Bioengineering Research

Three Dimensional Evaluation a Dental Implant in Different Angles by Finite Element Method

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Abstract

Introduction: Recently, teeth drawbacks, which account a source of discomfort for people and also decrease self-confident among them, can be correct with dental implants.

Objective: In this paper, precise modeling of the various geometric sections for a dental implant (number 5) is performed.

Materials and Methods: The rate of loading on the dental implant is variability considered in three angles of 0, 15 and 25 degrees at a time interval of 0 to 1 seconds to apply a force similar to the chewing cycle. By examining the stress and strain patterns in the spongy, components, fixture, spongiform, buccal and lingual bones a model is employed in order to obtain the exact distribution of stress and strain within the bone and the angled abutment.

Results: According to the obtained results, the angle of 25 degrees is an ideal model in the dental implant. These results also indicate that the areas around the buccal and lingual neck are more susceptible to damage in the location of the attachment to the fixture.

Conclusions: We will see a lot of bone resorption after a long time due to the increase in stress and strain in the compact bones and bone formation. Whereas in spongy bone, unlike compress bone, low stress results in a very high strain that is ideal and declines the bone resorption. The increase of the angle enlarges stress in the fixture that it is important not only for choosing the implant model but also the quality of the implant so that it can withstand high stress.

Keyword: 3-D Evaluation; Dental Implant; Finite Element Method

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1. Introduction

In the present age, problems of teeth or poor appearance of teeth can be solved with dental implants. These problems account a source of discomfort for people and also decrease self-confident among them [1]. In order to overcome these problems, dental implants have been put on the market that dentists use it to relieve the problems for the patient. If a person loses one or more teeth due to different causes such as tooth decay, gum disease, impact, fracture, accident, etc., they can use the dental implant method to replace the missing teeth [2, 3]. In a dental implant, the dentists place a screw in place of the root of the tooth inside the patient's jaw bone, and the crown of the tooth is placed on it [4]. One of the positive advantages of tooth implant is an independent being of scrubbing neighboring teeth that results in preventing the damage of other teeth [5]. According to reports, a tooth implant is considered the

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best way to replace missing teeth [6,7]. Considering these basic concepts, we will go through several recent studies on this subject:

In 2013, Moga examined the bone stress to investigate reliable methods in a particular position with the goal of mouth rehabilitation [1]. They assumed that it would lose the support of the load on the teeth and could break when tissue around the teeth including cortical bone, spongy bone, and PDL have been scratched. They carried out a study of 3-D analysis on bones using finite element method. The type of their study was Von-Mises stress. Carla M. Rocha and their colleagues developed a denture prosthesis using bone-compatible implants in 2010, in a three-dimensional modeling model [2]. And examined the bone remodeling through the 3D finite element analysis. They studied the restoration responses of biological bone during chewing to achieve meaningful results for studying the design of tooth movable prostheses.

In a presented analysis by Risitano et al. in 2010 several surgical techniques were proposed, that are currently are available, to improve jaw bone defects [8]. Obtaining a 3D volume from the location of the dental implant and an improvement of the patient's aesthetics was the goal of their surgery. Several solutions considered for prosthetic rehabilitation. After the Toronto bone graft surgery, a prosthetic screw of the dental implant was considered a better prosthetic rehabilitation solution. According to Wolff's law, the bone of dental implants are directly related to the force in the jaw bone.

Park and their colleagues in [9], proposed a method on the effect of stress in the hard tissue around the angular abutment. Their results showed that the increased stress in the bone around the implant is accompanied by an increase in the angle of the implant. Of course, there is no significant difference between a flat and angular abutment. They showed that the angular abutment can reduce stress in the bone where around a single axial dental implant. By finite element method analysis, four specimens were designed to prove this claim by placing in an axial and angular position. They designed a pair of axial implants and a pair of flat implants that a 100-Nt axial load applied at their mouths. The Von-Mises stress and strain were measured for each model. The acquired results indicated that the angular abutment decreases the stress when not being in the axial position, and the pressure applied to the surrounding bone is the vertical component of the force.

In this paper, a precision 3D modeling of a teeth implant (number 5) is carried out. For this purpose, the loading rate on the tooth implant in three different angles is variability considered at an interval of 0 to 1 second unlike other works which considered only evaluation of 3D human jaw [10] and patients' characters [11] in a dental implant. Also, another work investigated impacts of 3D bone to implant contact on stability of dental implant [12]. According to the obtained results of our research, the angle of 25 degrees is a good and ideal model. Also, the results indicate that areas around the dense bone neck (buccal and lingual) at the site attached to the fixture are more susceptible to damage. In a fixture that the angle increasing accompanies with stress expanding, the amount of stress is a key factor for choosing the implant model and its quality.

