applied on the structure, in parallel and perpendicular to the implant axis (Fig. 3). The analysis of the equivalent stress was made from the bottom to the top of the structure.

Analysis of the equivalent stress along the implant and the bone

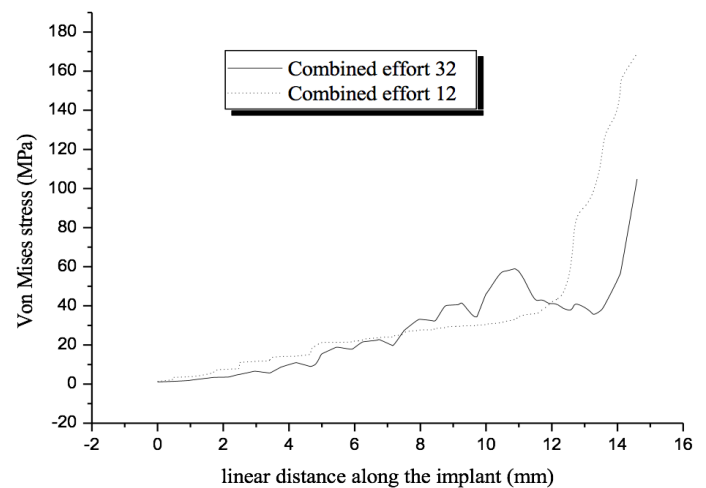
Figure 4 represents the variation of equivalent stress along the implant under the combined effort.

- Along the implant

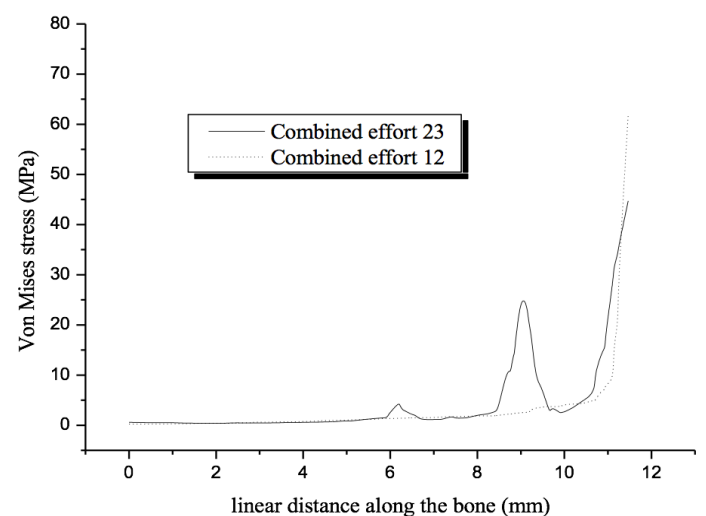
A combined loading exerted following the directions noted 2 and 3 produces a strong localized stress on the top of the implant. The intensity decreases gradually as one move away from this zone (Fig. 4). In the latter the stress is almost completely released. The study of this figure illustrates that the equivalent stress distribution along the implant presents two maximum; this later are the results of a strong contact implant-bone. An effort applied according to directions 2 and 1 led to a heterogeneous distribution of the stress along the implant (Fig. 4a). On its higher part, the implant is strongly solicited, and subsequently the equivalent stress reduces brutally in the zones close to the end of the implant and finally decreases slowly until its bottom.

- Along the bone

According to directions 2 and 3, the distribution of the equivalent stress in the bone has additional significant stress intensity on the upper surface of this body in contact with the implant. It presents two maximum (Fig. 4b). The equivalent stress raises, decrease then increases along the bone. Its level gradually reduces from the surface towards the bottom of the bone. In this zone and with its close vicinity, the amplitude of the equivalent stress is null. Practically this loading type has no effect the bottom of the structure. The same variation of the stress is observed along the bone according to directions 2 and 1 (Fig. 4b).



(a)



(b)

Fig. 4. Variation of the equivalent stress along the implant and the bone under the effect of a combined effort.

The analysis of this figure shows that this loading generates much more significant stresses in the bone. Compared to the

first loading this one solicits much more both components (implant and bone) of dental prosthesis. The stresses induced on the implant are more significant than those generated on the bone. An implant designed out of resistant material easily supports the level of these stresses contrary to the bone which is an alive material having a weak resistance mechanical properties. This loading constitutes a damage risk for the bone by notch effect. Indeed, the bottom of the nets machined in this body is the seat of stress concentration that leads to the starting and the crack propagation.

