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NUMERICAL STUDY AND KNN METHOD APPLICATION IN CHOOSING BIOMATERIALS DEDICATED TO DENTAL IMPLANTOLOGY

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دراسة عددية وتطبيق طريقة KNN في اختيار المواد الحيوية المخصصة لزراعة الأسنان

ملخص

إن زراعة الأسنان هي عملية تُستبدل من خلالها جذور الأسنان بدعامات معدنية شبيهة بالبراغي و يتم تثبيتها جيدًا في الفك. تهدف هذه الورقة البحثية إلى دراسة خصائص المواد الحيوية المستخدمة في زراعة الأسنان باستخدام الطرق العددية من أجل تحديد أيها لها خصائص أفضل والأقرب إلى العظم. يمكن أن يؤدي نمط توزيع الضغط في الفك والغرسة إلى ترميم العظام وفشل عملية الزرع. في هذا السياق، تم إنشاء نموذج ثلاثي الأبعاد للعنصر المحدود (3D) لنظام الزرع/العظم ، لمادتين، للتنبؤ بتوزيع الإجهاد ودراسة تأثير الطول، اللولبة والطلاء، من أجل تحديد آثاره حول توزيع الضغط الناتج حول الغرسة والعظام المحيطة بها بموجب اعتبارات ميكانيكية حيوية. أشارت نتائج هذه الدراسة إلى أن الضغوط القصوى تحدث دائمًا في الدعامة وفي بداية التلامس على محيط العظم/الزرع.

Abstract

The dental implant is the equivalent of a tooth root well anchored in the jaw. This research paper aimed to study the characteristics of biomaterials used for dental implants using numerical methods in order to select which has better properties and is closer to the bone. The pattern of stress distribution in the jaw and implant can result in bone restoration and implant failure. In this context, a three-dimensional finite element (3D) model of implant/bone system has been established, for two materials, to predict the stress distribution and further study the influence of length, threading and coating, in order to identify its effects on the distribution of stress generated around the implant and the surrounding bone under a biomechanical consideration. The results of this study indicated that the maximum stresses always occurred in the abutment and at the beginning of contact on the bone/implant contour.

Keywords: Biomaterials, Bioactivity, Dental implants, KNN method.

1. INTRODUCTION

It should be known, that the tooth adjacent to the empty moves if spaces are created by the loss of a tooth (whatever its origin: extraction, falling etc.). The implant has a curative role because it plays the role of a new root on which a tooth will be placed; it is becoming an increasingly common act [1].

The presence of the implant in the oral cavity, which is one of the most biologically complex environments, can lead to changes in their properties, giving rise to local or general side effects. Indeed, the biodegradation of these materials will generate an ion release in the oral cavity. This release is at the origin, on the one hand, of deterioration and rupture of these biomaterials; and on the other hand, of allergic and / or toxic reactions. We then talk about interactions between oral tissues and biomaterials [2, 3].

One of the main problems that prevent the rapid fusion of an implant with living tissue is the occurrence of inflammatory reactions. The impossibility of an implant to integrate with the adjacent bone, due to micro-movements, causes the detachment of the implant and the formation of a fibrous tissue resulting in the implant’s rejection [1]. Faster healing and better anchoring quality during osseointegration increases safety early in the healing phase and results in a better structural and functional connection between the vital bone and the implant [1]. To improve the crucial stage of primary stability (mechanical fixation), obtain a specific surface topography and roughness, eliminate surface contamination and/or improve adhesion, various complementary strategies have been developed, such as surface finishing, surface treatment and the choice of appropriate materials [4].

The surface treatment technology is based on covering a titanium model surface with a bioactive coating that protects the body from inflammation and promotes osseointegration. It will also prevent the rejection of these foreign elements after implantation and reduce the postoperative period in addition to improving the mechanical properties of the Ti [5, 6]. Bioactivity corresponds to the positive interaction between the biomaterial and tissues, leading to tissue differentiation with strong adhesion and interconnection along the biomaterial-tissue interface [7].

