Mechanics and Mechanical Engineering
Vol. 22, No. 4 (2018) 1061–1076
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https://doi.org/10.2478/mme-2018-0084

Parametric Optimization of Dental Implants

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Received (29 January 2018)
Revised (1 August 2018)
Accepted (20 November 2018)

Osseointegration is a fundamental phenomenon of dental implantology. It ensures the stability, the safety and the durability of dental implants and predictable clinical success in long-term. The geometric form of the implant is a defining parameter of osseointegration and implant-bone charge transfer. This is the essential constitutes of this study. In fact, we demonstrate using the finite elements method with tridimensional numerical computations, that the geometrical parameters of the implant conditionate the level and the repartition of the stresses, induced in the cortical bone and the spongy bone during the masticatory process, simulated here by dynamic charging. The effect of several parameters [size and conicity of the implant neck, size and radius of curvature of the implant apex] and the shape of the implant corps on the biomechanical behavior of the bone. The latest was analyzed in terms of variation of the equivalent stress induced in the bone. The purpose of this analysis was the developing of an implant form allowing stress relaxation, during the mastication process, in the living tissue.

Keywords: Implant shape, finite element, stresses, effect of conicity.

1. Introduction

Outside osseointegration, another fundamental problem, of a biomechanical order, of the dental implantation remains the nature and intensity of the forces applied to the implants in place during the chewing process. Also aesthetics is a problem to be satisfied. These two aspects of implantology [biomechanics and aesthetics] led surgeons and periodontitis to optimize the positioning and inclination of implants in order to satisfy the functional requirements of occlusion and cosmetic patients.

Due to its development, implant dentistry has become, in recent years the treatment of choice and a reliable and necessary solution for filling the space left by torn and damaged teeth causing a catastrophe functional and aesthetic situation. Furthermore, the vacant space left by the torn teeth can lead to a bone defect and facial deformity (the jaw bone) and facilitates the migration of adjacent teeth. The reduction of this deformation and delaying an appearance of premature aging of the face requires that dental implant must be performed on time.

For this purpose, dental implants therefore have the advantage to offer patients the function and aesthetics of a natural tooth and thus a masticatory comfort and a smile of confidence [2]. Despite this advantage, problems related to the dysfunction of the constituents of the implantology and the restoration can occur [3–6]. Other studies have analyzed the biomechanical behavior of bone under static and dynamic stresses. They show that chewing, simulated by dynamic loading) stresses the bone more strongly [7–9]. These stresses are partially relaxed by the interposition of an elastomeric seal between the abutment and the framework [10, 11]. One study showed that the stresses induced in the bone during mastication are all the stronger that the implants are located in close proximity of one another [12, 13].

As we mentioned above, osseointegration, developed by Branemark [14] in 1965, is defined by the direct contact between the bone tissue and the implant, without the interposition of fibrosis. This author has used for the first time titanium implants. This latter has remarkable biocompatibility and is therefore an excellent biomaterial. This author explains that the mechanical attachment is made by plastic deformation of the metal at the bone-implant interface. In this case, this deformation favors encrusted titanium in the surface defects of the bone. These types of implants are used until the present time [15]. Osseointegration, widely used in dental implantology [16], is conditioned by the roughness and geometry and surgical placement of the implant, by the bone quality and the preparatory mode of the bone site, and finally by the disinfection of the premises, the hardware, stakeholders and the operative site.

One of the fundamental parameters of osseointegration is the geometric shape of the implant. This shape determines the quality of the implant-bone contact and the migration of the bone to the implant, and the intensity of the transfer of charge from the implant to the bone. This is the objective of this work. Indeed, we analyze, numerically by the method of finite elements in three dimensions, the performance, the reliability and the durability of the dental implantology in relaxation terms of the stresses level generated in the cancellous and cortical bone during the chewing process. The objective of this work is the analysis the effect of the implant geometric shape on the biomechanical behavior of the interface between a dental implant and the adjacent bone area (bone-implant interface) during the chewing process. Geometric parameters have been changed to ensure a reduction in the load transfer of implant-bone and improved osseointegration for the implant stability.

It should be noted that several studies have been devoted to the mechanical behavior analysis of dental implantology [8, 17, 18].

2. Methods and Materials

2.1. *Geometric Model*

In Figure 1 is illustrated the three-dimensional model used in this study with the constituent elements of the structure and their assembly respectively. Bone is composed of two parts: cancellous bone size: 24.2 mm in height and 16.3 mm in width, this size is representative of the lower jaw section. This living body is composed of a spongy center surrounded by 2 mm cortical bone. The implant is in the form of a screw with a length of 12.3 mm and a diameter of 4.2 mm and the abutment has geometrical characteristics: length: $L = 8.9$ mm and diameter $d_1 = 2.8$ mm, $d_2 = 4.24$ mm [19].

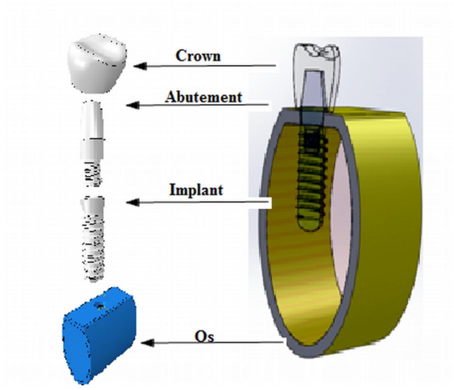


Figure 1 Elements of the dental structure

The geometrical characteristics of this implant will be progressively modified throughout this work, the purpose of which is to design a form allowing better osseointegration and a reduction in the load transfer from the implant to the bone.