2. Material and Method

2.1. The proposed method

In this work, 3-D modeling of a dental implant is examined. In fact, we try to reduce the weaknesses of previous studies by accurate modeling of different geometric sections for having more accurate information in this field. The fixture model is designed based on the basis of the Bionic Company, which produces dental implants, bringing the results closer to reality. The loading rate on the implant is also considered in a variable time interval so that the applied force is similar to the chewing cycle [13-15]. Finally, simulated and modeled Prony series constants have been used to obtain the exact amount and distribution of stress within the bone and the angular abutment. In addition, the type of dynamic problem solving is considered for this work. The distribution of stress (force on the surface) and amount of displacement (strain) in the bone, the fixture and also the attached location of the angular abutment with the fixture and around its soft tissue is important in the modeling to identify the maximum stress and damage in the relevant models.

2.2. Model geometry and mechanical properties of material

This modeling consists of three parts: the design of two parts in the Part environment of the Abacus software and one section by CATIA software. Of course, there are three models in this work, in which the geometry of the three models will be presented. This three models consist of jawbone, fixture, and rigid body.

In the jawbone design, the bone design is actually transmitted from Mimix to Abacus, and all sizes are based on real sizes. The bony part of this model consists of two parts of the dense and spongy bones, in which the lateral and upper parts of the jaw bone is a layer with a thickness of 1.5 mm, and a lower part of the bone is a dense layer of 2 mm-thick and remnants are spongy. It should be noted that only the crown of the fixture is removed from the dense bone and the rest of the dental implant is placed in the spongy bone. Here, the geometry of the jaw bone is presented at three angles, as shown in figure 1.

The design of the fixture is illustrated in Figure 2 which includes two parts. The upper part of the fixture involved with the dense bone, which has more elastic coefficient than the spongy bone, is used a further number of threads per unit length to have more strength of the fixture in the jaw bone. But in the spongy section, that the elastic coefficient is lower, the number of threads per unit length is reduced so that the threads fit well into the spongy bone and do not chop the parts involved with the fixture. Also, some of its volumes have been removed in 3 areas. By putting the bones in these parts, the permission of rotation around the axis from the fixture is deprived.

Due to the use of concentrated force in loading a section, a pattern is designed and modeled from the cavity above the crown of the fixture, which is the location of the abutment (figure 2-b). By doing this, the force applied to the crown of the tooth can be correctly transmitted to the fixture when chewing the food.

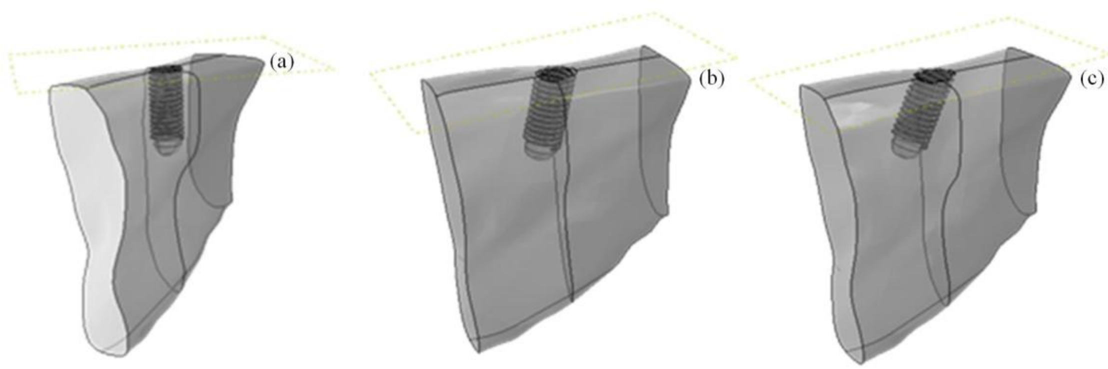

Figure 1. Spongy and dense bone model used for three angles (a) 0, (b) 15 and (c) 25 degrees.

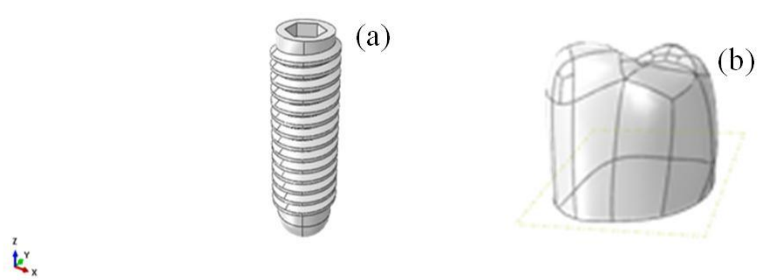

Figure 2. (a) The designed fixture (b) The rigid body designed to apply force to the fixture.