Currently, there is an infinitely varied range of implantable materials that can be used to promote bone repair or reconstruction as biomaterials, so the choice of materials is a fundamental and very complex task. Several studies have focused on the distribution of inter-facial constraints of the bone implant and their influence. Tanwongwan [8], makes a comparison between two analyses, one with the solid titanium implant and the other with the Ti-Mousse implant. The results show that the distribution of equivalent stress concentrates in the implants to the neck region. The level of stress within the Ti-Foam implant is lower than that of the solid titanium implant.

Shamami [9], realizes a three-dimensional (3D) finite element model containing the titanium implant under three different loads 50, 100 and 200 N, with different directions from 0 to 30 degrees with respect to the vertical axis. The confirmed results show that maximum stress in implant and cortical bone increased almost linearly with an increase in loading angle up to 30 degrees. Chiang [10], studies and compares the stress distributions in a Ti dental implant, and the SLAffinity-Ti (to make SLAffinity-Ti specimens, pure Ti samples were grit-blasted with Al_2O_3 particles, acid-etched in an HCl/H2SO4 solution, and electrochemically treated. After being cleaned with de-ionized water, the test specimens were air-dried) treated surface implants for different thicknesses of the coatings and compared in particular between a length of 11 mm SLAffinity-Ti-L and 8 mm SLAffinity-Ti-S by using a finite element analysis. They found that the stress in the implants to a surface treatment is lower than that in the implants without surface treatment and the stress in SLAffinity-Ti-S was about 1.3 times higher than that observed in SLAffinity-Ti- L.

This study aimed to establish a three-dimensional finite element (3D) model of implant/bone system for different materials and lengths to predict stress distribution in addition to studying the influence of threading and coating, in order to identify its effects on the distribution of stress generated around the implant and the surrounding bone under a biomechanical consideration

2. MATERIALS AND METHODS

2.1 The KNN method

The nearest neighbor method represents one of the simplest and most intuitive techniques in the field of statistical discrimination. It is a nonparametric method, where a new observation is placed into the class of the observation from the learning set that is closest to the new observation, with respect to the covariates used. The determination of this similarity is based on distance measures.

Formally this simple fact can be described as follows [11]: Let

$$L = \left\{ (y_i, x_i), i = 1, ..., nL \right\} \qquad (1)$$

where $y_i \in \left(i = 1, ..., nL \right)$ denotes class membership and the vector and the vector $x_i^{'} = (x_{i1}, ..., x_{ip})$ represents the predictor variables of individual i. Determining the nearest neighbor is based on an arbitrary distance function $d(.,.)$. The Euclidean distance or dissimilarity between two individuals characterized by p covariates is defined by [12, 13]:

$$d((x_1, x_2, ..., x_p), (u_1, u_2, ..., u_p)) = \sqrt{(x_1 - u_1)^2 + (x_2 - u_2)^2 + ... + (x_p - u_p)^2} \qquad (2)$$

Thus, for a new observation (y,x) the nearest neighbor ($y_{(1)}$, $x_{(1)}$) in the training sample is determined by:

$$d(x, x_{(i)}) = \min_i d(x, x_{(i)}) \qquad (3)$$

and $\hat{y} = y_{(1)}$, the nearest neighbor class, is selected for the prediction of y. The notations *x(j)* and *y(j)* represent respectively the *j*th nearest neighbor of *x* and its class of membership, respectively.

To calculate the Euclidean distance, all the chemical, biological and mechanical properties are grouped in Table 1.