2.2. *Properties of the Materials*

The mechanical properties of materials used in this study are grouped in Table 1.

Table 1 Mechanical properties of materials used for dental prosthesis [20.21]

	Materials modulus E [GPa]	Elastic ratio ν	Poisson's strength [MPa]	tensile strength [MPa]	density [kg/m^3]
implant	Titanium Ti–6Al–4V	110	0.32	800	4428.8
crown	Feldspathic porcelain	61.2	0.19	500	2300
bone	cortical bone (anisotrope)	$Ex = Ey = 11.5$ $Ez = 17$ $Gxz = Gyz = 3.3$	$\nu xy = 0.51$ $\nu xz = \nu yz = 0.31$	130	1700
	cancellous bone	$E = 3$ $Gxy = 3.6$	$\nu = 0.3$	130	270

2.3. *Limit Condition*

In order to define the boundary conditions, a restriction on the movements of translation and rotation of the mandibular bone has been applied, the lower plane of which is defined as having zero displacements.

The upper surface of the crown is subjected to a load of 4 MPa in the disto-mesial directions, and 2 MPa in the linguo-buccal directions, or 10 MPa in the corono-apical directions (Figs. 2 and 3). The other surfaces are treated as free surfaces (zero charges).

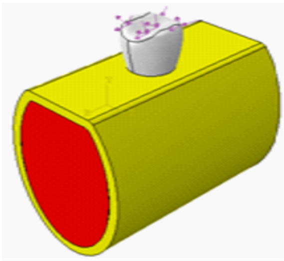
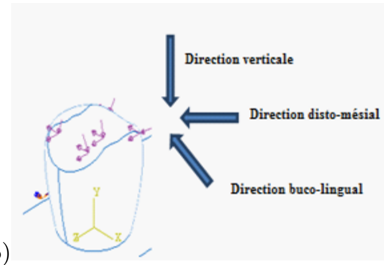
(a)  (b) 

Figure 2 Loads applied to the dental structure and boundary conditions: (a) model of dental structure (b) the crown

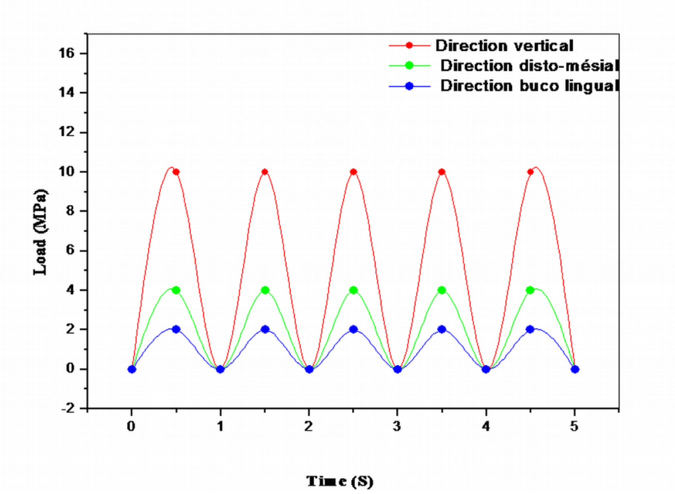


Figure 3 Variation of the chewing efforts according to the three loads in the corono-apical, linguo-buccal and disto-mesial directions as a function of time

2.4. *Finite Element Modeling*

The calculation code used for this study is the ABAQUS software. The latter has a powerful mesh automatic, which can analyze the geometry and generate the most suitable mesh for the structures studied. Analysis of the dental prosthesis mechanical behavior requires the use of tetrahedral elements, type C3D4. This mesh has been particularly refined for the reliability and reproducibility of the results. The meshes of the assembled dental prosthesis and its elements respectively are represented in Fig. 4.

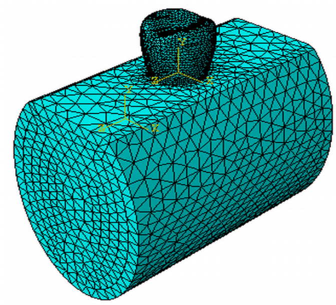


Figure 4 Overall mesh of the assembled dental prosthesis

3. Analysis and Results

The geometrical shape of the implant condition the interfacial interactions between these two components of dental implantology. These interactions are responsible for the load transfer to the bone and osseointegration phenomenon determining the stability and performance of dental implantology. The geometrical parameters of the implant determine its shape. This interaction effect is analyzed here in terms of stress distribution in spongy bone and cortical bone around implant geometries. To this end, several implant systems have been studied. These systems differ only in their form.

