Choosing Among Different Dimensions in A Newly Designed Dental Implant, 3 Dimensional FEA Comparative Study

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Abstract: *Introduction*: There are many dental implant designs, which have been adopted by hundreds of dental implant companies. These designs are modeled following certain micro and macro design criteria. One of these criteria is the dental implant thread design. The aim of introducing a new dental implant with a modified reverse buttress design has been suggested. The objective of the current study to choose the suitable implant material and dimensions among the tested range of implant designs under study using 3D Finite Element Study.

Materials and Methods: A modified Reverse Buttress dental implant in two models (TiG4 and TiG5 models, a range of different implant dimensions (3/13, 3.5/11, 4.11, 4/9, 4.5/9, 4.5/7, 5/9, 5/7, 5.5/9, 5.5/7 mm) were analysed for stress distribution over the surrounding cortical and cancellous bones. A three-dimensional Finite Element Analysis has been carried out in both normal (70 N vertical load) and overload (500 N, 25°) conditions.

Results: in all implant dimensions, maximum Von Mises stress was less than average cortical and cancellous bone elastic modulus. Mann Whitney U Test did not show a statistically significant difference between maximum Von Mises stress in both implant models over both cortical and cancellous bones in normal and over-occlusal loads (p>0.05).

Conclusion: All implant dimensions, showed far fewer stress levels over both cortical and cancellous bones. However, it would be advisable to eliminate the 3/13 mm implant dimension, especially, if the TiG5 model is to be considered, and 5.5/7 mm implant dimension if TiG4 model is to be considered.

Keywords: Dental implant. New dental implant. Modified Reverse Buttress design. Stress distribution.

INTRODUCTION

There are many dental implant designs, which have been adopted by hundreds of dental implant companies. These designs are modeled following certain micro and macro design criteria. One of these criteria is the dental implant thread design. There are four thread designs; V-shaped, Buttress, Reverse Buttress, and Square thread designs [1-3] and their modifications [4, 5].

Despite each thread design has its advantages and disadvantages, there is specific attention to greater thread depth and larger pitch [6-9]. It has been found that these two criteria reduce stress over the bone surrounding the dental implant. Studies have found that reducing the thread face angle might play a role in reducing the shear force applied to the bone during implant insertion [10, 11]. This in turn minimizes bone trauma and reduces the osteointegration time.

For the aim of introducing a new dental implant, the research team suggested a range of modified Reverse Buttress designed implants. The dimensions of the suggested design ranged from 3 mm diameter, length 13 mm to 5.5 mm diameter, 7 mm length. The suggested range of dental implant dimensions was of TiG4 and TiG5 models.

TiG5, unlike commercially pure Titanium (TiG4), (Ti-6Al-4V) is a titanium alloy with 6% aluminum and 4% vanadium. It is the stronger than TiG4. However, it is not as popular as TiG4, despite its desirable mechanical and physical properties [12].

The current study aims to choose the dimensions among the range of the newly designed implant in both implant material (TiG4 and TiG5) using a 3D Finite Element Study.

MATERIALS AND METHODS

A newly designed modified Reverse Buttress dental implant in two models (TiG4 and TiG5 models, a range of different implant dimensions (3/13, 3.5/11, 4.11, 4/9, 4.5/9, 4.5/7, 5/9, 5/7, 5.5/9, 5.5/7 mm) were analysed for stress distribution over the surrounding cortical and cancellous bones. Bothe implant and bone models were created using 2016 Autocad program and supposed to be linear isotropic material.