Table 1. The chemical, biological and mechanical properties of biomaterials and their Euclidean distances with bone

Biocompatibility criteria		Bone	Ti	ZrO_2
Chemical [14,15,16]	Corrosion	++	+	+
	Degradation	++	+	+
Biological [14,15,16]	Adhesion	++	+	+
	Immune reaction	++	+	+
Mechanical	Young Module(Gpa) [13,17,18]	17	110	200
	Ʋ Poisson coefficient [14,18]	0.3	0.3	0.35
	Density g/cm^3 [14,19]	2.3	4.5	6.08
	Resistance in comp (Mpa) [14]	180	250	2500
	Resistance to def (Mpa) [14,17]	156,9	760	900
	A (%) [14,15]	1.49	15	15
	HV [14,15]	26.5	240	1200
	Tear resistant (MPa) [15,17]	12	550	10
The Euclidean distance between the bone and materials		/	1.3012	1.5981

2.2 Modeling

The 3D finite element models are created and analyzed with SolidWorks 2017. The model contained a one-piece implant (ITI Straumann AG, Waldenburg) [12], cortical bone and cancellous bone. The main advantage of this dental implant lies in the fact that it increases the mechanical strength of implants in the neck area. It simplifies the number of tools required for positioning and eliminates shear forces, micros and macro-movements between the parts (implant and abutment) that are exerted on the implants during the bone remodeling phase and bone proliferation. On the other hand, it avoids the formation of bacterial colonies or the deposition of dirt in common areas [12].

The results we acquired using MATLAB code, note that the distances between the bone and the biomaterial are very close but the lower value is for the Ti.

2.3 Implantation system

Two types of dental implants with a standard diameter were presented in this study, one implant without thread and the other threaded with two different lengths (long and short).

Its dimensions respectively are 4 mm diameter, 15 mm length and 7 mm for pillar length, 4 mm diameter, 10 mm length and 7 mm of pillar length to replace a root of the first premolar in the lower jaw. The bone model was simplified to a cuboid shape (14 mm × 10 mm × 17.5 mm) and was classified as type II bone. Type II bones consisted of a layer of cortical bone having a uniform thickness of 2 mm, which was surrounded by a dense cancellous bone core. The 3D model implant/bone system was built by a SolidWorks 2017, able to incorporate geometric features such as length, angle, diameter, and profile to make drawings of parts and samples sets (Figure 1).