3.1. *Effect of the Shape of the Implant Apex*

The implant apex is an essential element for the stability of dental implantology. The biomechanical behavior of the dental structure depends on its shape. In the following, an analysis of this form on the transfer of charge to cortical and spongy bone in terms of variation of Von Mises stresses and its intensity. To do this, five implant systems were analyzed. The latter are differentiated only by the shape of their lower part, defined here by the radius of curvature. Figure 5 clearly shows that a reduction in this radius causes in an intensification of Von Mises stress in the cortical and cancellous bones. Implants with low curvature led to a strong implant-bone interaction and a transfer of charge to the living tissue more important. This biomechanical behavior results in a zone under strong more extensive stresses as shown in Figs. 5(a), (c)–(e). The shape illustrated in Fig. 5(b), characterized by a very strong curvature, generates efforts in the less intense bone. This geometry of the implant results from a perfectly flat implant (radius of curvature equal to infinity) with transformation of the acute edges into rounded edges. This configuration minimizes the stress concentrations of the implant transferred to the bone. The perfectly flat apex transmitted to the bone of the stresses more intense the localization of the strong stresses.

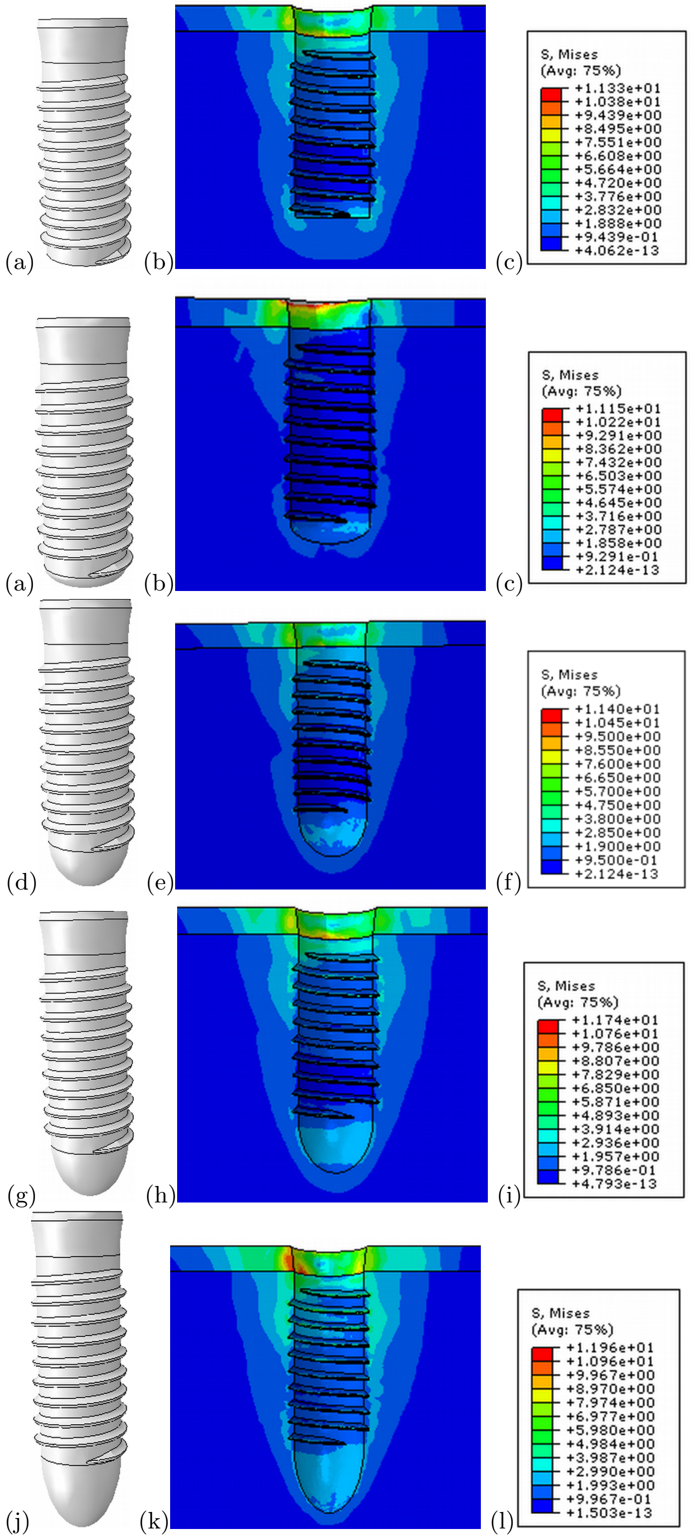


Figure 5 Effect of the curvature of the implant lower part on the amplitude and distribution of Von Mises stresses in cortical and spongy bone

Figure 6 shows the variation of the von Mises stress in the bone as a function of apex radius. It shows that a reduction of this parameter leads to a load transfer at the implant-bone interface more important. The implants designed with such a shape are the seat of stresses for the bone and can be source of pain for the patient. The almost flat implants (high radius of curvature) transmit less effort to the bone and have good stability and good biomechanical behavior.