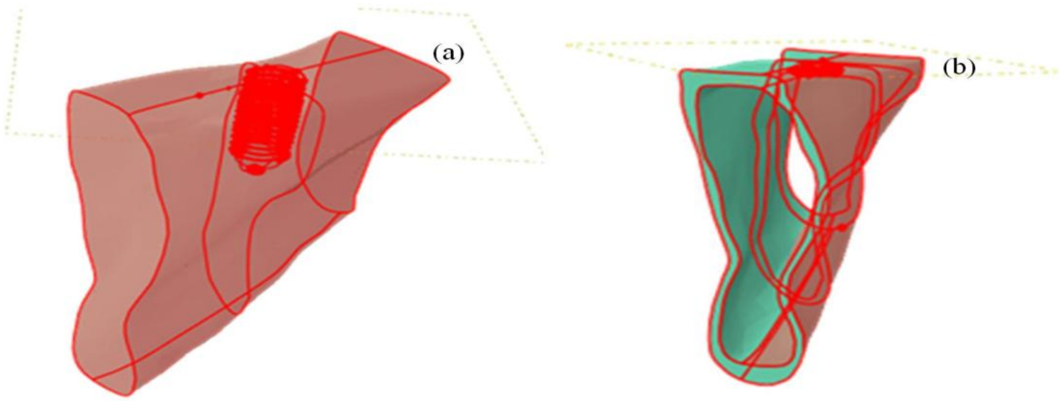

Figure 3. The location of the mechanical properties of (a) the dense bone, and (b) the spongy bone.

All materials in different parts of this modeling are considered homogeneous and isotropic. In this work, the mechanical properties of the fixture are modeled in an elastic manner. While jaw bone by sectioning, various mechanical properties are assigned to it (figure 3). Jawbone segmentation consists of dense bone, spongy bone and the mechanical properties of them are considered elastic.

Furthermore, the abutment and the crown of tooth are modeled as a function of time, and to do this, the constant parameter of this texture in the Prony series is used. In this mode of viscoelastic material modeling, elastic modulus and Poisson coefficient are necessary. Also, due to the design of the power transferring section, which is solid, it is not necessary to assign mechanical properties to it.

2.3. Boundary conditions and discretization

The lateral section of the jaw bone is fixed, so that all degrees of freedom, whether transmitted or rotated, are discarded. For this purpose, Encaster constrain is used in the load section of the Abaqus software and in the boundary conditions (figure 4). The Tie constrain is used in this modeling and the interface of the components between the spongy and dense bone sections (figure 5-a), between the dense bone and the fixture (figure 5-b) as well as the fixture and the abutment, which the abutment and the crown of the tooth are merged together and both are considered as a rigid body. Also, in order to transfer the force applied to the rigid modeling part, this section is connected to the fixture by the Tie's constraint (figure 5-c). In the rigid body also the Tie's constraint has spread over all of it (figure 5-d).

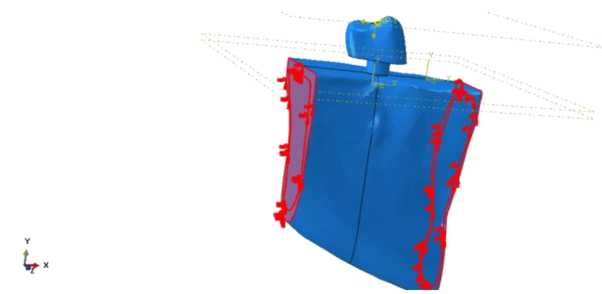

Figure 4. Boundary conditions applied on the proposed model

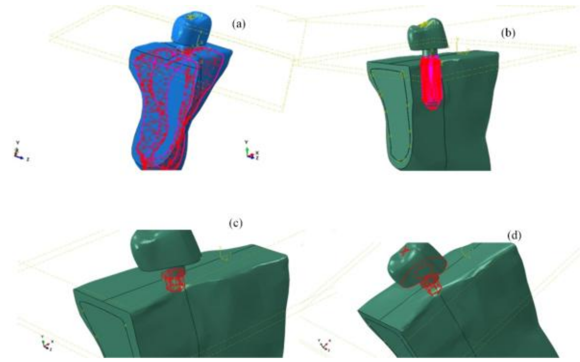

Figure 5. Application of the Tie constrain (a) between the spongy and dense bones, (b) between the fixture and the dense bone, (c) Rigid body, and (d) between the fixture and the abutment (rigid body).

To solve this model, the spongy and dense parts of the bones, the fixture, and the rigid body are individually divided, and all elements considered for all sectors are 3D stress (figure 6-9). The structure of jawbone, due to its complex and non-structural form, can be used with a four-dimensional free-form mesh. Finally, parts of this structure, which remained at a free-form, were partitioned into four-faced mesh with the following characteristics (Figures 7).

The fixture also has a complex structure, like the jaw bone, and it is not able to partition and simplify the model because of its complexity. According to this, it is not possible to use a structural mesh for partitioning. For this reason, the quadratic mesh, which is characterized by its partitioning, was used for this model (figure 8).

The four-element structures, which the method of disjointing and assignment is shown in three angles (figure 9), are used at three angles for the rigid body.