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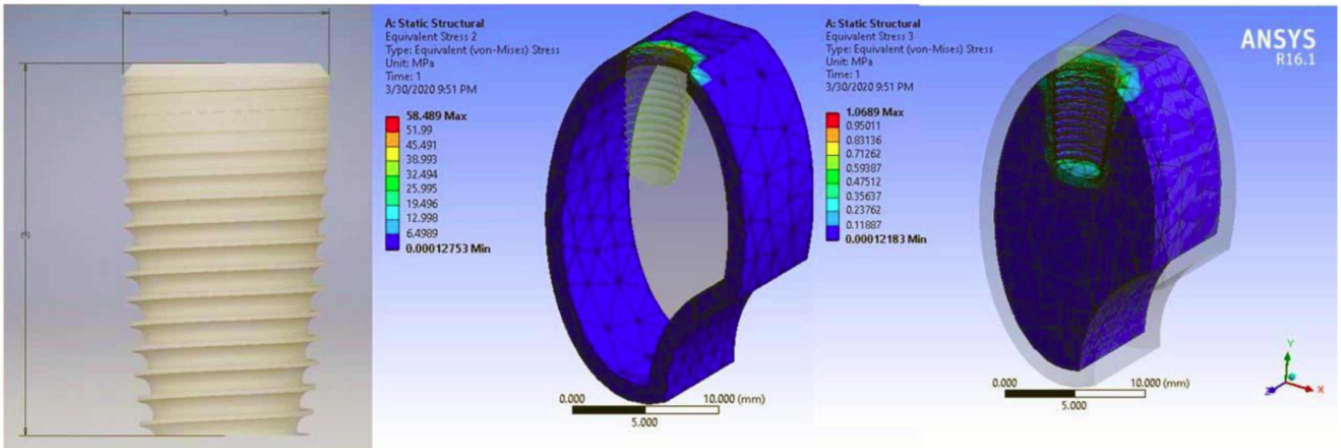

Figure 1: Dental implant with 5/9mm dimension (TiiG4 model) with maximum Von Mises stress level over both cortical bone and cancellous bones under 500 N, and 25 degrees load condition.

A three-dimensional Finite Element Analysis has been carried out in both normal (70 N vertical load) and overload (500 N, 25°) conditions [13, 14].

All the implants were inserted in a simulated 3Dimensional model of a mandibular bone section with (16 × 26 ×18 mm). The bony section consists of a 2 mm thick cortical bone surrounding a core of cancellous bone. Mechanical properties of the implant models and both cortical and cancellous bones. are shown in Table **1**.

The pattern of stress distribution over both cortical and cancellous bone around 5/9mm implant is shown in Figure **1**.

Table 1: Mechanical Properties of the Implant Models

Part	Poisson's ratio	Elastic modulus (Mpa)
TG4	0.37	105000
TG5	0.33	114000
Cortical bone	0.3	1360
Cancellous bone	0.3	24.9- 240.0

Load and boundary conditions: the study assumed the materials are homogenous, isotropic with elastic linearity. BIC is considered 100% osseointegration. Node and element numbers for bone and implant models are shown in Table **2**. No movements were within the suggested models, making those parts share the same nodes.

The applied loading on the top of the middle node of all implants was linear and static. The stress distributions on implant-bone interface were investigated under static loading condition in order to provide design guidelines for the development of new implants.

Table 2: Node and Element Numbers for each of the 3 Implant Models

Model	No. of nodes	No. of elements
Buttress	39,135	93,529
Reverse Buttress	26,639	64,847

The sides and bottom of cortical and cancellous bones were set to be completely constrained. Mesh density is one of the important relevant parameters. At the curved parts of the geometry, improving the mesh improves the results, (increasing the accuracy of stress levels obtained in the regions of high-stress gradients). Increasing the number of elements was considered to reduce the sharp angles that are artificially created through the model construction process (by the mesh). This in turn reduces the artificial stresses through the improvement of actual geometry representation. Static structural Finite Element Analyses (FEA) were performed with ANSYS Workbench (Ver. 16).

RESULTS

Maximum Von Mises stresses over different dental implant dimensions for each implant model for both materials in each simulated cortical and cancellous bones were reported. Figure **2** shows the highest equivalent stress over the cortical bone in normal load was less than 22 MPa and was reported around implant 3/13 mm, whereas the lowest equivalent stress was found around 5/7mm implant (around 8.5 MPa in both TiG4 and TiG5 models).