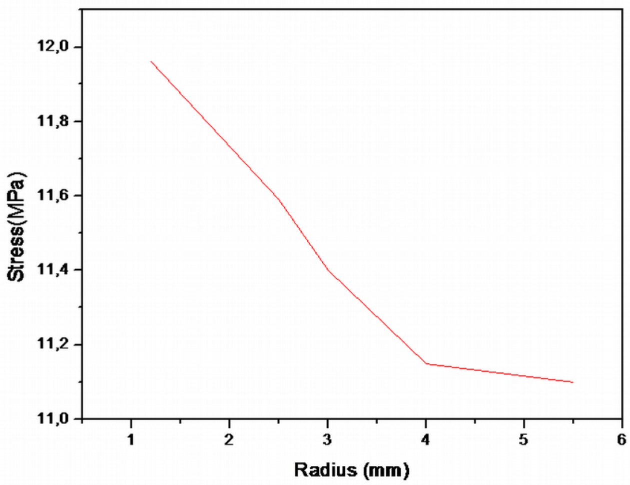


Figure 6 Variation of the von Mises stress induced in the bone as a function of radius of the implant base

3.2. *Effect of the Shape of the Implant Neck*

In this part of the work, an analysis of the effect of the implant neck morphology on the biomechanical behavior of dental implantology in terms of implant-bone interaction. The geometry of the implant lower part retained for this study corresponds to the configuration leading to an effort transfer to the bone less important (fig.5b). The effect of two parameters, conicity and size, characteristic of the implant neck geometry has been particularly studied.

3.2.1. *Effect of Conicity*

The shape of the implant head is an essential parameter for the biomechanical behavior and stability of dental implantology. To this effect, an analysis of the conicity, defined here by an angle of inclination, is carried out in this first part of this study. To do this, the angle of the implant upper part has been progressively modified (Fig. 7). This figure shows the effect of this angle on the distribution and the level of the equivalent stress of von Mises induced in cortical and spongy bone during the chewing process. The intensity and extent of these stresses are even more important as implant-bone (cortical bone) contact angle is higher (7(a) to 7(d)).

Such geometry leads to a strong interfacial interaction between a dental implant and the adjacent bone region (bone-implant interface). This behavior is explained by the strong constraints recorded in these two living tissues. The cortical bone is more heavily solicited by such shape of the implant head. A strong inclination of the implant upper part results from an implantable contact surface as well as a load transfer to the living tissue more significant and distributed at a big distance.

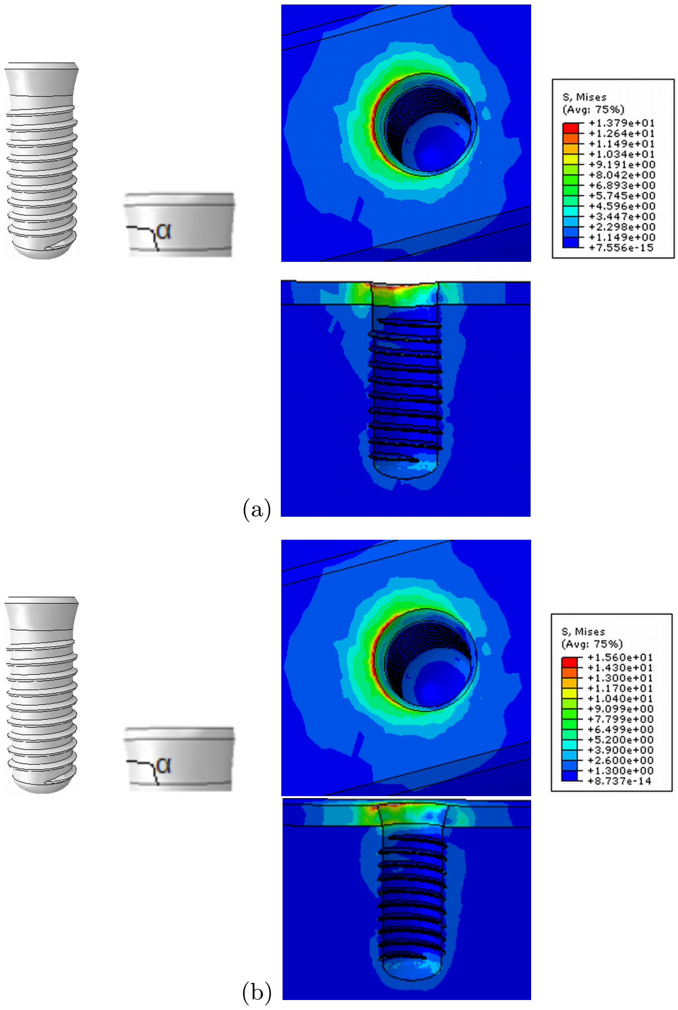


Figure 7 Effect of the implant shape on the distribution and level of von Mises stress induced in cortical and concellous bone during mastication (continued at the next page)

Figure 8 show a better illustration of the effect of this geometrical parameter on biomechanical behaviour of the bone during the chewing process. This figure clearly shows that a larger head of the conicity implant leads to a transfer of charge from the implant to the more significant cortical and spongy bone. This behaviour is explained by a very strong implant-bone interaction due to an intimate contact