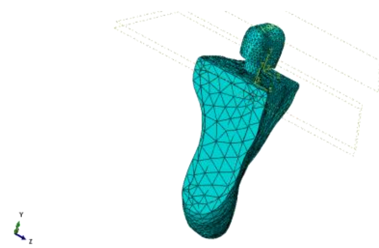

Figure 6. Discrete models made with the presence of abutments and fixture

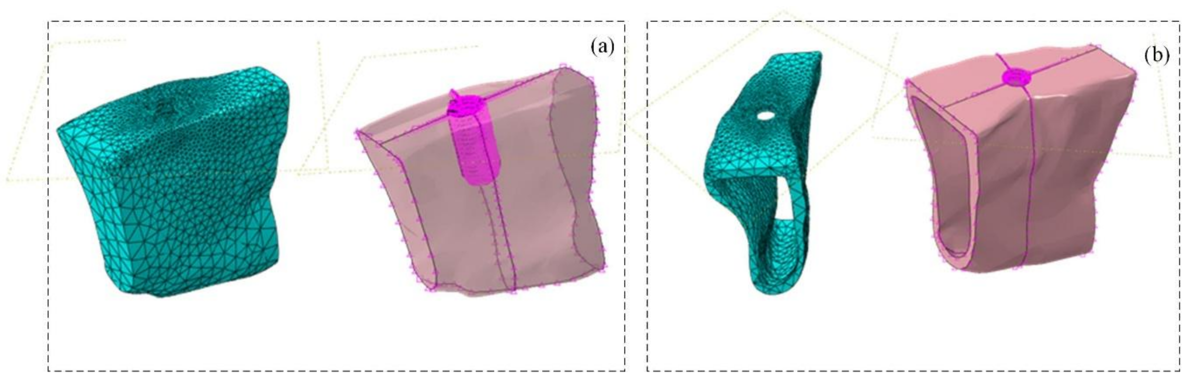

Figure 7. Partitioning and modeling; (a) spongy bone and (b) density Bone.

Figure 8. Partitioning and modeling fixture

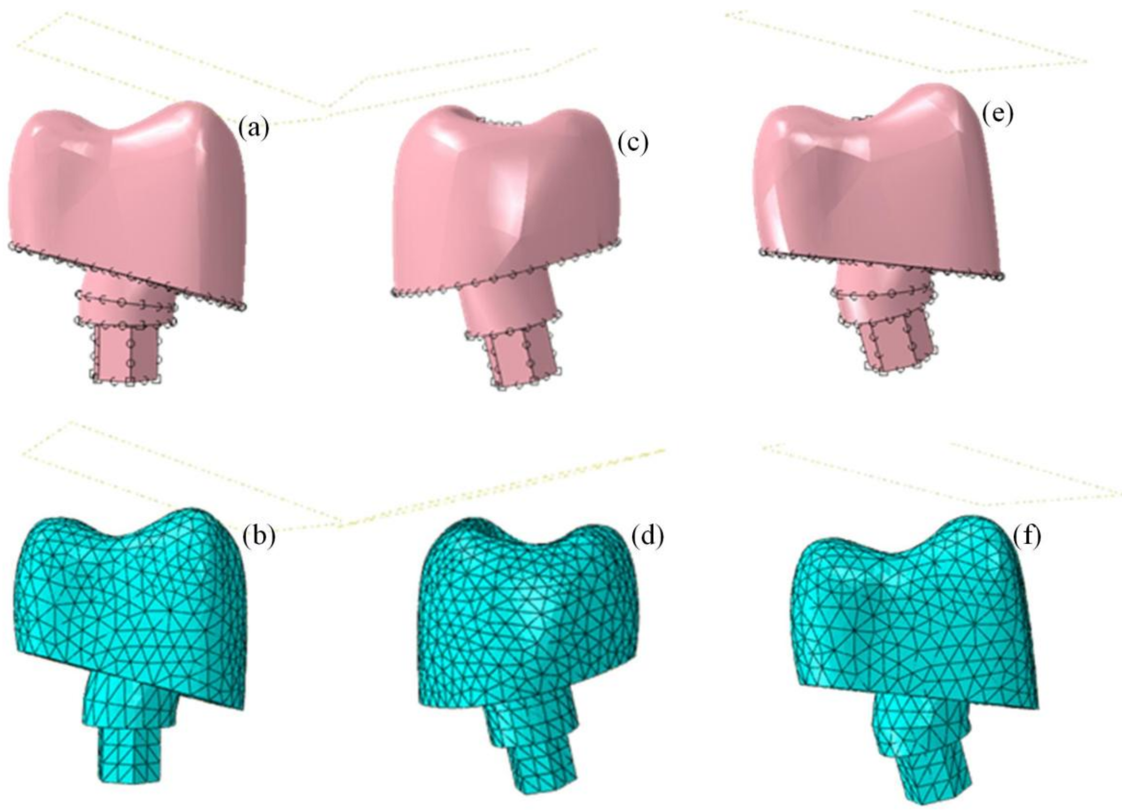

Figure 9. Partitioning and rigid body nodes (a-b) zero degree, (c-d) 15 degrees, and (e-f) 25degrees.

3. Results

This section examines the results in jawbone, rigid body and fixture in three different angles. In the beginning, we investigate loading on the structure and then we see changes in the stress and also the strain.

First, we identify how make the loading on the structure. The only force intended to apply to the fixture and tooth abutment is the force generated by a chewing cycle. According to studies in similar articles [14-17], it was found that the duration of this period (one time the opening and closuring the jaw) was approximately equal to 1 second. Thus, the chewing cycle in 1 second in 17 times is exponentially measured.