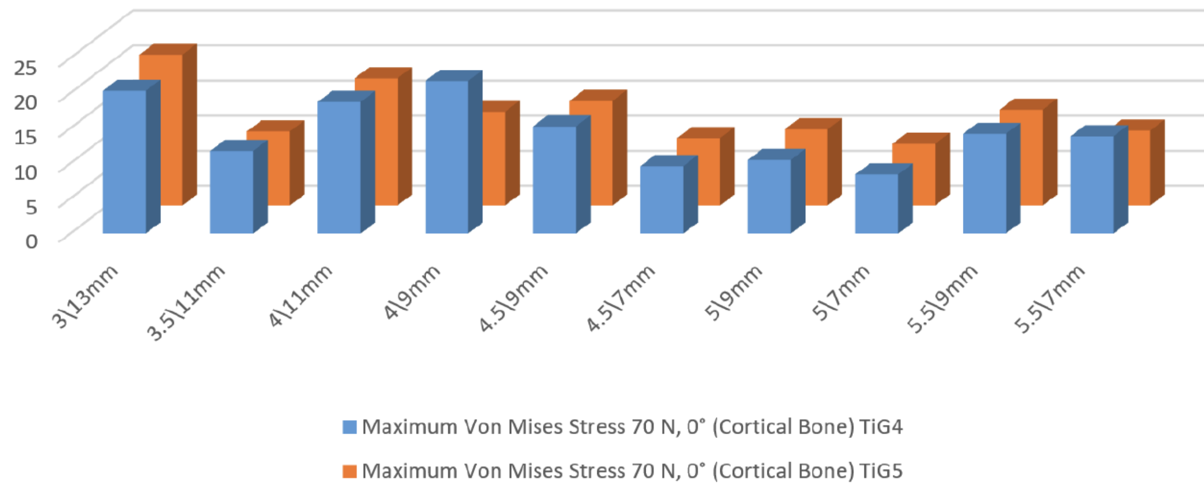

Figure 2: Maximum Von Mises stress levels over the cortical bone in both TiG4 and TiG5 models under 70 N, vertical load condition.

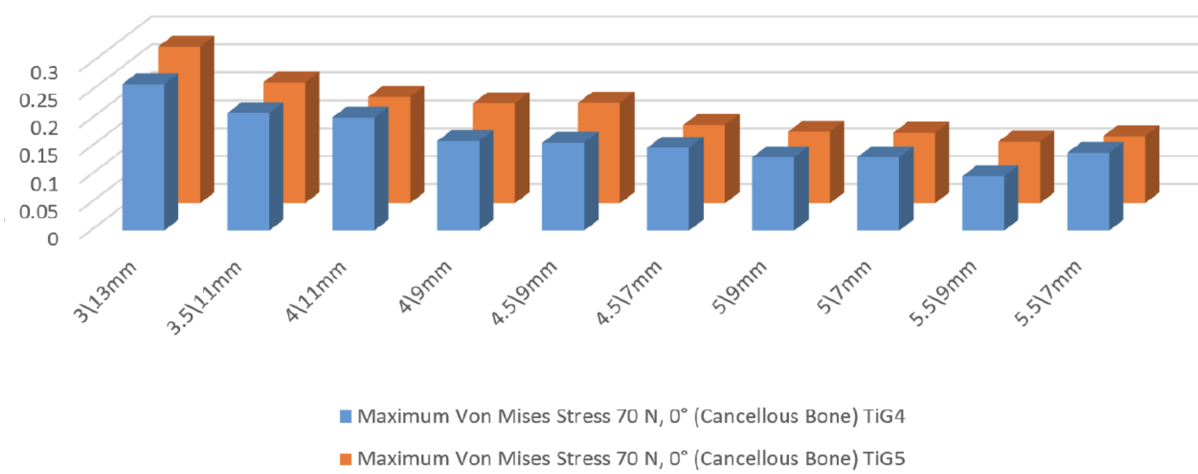

Figure 3: Maximum Von Mises stress levels over the cancellous bone in both TiG4 and TiG5 models under 70 N, vertical load condition.

On the other hand, when normal stress is applied on the top of the implant maximum Von Mises stress level over the cancellous bone takes a somehow more regular pattern, being the highest with 3/13 mm implant dimension and decrease gradually until 5.5./9 mm. This is followed by a slight increase with 5.5/7 mm. The highest equivalent stress was about 28 MPa around the TiG5 model and 20 around the TiG4 model. The lowest stress was about 0.1 MPa Figure **3**).