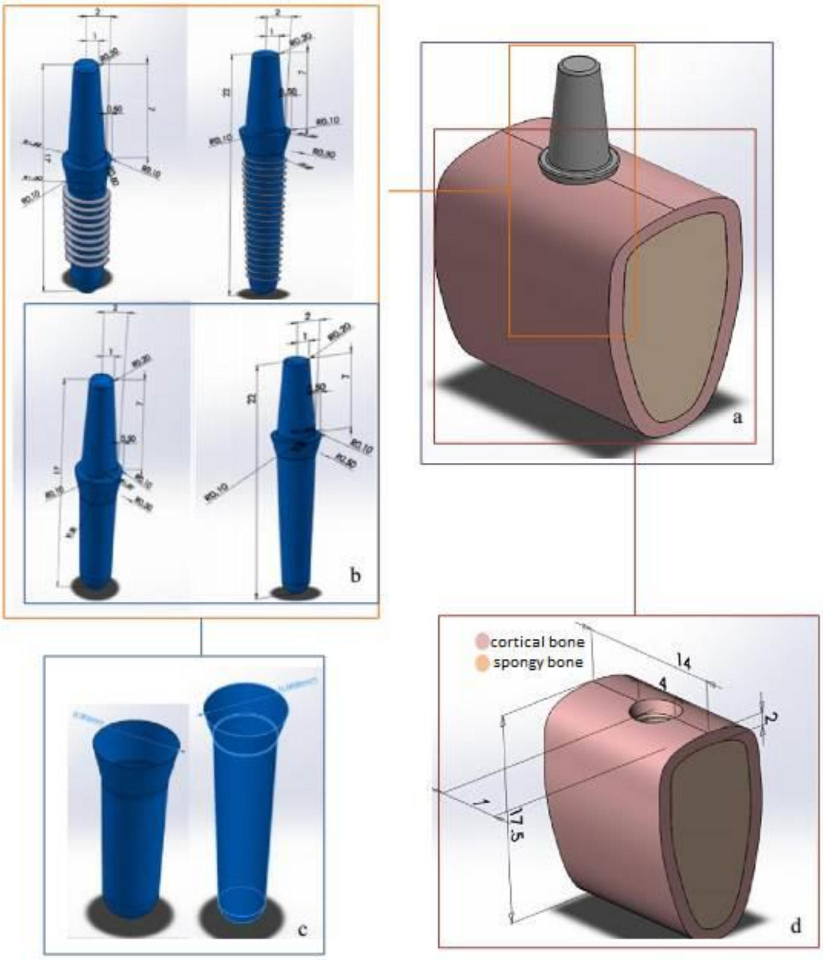


Figure1. The bone / implant system design. (**a**) the complete model; (**b**) the dimensions of long and short implants with and without threads; (**c**) the coatings (short and long); (**d**) the dimensions of the bone

2.4 Limit condition and loading

Forces of magnitudes Fx = 17.1 N, Fy = 114.6 N, and Fz = 23.4 N, respectively in the lingual, axial and mesio-distal directions were applied in the center of the crowns [8,13].

Boundary conditions were applied to restrict any form of translational motion in the model. The interface between the implant and the bone has been treated as a perfectly embedded interface (Figure 2.a).

2.5 Properties of materials

Computations were carried out for two different biomaterials (Ti, ZrO2) in order to compare their stress distribution; the second objective is to select among them the most suitable to replace the