In dynamic loading, from the beginning the chewing to end of it (a period), the amount of force applied to the tooth initially varies from low to high in all directions, and then decreases after recording a maximum amount in each direction, So that after 1 second the force at the tooth returns to zero. While static loading is constant from the start to the end of the analysis and its value is equal to the maximum force in dynamic loading in all directions. In this modeling, due to the force applied to the tooth in different directions, there is a need for the use of concentrated force. Therefore, the force is applied to the designed rigid body. Maximum forces in the X, Y, and Z (which is perpendicular to the surface of the fixture) directions, respectively, are equal 17.6 N, 24.3 N, and 119.5N. In figure 11, the force plots are shown in different loading intervals in each direction. The obtained results of stress were determined in overall the structure. As shown in figure 11-a, the stress is measured at 17 times per second for spongy bone, which the highest value occurs in the 25-degree. In figure 11-b, the stress of dense bone is indicated at three angles, that maximum stress at an angle of 25 degrees. Figure 11-c shows the stress at three angles in the fixture, which the stress of the fixture at 25 degrees is a maximum value, as we already expected.

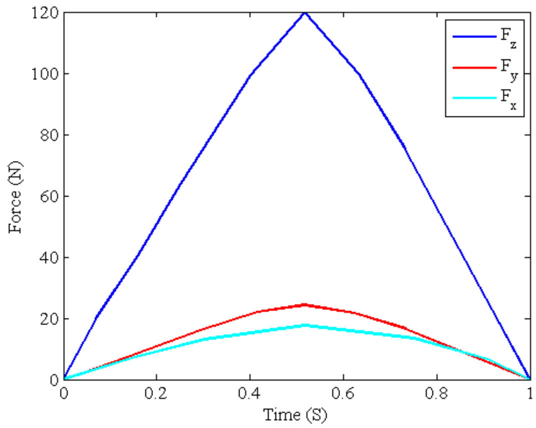

Figure 10. The force applied along the three axes of length, width and height.

In figure 11-d, the maximum stress is at 15 degrees on the floor of the spongy bone (the end point of the fixture and the spongy bone or apex fixture), which we interpret it in the next section. In figure 11-e, the maximum stress occurred at 0 degrees and decreases and increases unevenly by increasing the angle. In figure 11-f, stress at 25 degrees in linguinal (dense bone graft) is at its highest that its value expands by increasing the angle.

Also, we investigated the structure stand on the strain. Indeed, strains are designed for better computing and analysis are based on microstrain. Figure 12-a shows the spongy bone strain at three angles, which illustrates that the highest strain of the spongy bone is at 25 degrees. Figure 12-b demonstrates a dense bone strain at three angles, with a maximum strain of 25 degrees. It should be noted that we ignore the strain in the fixture because the obtained strain from the stress in the implant is different from the jaw. In figure 12-d, the maximum strain on the spongy bone floor is at 15 degrees, which is discussed in the next section (discussion). In figure 12-e, like stress, the strain also affects irregularities in increasing and decreasing and the maximum strain is 0 degree. As shown in figure 12-f, the maximum strain is 25 degrees and has been decreased irregularly at 0 and 15 degrees. In figure 13, the maximum stress and strain are considered for three selective modes and have shown.

4. Discussion and Conclusions

This section examines the obtained results and describes the results of the three models. In all three models, the maximum stress and strain in the components will be expressed and the process of variation will be examined according to the angle of the fixture.

According to the results of spongy bone, the maximum stress of 3.70314 MPa was observed at 25 degrees in 0.49 seconds. As we expected, the stress has increased with increasing angles. On the other hand, the strain expands with an increase of the angle and reaches its maximum value (2728.48 microstrains) in 0.49 seconds. So, with the stress increase in the spongy bone, the strain also enlarges which is ideal. When the stress increasing leads to strain expanding, it results in ossification [19-21]. Now, measuring the stress and strain percent at different angles is considered for more detailed examination. As Table 2 shows, there is an increased strain in the spongy bone at three angles due to increased tension, which means more ossification. Since the strain increasing due to stress in 25 degrees is higher than 15 degrees, the angle of 25 degrees is more ideal. With considering the Wolff's law, the spongy bone never undergoes the bone resorption because the maximum strain is close to the 3000 microstrains. Indeed, it is entered to the bone resorption [22] with greater stress than 60 MPa, which is not possible in the spongy bone.

In the obtained results from dense bone, the maximum stress in the bone density at 25 degrees reaches to 65.9043 MPa in at 0.49 seconds which is a large amount and the stress also expands with an angle increase from 0 to 25 degrees. On the other hand, the angel increasing causes of expanding the strain. As a result, the strain reaches to its maximum value at 25 degrees at the time of 0.49 seconds (1790.68 microstrains). The increase of the stress and the strain are ideal and the ossification is applied by stress. As shown in Table 3, the increase in the stress causes the strain enlarging, which the stress and the strain at 25 degrees more strongly enlarge than 0 degrees, which is acceptable. At 15 degrees, the stress increase results in strain expanding, but is not as much as the stresses enlarging, that means that a bit of the stress has been