Equivalent stress analyzes in the proximal, median and distal zones of the implant and the bone

The level of the equivalent stress was analysed in the three zones of the prosthesis dental (proximal, median and distal) along the helicoids according to a combination of the two loadings defined previously (Fig. 5).

- Implant

Proximal zone

The obtained results under the effect of the combined loading towards the directions 2 and 3 represented on the Fig. 6a confirm that the level of stress decreases by the end of the structure towards the bottom. The first zone is most strongly requested. In this case, the stress distribution along the helicoids is almost symmetrical with amplitude more marked in the mechanically solicited part. The stress of Von Mises decrease along the helicoid and stabilized then grows after. The applied efforts simultaneously according to the directions 2 and 1 are very strongly request the first zone. Indeed, the equivalent stresses are intensively localized in this implant part. Its distribution is almost symmetrical on both sides of the helicoid. It decreases brutally afterwards slowly, null then grows little considerably, then suddenly tending towards its optimal value (Fig. 5a).

Compared to the first loading, this case generates more important amplitudes of stresses.

Median zone

The combined loading according to the noted directions 3 and 2 the level of the stress in the second part of the implant is marked compared to the proximal zone. Its intensity falls approximately by three times. Let us note however, that the stress distribution around the helicoids is appreciably periodic with three maximum and two minima (Fig. 5b). The level of the stress recorded in the median part of the implant following directions 2 and 1 varies along the helicoid. Indeed, it passes by a maximum and decrease then increases to reach its initial level (Fig. 5b). It is marked more than that resulting from the loading exerted at the same time along axes 3 and 2.

Distal zone

The applied effort towards directions 3 and 2 in the distal zone of the implant generates a slightly distributed stress (Fig. 5c). Indeed, the equivalent stress intensity in this part remains insignificant. According to the directions noted 2 and 1, the implant is subjected to more marked stress much than induced by the first loading (according to 2 and 3), but its level remains low compared to that recorded in the first two zones (proximal and median). It is six times less than that of the proximal part and approximately four times less than that of intermediate zone. However, along the helicoid, the stress

reaches a maximum value, is null followed by rises again to reach its initial level (Fig. 5c).

- Os

Proximal zone

According the directions 2 and 3, the stresses level varies along the helicoid. This level decreases in the proximal zone, remains constant then increases along the helicoid (Fig. 5d). The combined loading applied according to directions 1 and 2 (fig. 5d) effect doubly the bone part. Indeed, the equivalent stress induced in this zone has an important intensity. It tends towards the failure stress in traction of the bone; its level can largely exceed the rupture threshold with notch effect at the bottom of living edge of the threads in this body. Such loading presents a damage risk of the bone and consequently of the structure. This risk is accentuated by the cyclic phenomenon of the dental prosthesis fatigue or the rupture stress of the bone is largely greater than the rupture threshold.

The level of the equivalent stress induced in the proximale part of the bone is lower than that generated in the same implant zone.

Median zone

The applied loading according to directions 3 and 2 involves practically the same stress level in the second zones of the bone as that induced in the similar zone of the implant (fig. 5e). This level decrease and after remains constant then increases along the helicoid. Although, according to directions 2 and 1 and in former zone the stresses decrease, and be null then increase on the hollow helicoid in the bone. Let us note however, that this stress generates an important stresses than those resulting from the first loading of comparable amplitude with those induced in the implant. In this part of the bone, the stresses generated by such loadings led to important intensities and can constitute a failure risk for the bone. The threshold of crack stress on cyclic fatigue of this body is largely exceeded.

Distal zone

On the directions 3 and 2 the distribution of the equivalent stress is quasi-symmetrical along the helicoid of the distal zone. It decrease brutally and become negligible, then augment and tend towards its initial values (Fig. 5f). It is of a greater level than that induced in the implant in the same zone and of different distribution. The stresses in the bone are intensively concentrated in the zones where the loading is applied. According to directions 2 and 1 the stresses vary not only along the bone but also along the helicoid. Indeed, the stresses decrease, takes a null values then increase on the helicoid hollow in the bone. Let us note however, that this type of loading generates an important stresses than the first loading. The distribution of the equivalent stress is almost symmetrical along the helicoid for all loading nature. The stresses marked in the bone are not intense compared to those induced in the first two zones.

*The obtained results based on this analysis show that the induced stresses on the dental prosthesis elements under the effect of a combined loading are of more significant level. The stresses recorded in the bone are very significant and can lead to a damage risk of this living organ and consequently of the structure and becomes fatal for the patient.