Overload conditions in both cortical and cancellous bones in TiG4 and TiG5 models reveal an irregular pattern of stress level around the dental implant (Figures **4** and **5** respectively). The difference, however, between TiG4 and TiG5 models when overload is applied on a 3/13 mm implant dimension is more obvious on the cortical bone, equivalent stress level being around 70 MPa highest in around TiG5 model. However, this difference is not as obvious in another implant dimension. The maximum Von Mises stress on cortical bone in overload condition for TiG4 and TiG5 models was around 150 and 197 MPa respectively.

There is a similar condition in the 5.5/7mm dimension (Figure **5**). It shows that equivalent stress over cancellous bone around the TiG4 model is double the stress over the cancellous bone around the TiG5 model. However, it remains far less than the cancellous bone physiological limit. The maximum reported Von Mises over the cancellous bones in TiG4 and TiG5 models were 1.83 and 1.79 MPa respectively.

Despite the level of Von Mises stress over the cancellous bone shows a distinctive pattern of a gradual decrease in stress level with the increase of

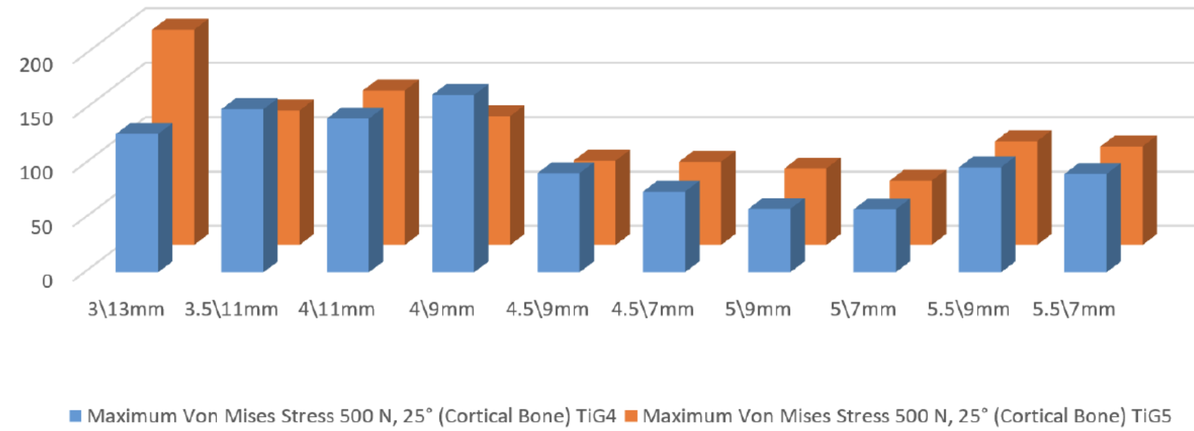

Figure 4: Maximum Von Mises stress levels over cortical bone in both TiG4 and TiG5 models under 500 N, 25 degrees load condition.

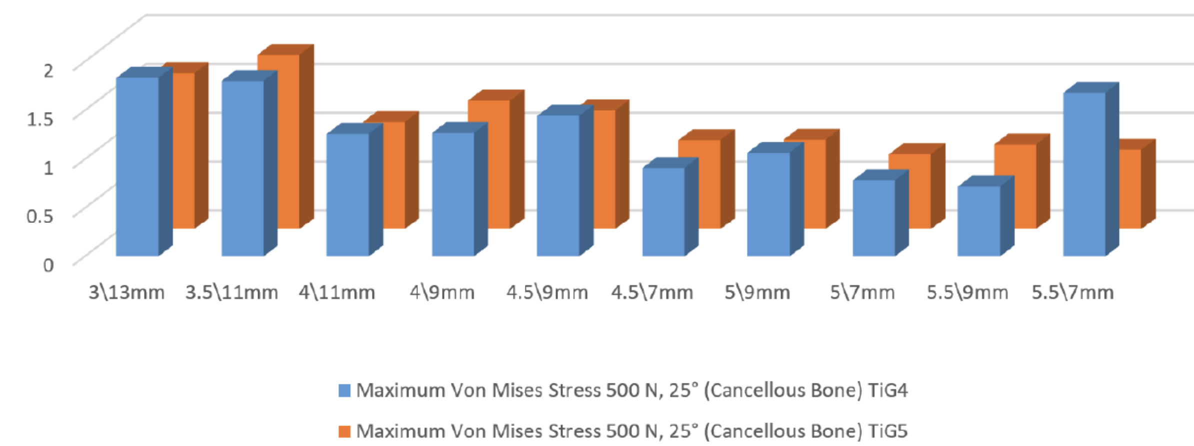

Figure 5: Maximum Von Mises stress levels over the cancellous bone in both TiG4 and TiG5 models under 500 N, 25 degrees load condition.

implant size (Figure **3**) compared to other stress levels, Linear regression analysis showed no significant relationship between the implant size and length and the stress level over both cortical and cancellous bone ($p > 0.05$).