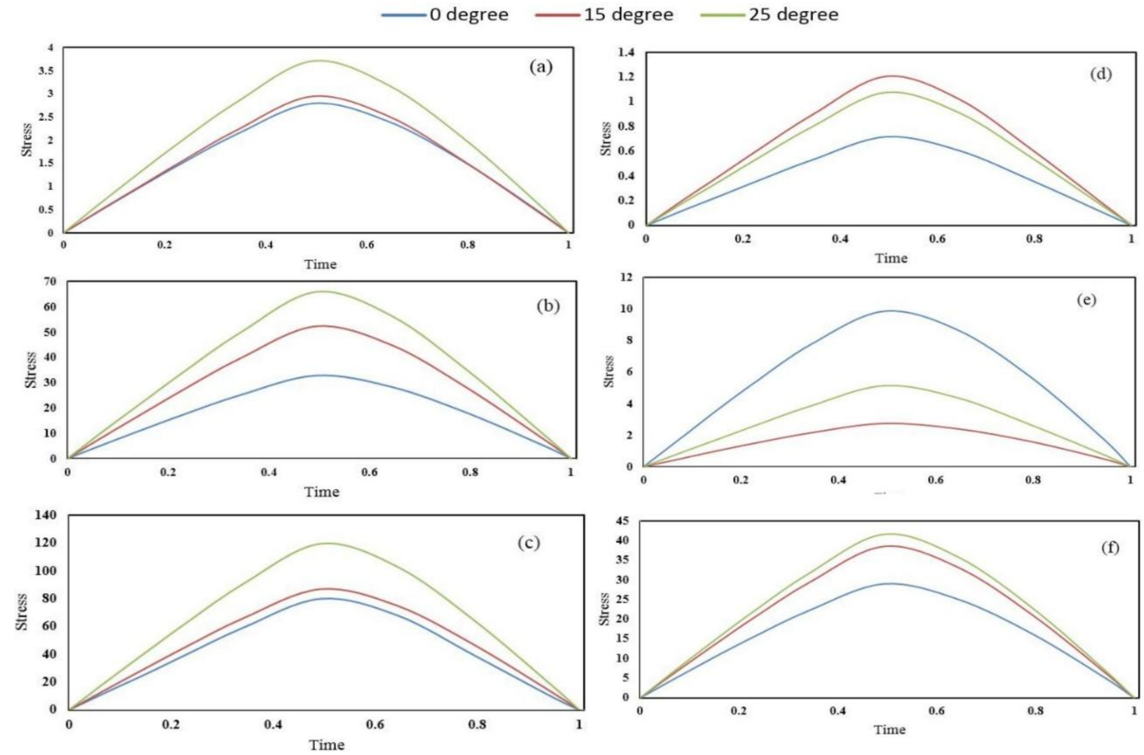

Figure 11. Stress analysis at three different angles of 0, 15 and 25 degrees for (a) spongy bone, (b) components, (c) fixture, (d) floor of spongy bone, (e) buccal, and (f) linguinal.

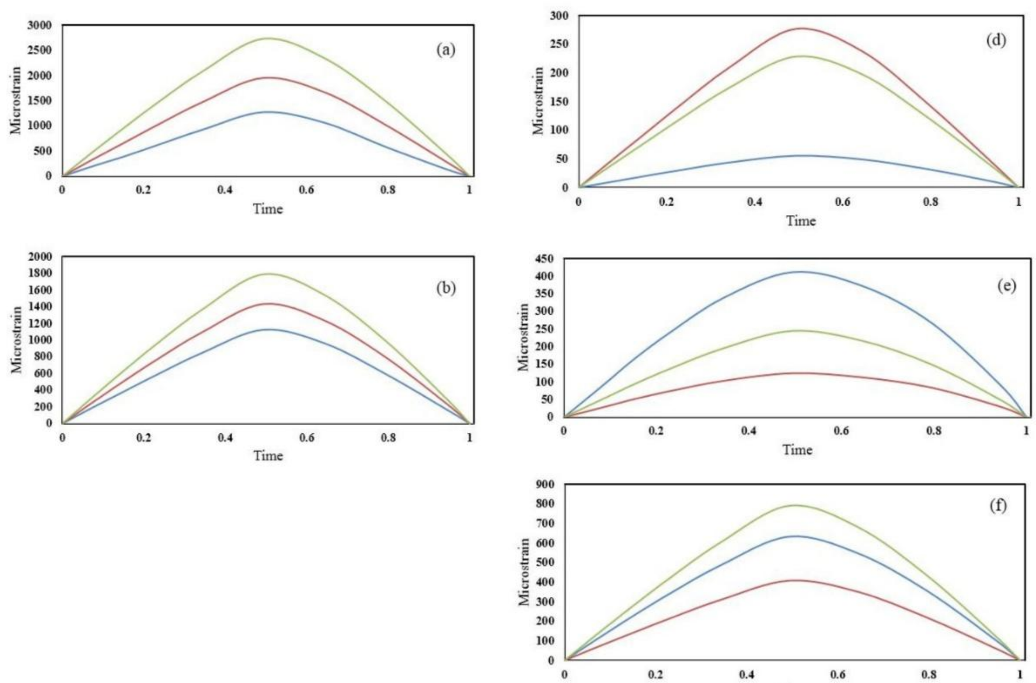

Figure 12. Strain graph at three different angles 0, 15 and 25 degrees for (a) spongy bone, (b) dense bone, (d) floor of spongy bone, (e) buccal and (f) linguinal.