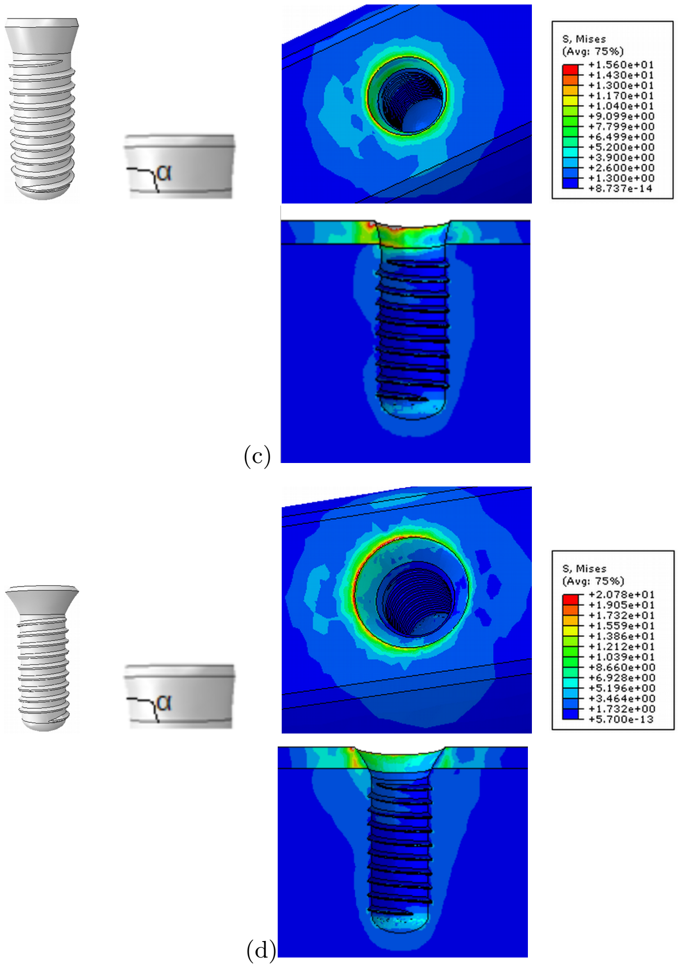


Figure 7 continued Effect of the implant shape on the distribution and level of von Mises stress induced in cortical and concellous bone during mastication

between these two more extensive components. Designers of dental implants must consider biomechanical behavior to ensure good stability of the implant and relieve the pain resulting from these strong interactions. A lower and optimized taper is therefore necessary to ensure both a good stability of the implant and the reduction of the charge transfer to the bone.

3.2.2. *The Effect of the Length*

To complete the previous analysis, a study of the effect of the size of the upper part of the implant on the biomechanical behavior of dental implantology subjected to masticatory efforts. The optimum taper of the implant head causing a weak implant-bone interaction, Fig. 7(a), was selected for the design of this implant. The length of this part was progressively reduced in order to analyse the transfer

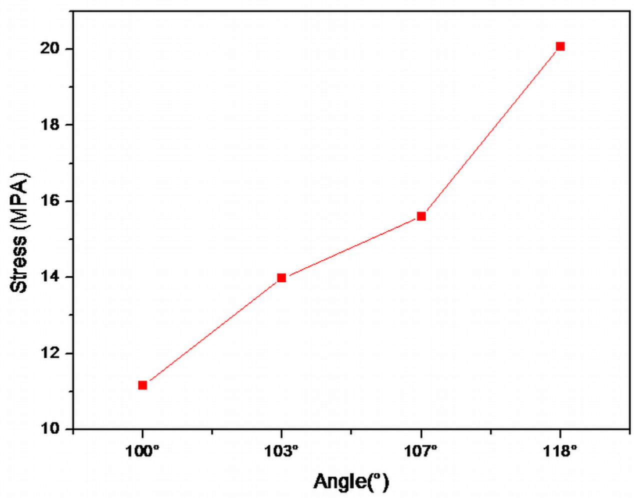


Figure 8 Variation of the induced von Mises stress in the cortical bone as a function of the angle of inclination of the upper part of the implant

of implant-bone load (cortical and spongy) as shown in Fig. 9. The latter clearly illustrates that the longer heads implants induce in bone constraints von Mises less intense and less extended, Fig. 9(a) and (b). The implant-bone interfacial interaction is more marked for implantology using a shorter size of implant, Fig. 9(c)–(e).