lost root. In this study, our choice as a coating focused on the Hydroxyapatite, which is a bioactive material and its structure and nature are very similar with the mineral matrix of natural hard tissues (Young's modulus 80 GPa) with a thickness of 0.005 mm, (Figure1.c). The investigative materials used in this study were all assumed to be homogeneous, isotropic and linearly elastic. Table 1 summarizes all the physical properties of the various modeled system components.

2.6 Mesh development

The finite element model was performed with an implant system, which contained a type of device combined with a type of bone quality; the number of elements and nodes has been well refined in the model for important interfaces such as implant and coating and using the mixed mesh (volume and surface), (Figure 2.b.c and d).

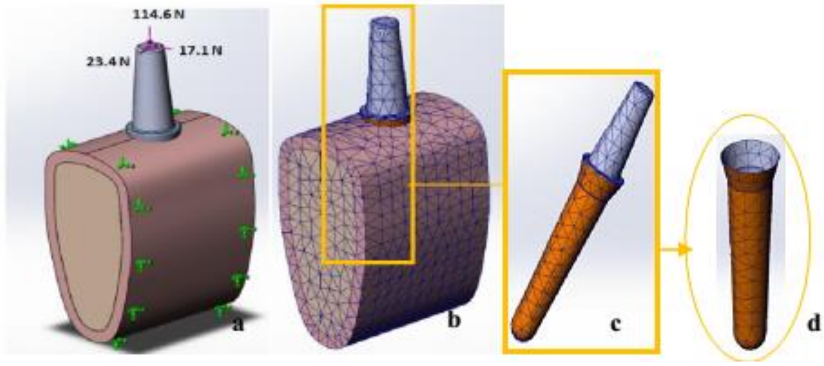
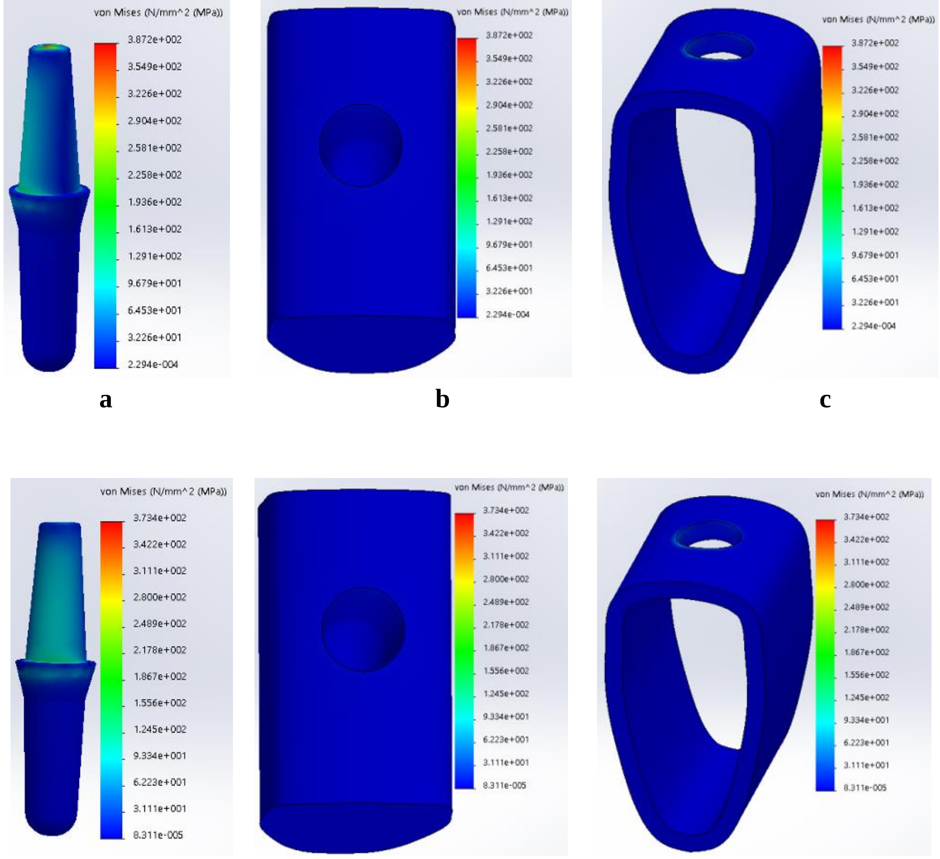