Tabe1. Wolff's law [15-16]

Stress (MPa)	Strain (microstrain)
1-2	50-100
20	1000
60	3000
120	25000

Table2. Table of percentage of stress-strain changes in spongy bone

Angular domain	Percent of strain variations	Percent of stress variations
0 to 15 degrees	35.42%	5.14%
15 to 25 degrees	28.23%	20.59%
0 to 25 degrees	53.65%	24.69%

Table 3. Table of percentage of stress-strain changes in dense bone

Angular domain	Percent of strain variations	Percent of stress variations
0 to 15 degrees	21.46%	37.26%
15 to 25 degrees	19.98%	20.90%
0 to 25 degrees	37.26%	50.37%

Table 4. Table of percentage of stress changes in fixture

Angular domain	Percent of stress variations
0 to 15 degrees	8.13%
15 to 25 degrees	27.32%
0 to 25 degrees	33.36%

Table 5. Table of percentage of stress-strain changes in spongy bone floor

Angular domain	Percent of strain variations	Percent of stress variations
0 to 15 degrees	80.03%	40.61%
15 to 25 degrees	-17.67%	-11.96%
0 to 25 degrees	75.75%	33.50%

Table 6. Table of percentage of stress-strain changes in buccal

Angular domain	Percent of strain variations	Percent of stress variations
0 to 15 degrees	-69.75%	40.61%
15 to 25 degrees	49.03%	-11.96%
0 to 25 degrees	-40.80%	33.50%

Table 7. Table of percentage of stress-strain changes in buccal

Angular domain	Percent of strain variations	Percent of stress variations
0 to 15 degrees	-35.67%	25.09%
15 to 25 degrees	48.44%	7.10%
0 to 25 degrees	19.73%	30.41%

spent on the bone loss [23]. According to Wolff's law (number 2), the maximum stress is 20 MPa for 1000 microstrains. In the dense bone, stress more than 20 MPa have been entered the bone for every 1000 microstrains that indicate the dense bone is entered to bone resorption and will become a problematic issue over time.

According to the results of the fixture, increasing angle have significantly expanded the stress in the fixture and it reached its highest value (119.575 MPa) in 0.49 seconds at 25 degrees, which was very tense and the fixture worked almost like a stress shield. As shown in Table 4, an increase 33.36 percent is observed in the stress at 25 degrees than 0 degrees, which the dentists should use good genus and high quality of the implant in the tooth 5 according to the jaw model, so that it can withstand a lot of stress.

In the obtained results of the spongy bone floor, the highest stress and strain rate are at 15 degrees at 0.49 seconds which are 1.20249 MPa and 277.459 microstrains, respectively. This amount reduces by 15 to 25 degrees, while generally increased rather than 0 degree, which is quite obvious in Table 5. As Table 5 shows, the variation of the strain than strain changes is near twice, which is ideal. Since the obtained stress and strain are higher at 15 degrees, thus, 15 degrees is more ideal. According to the first Wolff's law, which the bone resorption region is for the stress of 50-100 MPa (greater than 2 MPa), does not result in the bone resorption for the spongy bone floor. While there is stress less than 2 MPa for strains higher than 100 microstrains, which means an increase of the angle at the floor of the spongy bone will increase the ossification in which is ideal.