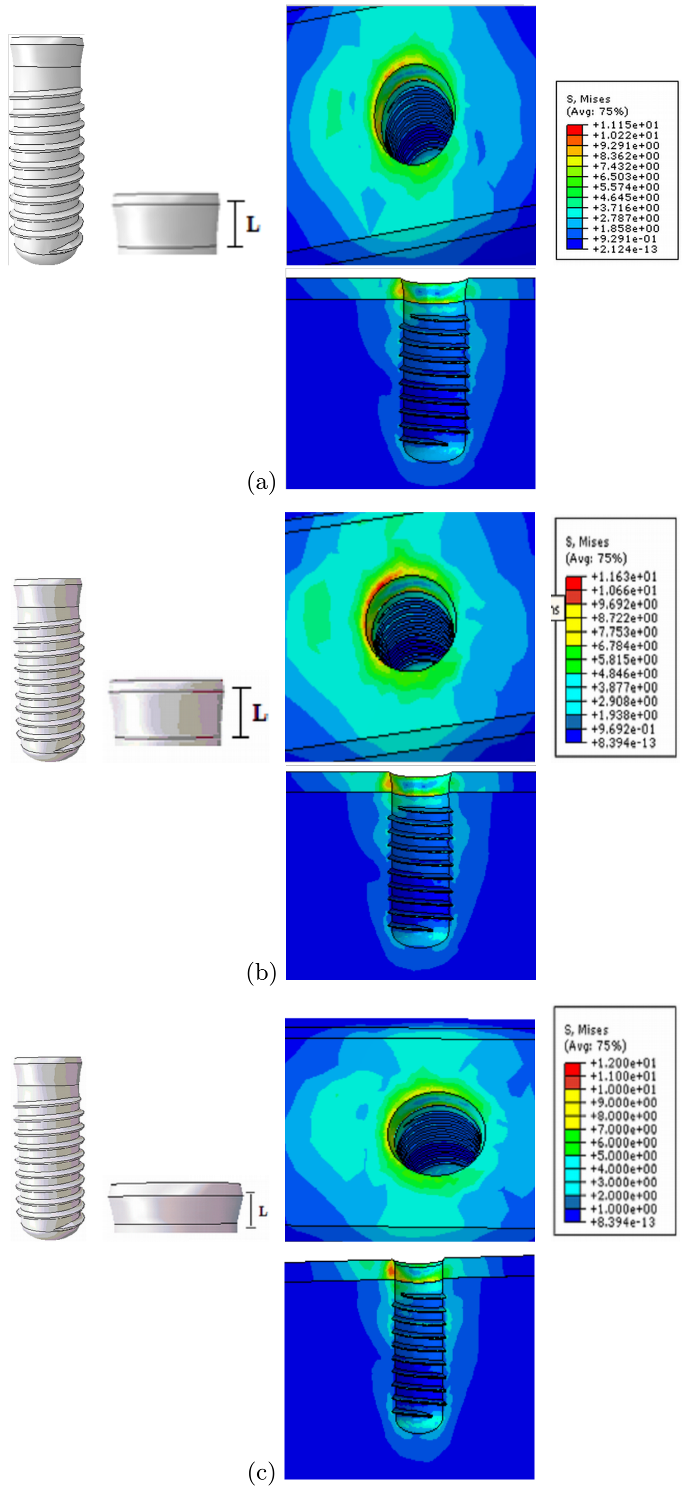
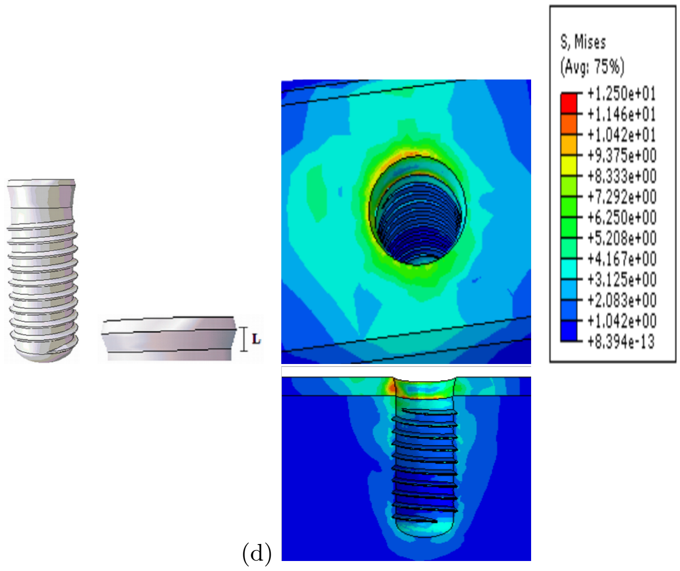
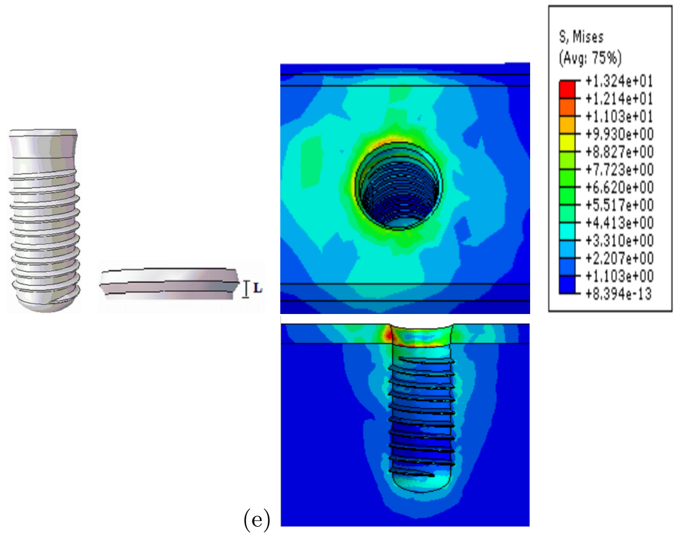


Figure 9 Distribution and variation of von Mises stresses in cortical and cancellous bone in dental structure



(d)



(e)

Figure 9 continued Distribution and variation of von Mises stresses in cortical and cancellous bone in dental structure

In Fig. 10 is shown variation of the von Mises stress in function of the size of the implant upper part (neck). It clearly shows that the biomechanical behavior of the dental structure is conditioned by the shape of the implant head. The more pronounced head implants are more stable and lead in a load transfer to bone less important. The strongest stresses are located on the cortical bone, which is in line with the research work carried out up to the present time.