Figure 2 (**a**) applied loads and boundary conditions of the FEM model; (**b**) mesh of finite elements of the model; (**c**) mixed mesh of the implant and the coating; (**d**) surface mesh for the coating

3. RESULT

The Figures 3-7 show the levels of the equivalent von Mises stress distributions in the implants and the surrounding bones for both cases investigated here.

3.1 The influence of length



a b c

d e f

Figure 3. The von Mises stress; (**a**) simple short implant for Ti; (**b**) cancellous bone in the case of Ti; (**c**) the cortical bone in the case of Ti;(**d**) simple short implant for ZrO_2; (**e**) cancellous bone in the case of ZrO_2; (**f**) the cortical bone in the case of ZrO_2.

3.2 The threading influence with both lengths

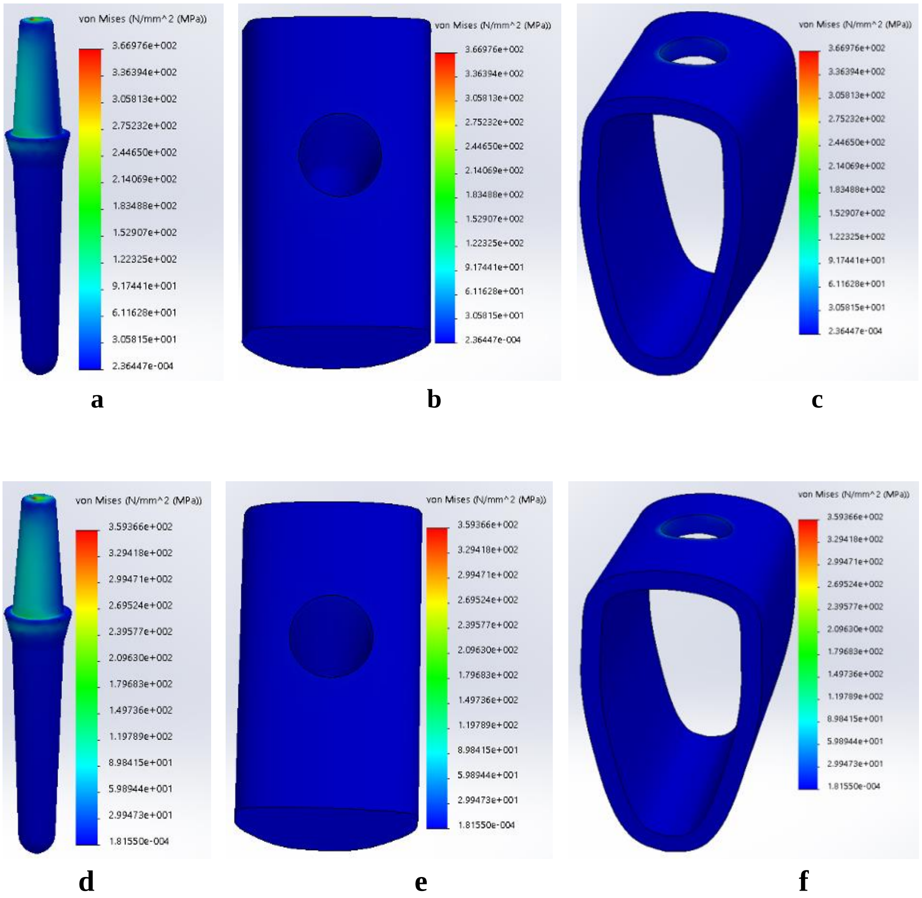
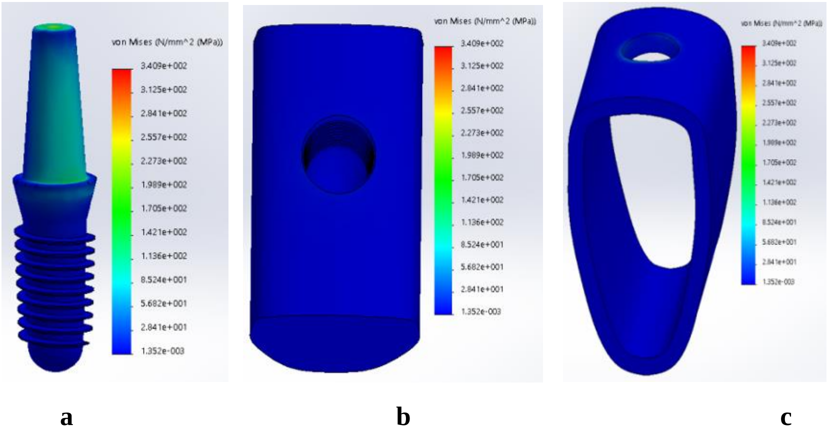


Figure 4. The von Mises stress; (**a**) simple long implant for Ti; (**b**) cancellous bone in the case of Ti; (**c**) the cortical bone in the case of Ti; (**d**) simple long implant for ZrO_2; (**e**) cancellous bone in the case of ZrO_2; (**f**) the cortical bone in the case of ZrO_2.



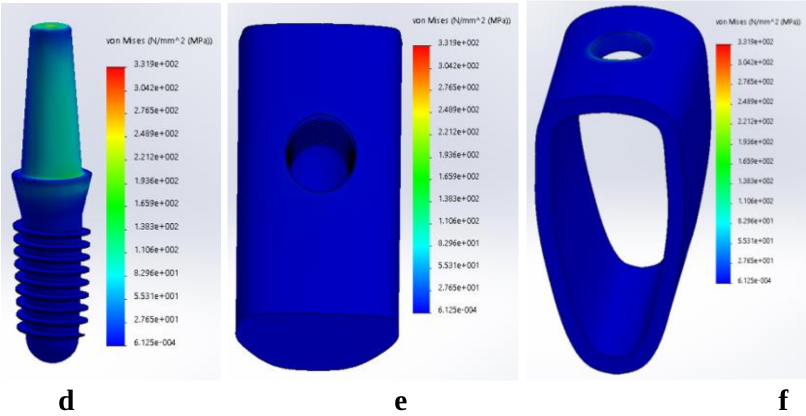


Figure 5. The von Mises stress; (**a**) threaded short implant for Ti; (**b**) cancellous bone in the case of Ti; (**c**) the cortical bone in the case of Ti; (**d**) threaded short implant for ZrO_2;(**e**) cancellous bone in the case of ZrO_2; (**f**) the cortical bone in the case of ZrO_2.