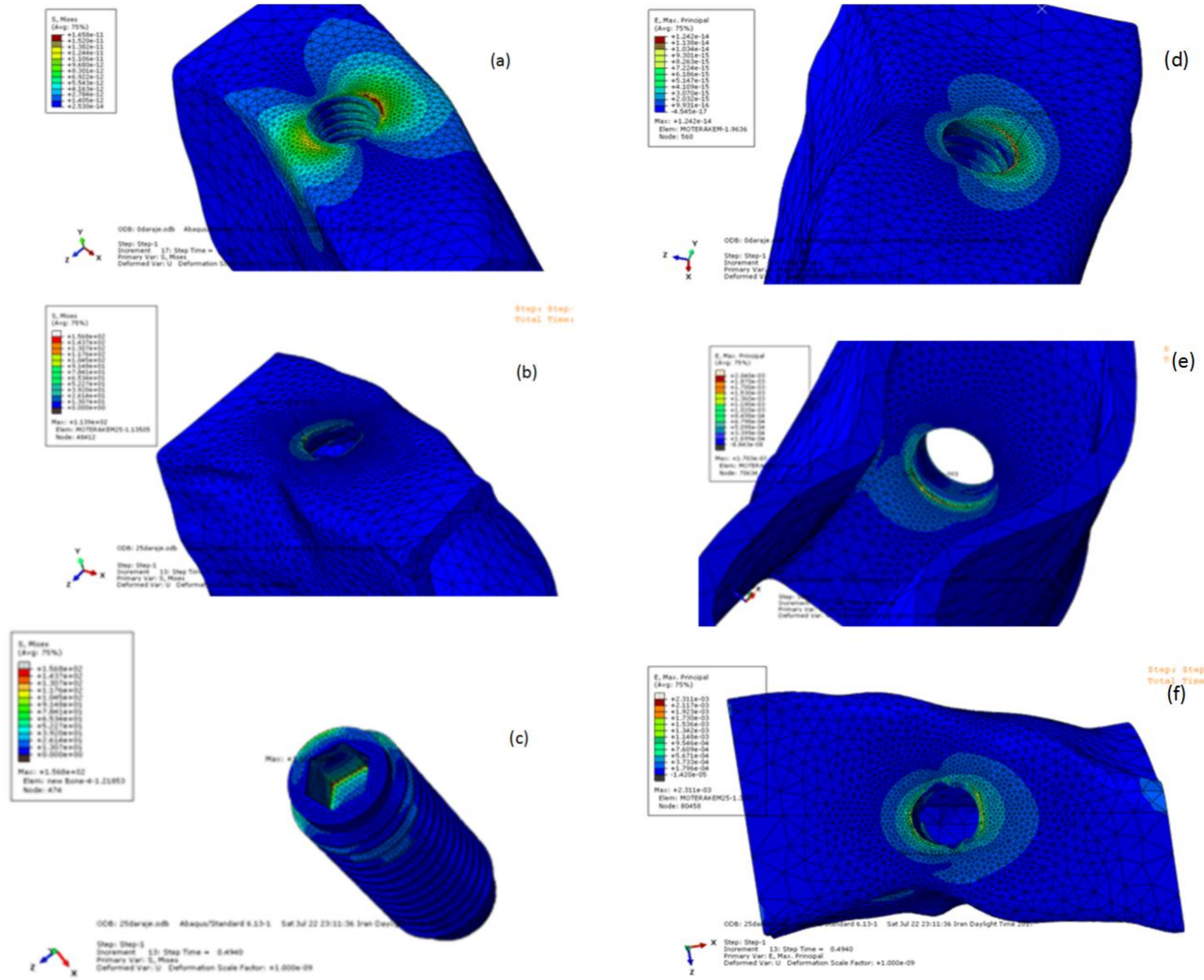

Figure 13. Maximum stress in (a) spongy bone, (b) dense bone, (c) fixture. The maximum strain in (d) the spongy bone, (e) the dense bone, and (f) buccal.

In the results of Buccal, it can be seen that the maximum stress is at 0 degrees and the stress and the strain have an appropriate decline at 15 degrees and 25 degrees. Table 6 explains better explanations. Most changes in stress and strain occur in the attached crater of the fixture to the jaw, it is the reason why we check buccal and linguinal. At 15 degrees, the reduction is proportional to the strain and is also ideal. In general, 0 degree is more ideal because it has maximum stress and strain. However, an angular implant should be selected in the tooth 5 due to the anatomical model of the jaw. Therefore, the 25-degree model is more ideal because of more proportion of the stress and the strain. On the other hand, according to the second Wolff's law, all three angles are in the region of bone resorption and the stress is more than 2 MPa while the strain range is more than 100 microstrains. As a consequence, the buccal region is more likely susceptible to damage and there will be the bone resorption at any angle.

In the obtained result of the linguinal, the highest stress and the strain are at 25 degrees in 0.49 seconds which the stress is 41.5162 MPa and the strain is 790.446 microstrains. As it can be seen in Table 7, the increasing stress accompanies with declining strain at 15 degrees, which means the stress expanding results in the bone loss and loss of its strength [24-25]. However, there is a direct relation between the strain and the stress for 25 degrees. In other words, by strain increasing also expands the stress and its outcome is the ossification. In general, there is an increase of stress and strain at 25 degrees than 0 degrees that part of the stress causes the ossification and another part leads to the bone loss, so 25 degrees model is more ideal. According to first Wolff's law, there is a very tense strain on the lingual rather than the strain, which makes bone resorption at all three angles. Also, the lingual than buccal is more vulnerable to damage because of more stress variations of lingual than buccal in all angles, especially at 15 degrees.

In this paper, 3-D modeling of the teeth implant of number 5 was done. According to the obtained results, the 25-degree model is a good and ideal model. Additionally, the angle is appropriate for the teeth 5 due to the anatomical position of the jaw. Also, the results showed that areas around the neck of dense bone (buccal and lingual) are more susceptible to damage at the site where is attached to the fixture. Considering the increase of the stress and the strain in the dense bone and emerging ossification after a long time, the bone resorption can be seen due to the extreme stress being. Of course, there is the bone resorption for all the angles in the bone that it is normal for the dental implant. On the other hand, applying low stress gives a very high strain in the spongy bone that it also is ideal, and dwindles the bone resorption. In the fixture, it was seen that with the angle increasing expands the stress that the amount of the stress will be a principal factor in choosing the implant model and its quality due to it has to withstand high tensions.

Conflicts of interest

The authors declare no conflict of interest for this article.

Acknowledgments

None declared.

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