Our results show that the taper of the implant neck is a geometric parameter determining the biomechanical behavior of dental implantology. This parameter

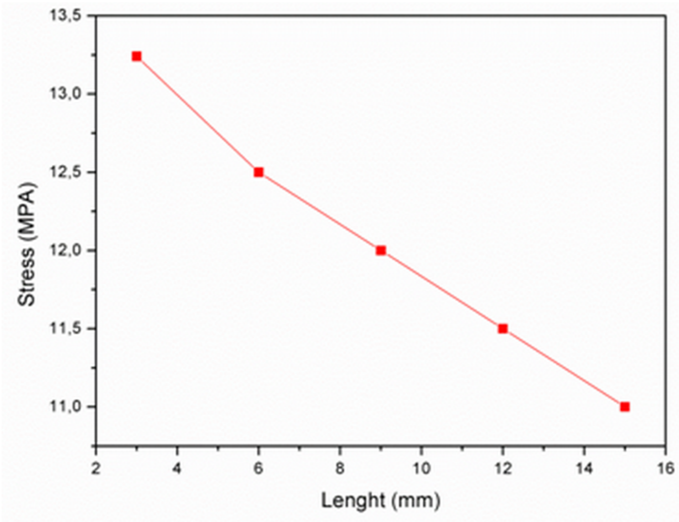


Figure 10 Variation of the von Mises stress induced in the bone as a function of length

should be as low as possible in order to avoid too exaggerated penetration of the bone by the implant and to induce fewer stresses in the living tissue. In other words, it must optimize in order to ensure both good implant-bone (osseointegration) and reduced load transfer from the implant to the bone.

4. Discussion

Dental implants designers must take into account the effect of these geometric parameters to improve the stability, performance and durability of implants and relieve pain patient caused primarily by an excessive load transfer from the implant to the bone. The shape of the implant neck (apex) affects the biomechanical behavior of dental implantology and implant stability. This is in good agreement with the results obtained by Sergio et al. [22], These authors studied, experimentally in the rabbit, the influence of three different apical implant designs at stability and osseointegration process of the implant. They show that the apical area to promote a better bone initial stability and its correlation with the osseointegration. In another study, Rismanchian et al. [23], by analyzing the effect of the shape of the implant on the stress level, show that the level is higher in the cortical bone, which is in good agreement with our results. Yamanishi et al. [24] studied, three-dimensionally finite element, the influences of implant neck design and implant-abutment joint type on peri-implant bone stress and abutment micromovement. They show that the compressive stress is highly concentrated on the cortical bone. This behavior is well correlated with the results obtained in this study. Han et al. [25] studied the effect of integration patterns around implant neck on the stress distribution in peri-implant bone. They show that the maximum compression stress is localized in the cortical bone, which is consistent with the results obtained in this study.

The intensity of the von Mises stress transmitted to the bone by the implant during the chewing process was affected by the modification of the neck design, characterized by its length and conicity and the base morphology, defined by its curvature radius of the implant. These geometric parameters determine the load transfer to the bone-implant interface, performance and durability of implant dentistry. These parameters must be optimized allowing good osseointegration, stability of the implant and reduction of force transfer to the bone.

5. Conclusions

The results thus obtained clearly show that:

- The von Mises stresses are highly concentrated on the upper portion of the cortical bone. These stresses are all the higher as the length of the implant neck is more pronounced. Such behavior demonstrates that the size of this geometric parameter determines the biomechanical behavior of dental implantology and the stability of the implant-bone interface;

- The conicity of the implant head conditions the load transfer of implant-bone. A decrease in this geometric parameter solicits the cortical bone more strongly in its upper part. The load transfer is all the more important and more extensive as this taper is more marked. In other words, a more conical head, chewing, in the bone more intense stresses. An increase of this conicity of four degrees produces in the cortical bone constraints about twice as strong. Such morphology affects the biomechanical behaviourof the implantology and the stability of the implant and can be a source of pain for the patient;

- The morphology of the implant base defined by the curvature radius of the implant lower portion determines the load transfer to the implant-bone interface. A reduction in this radius leads to an increase in the extent of the zone under stress lateral and inferior parts of the bone (spongy bone) in contact with the implant and intensification of stresses in the cortical bone of the implant.

References

[1] **Dorland Newman, W.A.**: *Dorland's illustrated medical dictionary*, 28th ed, **1994**.

[2] Human & Health: Les implants dentaires un ancrage solide pour un avenir souriant, **22**, January **2013**.

[3] **Marcián, P., Borák, L., Valášek, J., Kaiser, J., Florian, Z. and Wolff, J.**: Finite element analysis of dental implant loading on atrophic and non-atrophic cancellous and cortical mandibular bone – a feasibility study, *J. Biomech.*, **47**(16), 3830–6, **2014**.

[4] **Tavares, C.S.S., Belinha, J., Dinis, L.M.J.S. and Natal Jorge, R.M.**: The Elasto-plastic Response of the Bone Tissue Due to the Insertion of Dental Implants, *Procedia Engineering*, **110**, 37–44, **2005**.

[5] **Eser, A., Tonuk, E., Akca, K., Cehreli, M.C.**: Predicting time dependent remodeling of bone around immediately loaded dental implants with different designs, *Medical Engineering & Physics*, **32**(1), 22–31, **2010**.