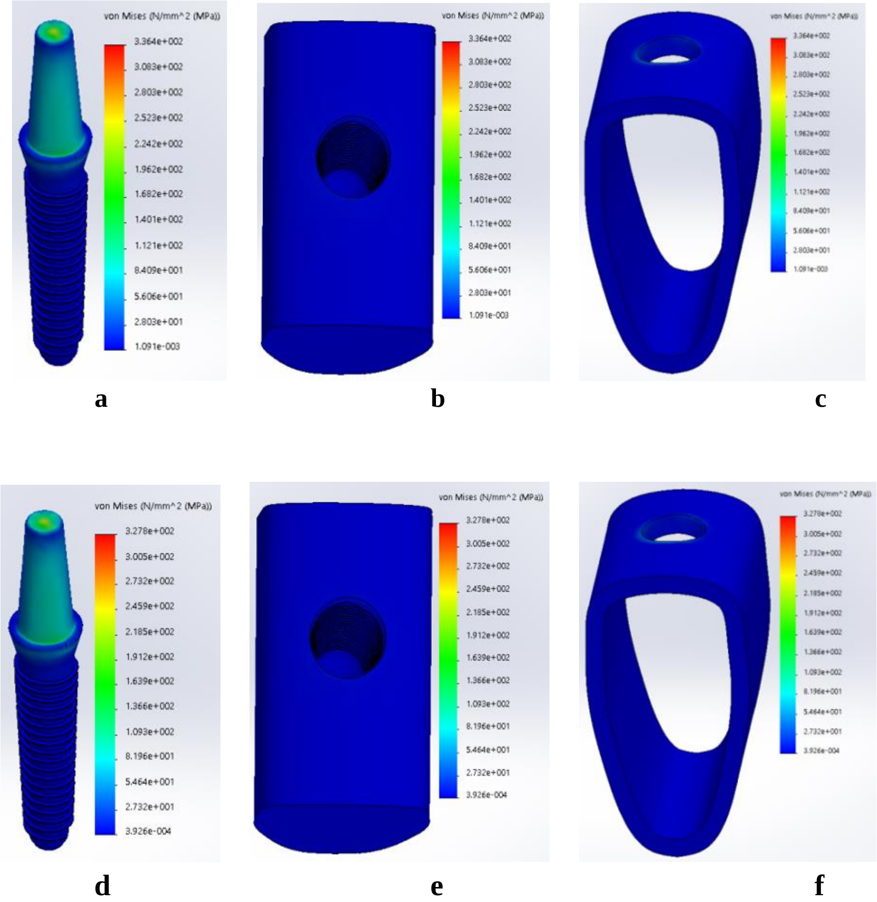


Figure 6. The von Mises stress;(**a**) threaded long implant for Ti; (**b**) cancellous bone in the case of Ti; (**c**) the cortical bone in the case of Ti; (**d**) threaded long implant for ZrO_2; (**e**) cancellous bone in the case of ZrO_2; (**f**) the cortical bone in the case of ZrO_2.