With one exception (overload over 5.5/7 mm implant of TiG4 model), dental implants with 4.5 size onwards showed the lowest levels of stress over both cortical and cancellous bones in both Titanium models (Figures **2**, **3**, **4**, and **5**). Mann Whitney U Test did not show a statistically significant difference between maximum Von Mises stress in both implant models over both cortical and cancellous bones in normal and over-occlusal loads ($p > 0.05$).

DISCUSSION

This study is the second within a research project to suggest the first dental implant designed by the Iraqi team. The aim is to select among different implant dimensions for a better outcome. As in the previous study, it used a simplified analytic model in which the influence of implant abutment and the crown shape has not been considered.

Despite there is no significant influence of implant dimension on the level of stress, 3/ 13 mm length tends to apply the highest level of stress compared to other implant dimensions, especially in the TiG5 model. Besides, long implants, as suggested by other studies might not reduce stress distribution [15]. Furthermore, it has been postulated that the small implant diameter might not ensure enough implant strength [16]. Thus, it might be logical to assume that removing this implant dimension would be an option, especially, if the TiG5 model to be considered. Narrow implants are indeed more suitable for the thin anterior aesthetic zone. However, the availability of bone augmentation options will preclude the need for such sizes. Also, bone augmentation for the aesthetic zone proved to have a better outcome in terms of aesthetics.

The study data showed that maximum stress around the cortical bone is important to consider for two reasons. The first reason is the stress level, which is significantly higher than stress over the cancellous bone. this agrees with other studies [3, 17, 18]. another reason is that the level of stress over cancellous bone, even in overload condition is far less compared to its physiological limit (Elastic Modulus). This makes it reasonable to consider all the implant dimensions, as far as stress over the cancellous bone is concerned. This would give the implantologist the ability to choose the suitable dimension in different bone height and quality.

Absence of clear relationship between implant dimension and stress level over both cortical and cancellous bones might be explained by the number dimension sample, which is more or less similar to the dimension sample provided by dental implant companies, and the fact that the difference in implant size between the lowest and highest sizes does not exceed 2.5 mm.

However, the study data seems to suggest that the increase of implant diameter reduces the stress level to a certain limit. The increase of the dental implant size (diameter) tends to distribute the stress over a larger surface area, which decreases the level of stress around the implant. It has been reported that an increase in implant diameter is more influential in decreasing the stress than implant length [5, 19, 20], especially over the surrounding cortical bone [21].

Despite the reported equivalent stress in overloaded conditions over cortical bone might be considered high compared to other studies [15, 22, 23], still, the loading condition in this study is near the double loading condition comparable to these studies. Besides, it remains far less than the level of cortical bone elastic modulus by 1/6 ratio. Still, it might be reasonable to suggest removing a 3/13 mm implant dimension, if the TiG5 model is to be considered.

As far as the maximum reported stress over the cancellous bone in an overload condition, the reported stress is far less than the average range reported in the literature ranging from 150-300 MPA [24, 25]. Despite the literature shows a very wide range of cancellous bone elastic modulus being slightly over 1 MPA up to over 500 MPA [26, 27].

Given the lowest level of the cancellous bone elastic modulus, it would be logical to remove the implant dimension 5.5/7 mm if TiG4 is to be considered due to its equivalent stress level over the cancellous bone. around 1 MPA level indeed represents an extremely minimum rigidity. However, very soft bone (D4 with large medullary spaces) is not uncommon in the posterior jaw regions.

CONCLUSION

All implant dimensions showed far fewer stress levels over both cortical and cancellous bones. However, it would be advisable to eliminate the 3/13 mm implant dimension, especially, if the TiG5 model is to be considered, and a 5.5/7 mm implant dimension if the TiG4 model is to be considered.

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