[6] **Lee, J.Y., Park, H.J., Kim, J.E., Choi, Y.G., Kim, Y.S., Huh, J.B. and Shin, S.W.**: A 5-year retrospective clinical study of the Dentium implants, *J. Adv. Prosthodon.*, **3**, 229–235, **2011**.

[7] **Djebbar, N., Serier, B. and Bachir, B.B.**: Finite element analysis in static and dynamic behaviors of dental prosthesis, *Structural Engineering and Mechanics*, **55**(1), 65–78, **2015**.

[8] **Merdji, A., Bachir Bouiadjra, B., Ould Chikh, B., Mootanah, R., Aminallah, L. Serier, B. and Muslih, I.M.**: Stress distribution in dental prothesis under an occlusal combined dynamic loading, *J. Materials and Design*, **36**, 705–713, **2012**.

[9] **Djebbar, N., Serier, B., Bachir Bouiadjra, B., Benbarek, S. and Drai, A.**: Analysis of the effect of load direction on the stress distribution in dental implant, *Materials and Design*, **31**(4), 2097–2101, **2010**.

[10] **Achour, T., Merdji, A., Bachir Bouiadjra, B., Serier, B. and Djebbar, N.**: Stress distribution in dental implant with elastomeric stress barrier, *Materials And Design*, **32**(1), 282–290, **2011**.

[11] **Merdji, A., Mootanah, R., Aminallah, L., Bachir Bouiadjra, B., Serier, B. and Mukdadi, O.**: The Interest of Damping materials in the stability of dental implants in alveolar bone, Proceedings of 2015 international conference on Bio-Medical Engineering and environmental technology, London, March 21-22, 186–192, **2015**.

[12] **Benlebna, M., Serier, B. and Bouiadjra, B.B**.: Numerical analysis of stresses in the dental implants, case of three implants, *Mechanika*, **20**(5), 460–465, **2014**.

[13] **Sifi, M., Benkhenafou, F., Bennacer, D., Benaissa. M. and Serier, B.**: Mechanical behavior of the spacing between two dental implants, *Advanced Materials Research*, **811**, 297–303, **2013**.

[14] **Branemark, P.I., Engstrand, P. and Ohrnell, L.O.**: *Rev. Implant*, **6**(1), 5–22, **2000**.

[15] **Branemark, P.I., Breine, U., Adell, R., Hansson, B.O., Lindström, J. and Ohlsson, A.**: Intraosseous anchorage of dental prostheses I, experimental studies, *Scand. J. Plast. Reconstr.Surg.*, **3**(2), 81–100, **1969**.

[16] **Branemark, P.I., Hansson, B.O., Adell, R., Breine, U., Lindström, J., Hallen, O. and Öhman, A.**: Osseointegrated implants in the treatment of edentulous jaw, Experience or a 10-year period, *Scand. J. Plast. Reconstr. Surg*, **16**, 1–132, **1977**.

[17] **Branemark, P.I.:** Osseointegration in orthopaedics surgery In Dolci G, Favero G.A, eds. Proceedings of first world congress of osseointegration, Venice, 17-18, **1994**.

[18] **Faegh S., Müftü S**.: Load transfer along the bone–dental implant interface, *J. Biomech.*, **43**(9), 1761–1770, **2010**.

[19] **Ali, B., Ould Chikh, B., Meddah, H.M., Merdji, A. and Bachir Bouiadjra, B.**: Effects of overloading in mastication on the mechanical behaviour of dental implants, *Materials & Design*,**47**, 210–217, **2013**.

[20] **Yang, J., Xiang, H.J.**: A three-dimensional finite element study on the biomechanical behavior of an FGBM dental implant in surrounding bone, *J. Biomech.*, **40**(11), 2377–85, **2007**.

[21] **Oguz, K., Emir, Y., Fehmi, E.**: Static, dynamic and fatigue behaviors of dental implant using finite element method, *J. Adv. Eng. Softw.*, **37**, 649–658, **2006**.

[22] **Gehrke, S.A., Pérez-Albacete Martínez, C., Piattelli, A., Jamil A., Shibli, J.A. and Calvo Guirado, J.L.**: The influence of three different apical implant designs at stability and osseointegration process, experimental study in rabbits, *Clinical Oral Implant Research*, **28**(3), 355–361, **2017**.

[23] **Rismanchian, M., Reza, B., Shahmoradi, M., Talebi, H. and Zare, R.J.**: Developing a New Dental Implant Design and Comparing its Biomechanical Features with Four Designs, *Dental Research (Isfahan)*, **7**(2), 70–75, **2010**.

[24] **Yamanishi Y., Yamaguchi S., Imazato S., Nakano T., Yatani H.**: Influences of implant neck design and implant-abutment joint type on peri-implant bone stress and abutment micromovement: Three-dimensional finite element analysis, *Dental Materials*, **28**(11), 1126–33, **2012**.

[25] **Han, J., Sun, Y.C. and Wang, C.**: Effect of Integration Patterns Around Implant Neck on Stress Distribution in Peri-Implant Bone: A Finite Element Analysis, *Journal of Prosthodontics*, **26**(6), 549–558, **2017**.