3.3 The influence of coating

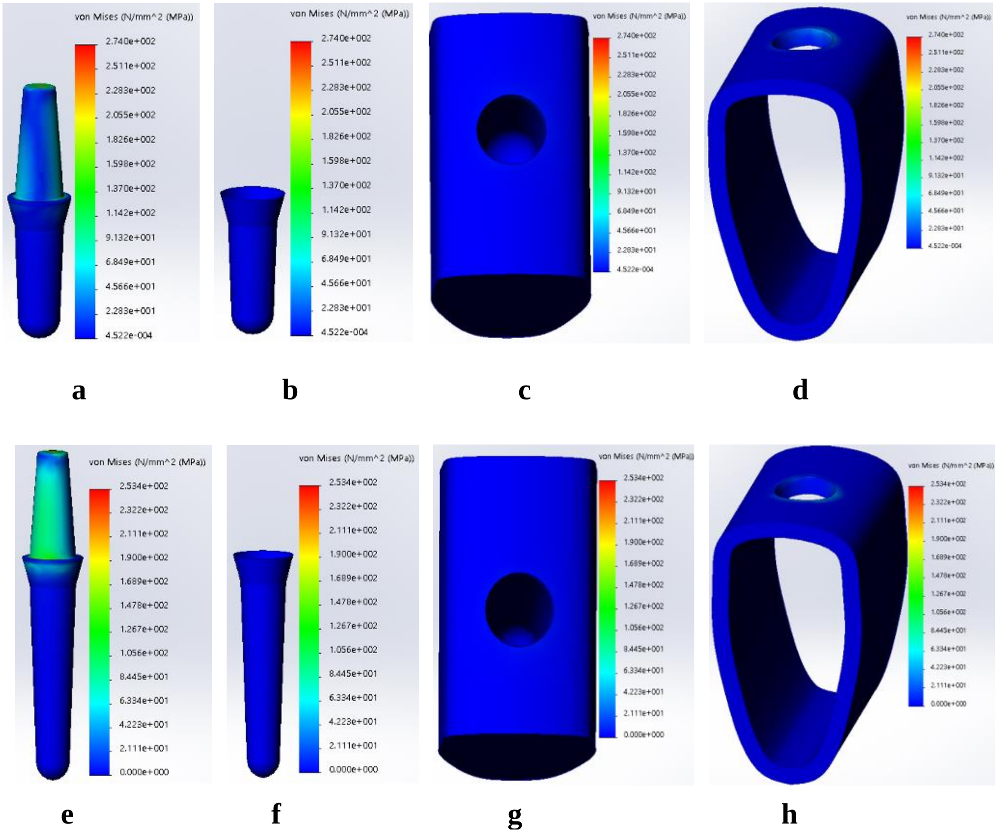


Figure 7. The von Mises stress in the implant in Ti covers; (**a**) simple short implant; (**b**) coating for short implant; (**c**) cancellous bone; (**d**) the cortical bone, (e) simple long implant; (**f**) coating for long implant; (**g**) cancellous bone; (**h**) the cortical bone

4. DISCUSSION

The result of this study indicated that the maximum stresses always occurred in the abutment and at the beginning of contact on the bone / implant contour.
- For non-threaded implants, the minimum von Mises stress value equal to 359 MPa is found for the ZrO$_2$ implant. Implant made from Ti presented, a little difference value of von Mises stress than ZrO$_2$.
- The greatest stress was observed in the short implant without thread (10mm) made with Ti which reaches 387 MPa, this result is far from the resistance to fracture (550 MPa).
- For implants with thread, the stress distribution is very close for both lengths, this value of less threaded implants than non-threaded implants. The minimum value of von Mises stress equal to 327 MPa is found for long threaded implant made of ZrO$_2$.
- The result indicate that stress concentrations are significantly higher in threadless implants than hreaded implants for both lengths.
- Lengthy implants showed less stress than short implants for both materials.
- Implants made of ZrO$_2$ give less stress than Ti implants in all cases.
- The group of Ti implants with coatings offers better results than the uncoated group; good results were found in the long implant without threading with coatings.

5. CONCLUSIONS

We have concluded that:

- The distribution of equivalent stresses is not homogeneous, they vary along the bone from its upper part to its lower part, the pillar and the areas of first contact with the implant are places of high stress.
- The von Mises stress decreases with increasing implant length for threaded and non-threaded implants for both materials.
- The ZrO2 biomaterial shows good results with minimal constraints in all lengths and shapes.
- The high stress value is found in non-threaded implants compared to those with thread for both lengths and both materials. The stress decreases when the length increases with the presence of threading.

- The group of implants with coatings offers better results; the length implant without threading presents good results.

We therefore conclude after this study that the material of choice for dental implants is Ti with bioactive coating; it has a small Euclidean distance, which means that its properties are closer to those of the bone, and offers better stress distributions.

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