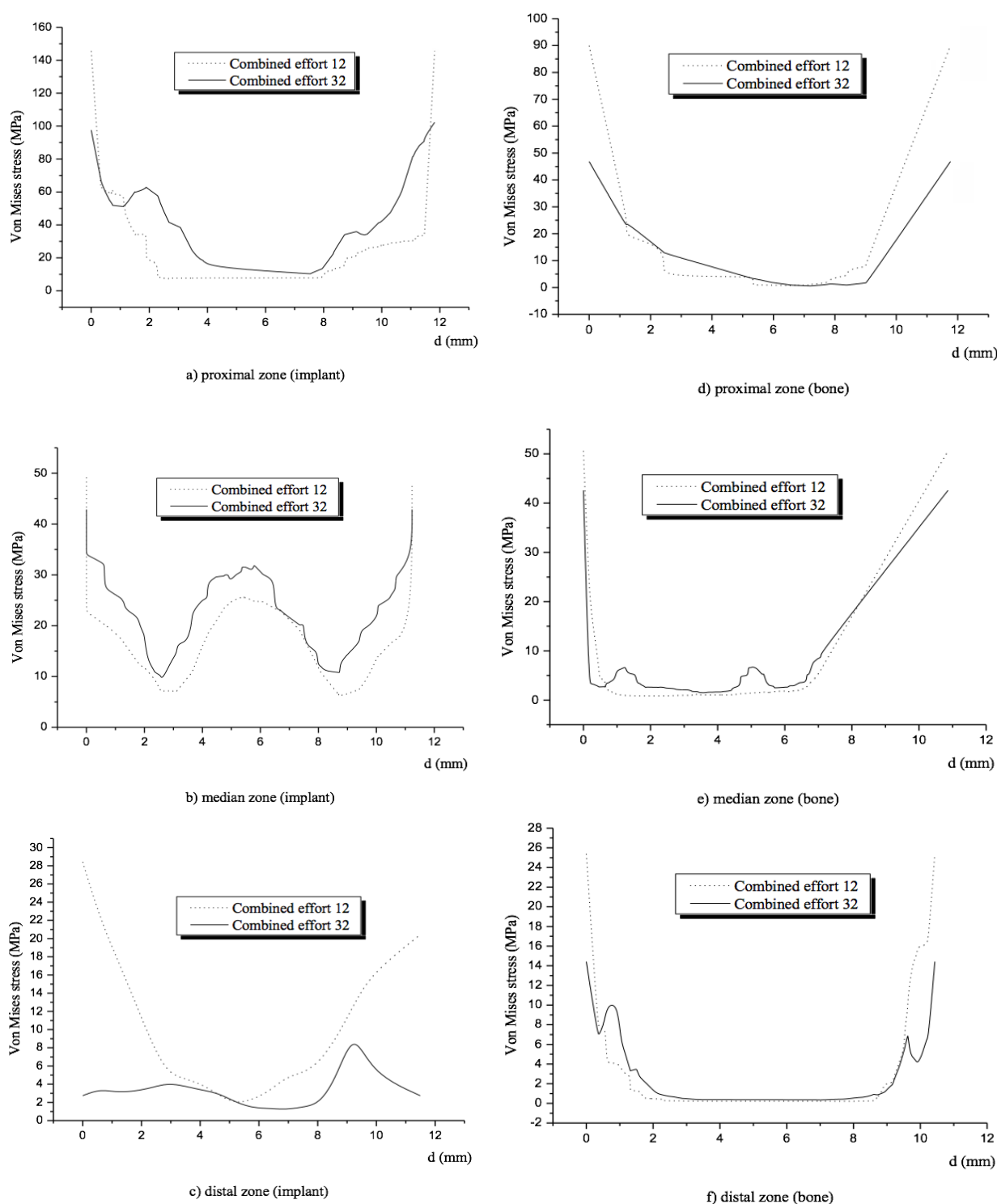


Fig. 5. Variation of the equivalent stress along the helicoids in the three zones of the implant and the bone under the effect of a combined effort.

Conclusion

The obtained results in this work show that:

- The parallel and perpendicular combined loading to the dental prosthesis axis generates on the implant and the bone more intense stresses and differently distributed that resulting from only one loading. Such loading solicit more strongly the proximal part of the implant and the bone. The stresses induced in the distal zone are relatively higher than those generated for only one loading.
- The induced stresses, under the effect of such loading, in the dental prosthesis elements and particularly in the bone are important and can be fatal for the structure and the patient.

The stress level is the result of significant intensity excess of the applied efforts.

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Conflicts of interest

Authors declare no conflict of interests.

Notes

The authors declare no competing financial interest.

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