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Original Article

A suggested design for a tissue level dental implant

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ABSTRACT

Objectives: The aim of the study was to test the stress distribution around a newly suggested design for tissue-level dental implant.

Material and Methods: Newly designed modified reverse buttress thread dental implant is tested for the stress over the surrounding bone. Nine implant dimensions of this design were examined on two types of materials; commercially pure Titanium (TiG4) and Titanium alloy (TIG5). These nine implant dimensions, which can be used in the full dental arch are: (diameter/length; 3.5/11, 4/11, 4/9, 4.5/11, 4.5/9, 5/11, 5/9, 5/7, and 5.5/7 mm). The suggested implant was designed using Autodesk Inventor 202. ANSYS Workbench 2020 R2 was used for meshing and 3D finite element analysis.

Results: Maximum Von Mises stress over the cortical bone is higher in the TiG5 model in all implant dimensions. The highest stress value was reported in the implant 4/9 mm dimension in both models. TiG5 model has the highest stress values over the cancellous bone. The higher level of stress over the surrounding cortical bone lies at the surface of the cortical bone, whereas the maximum stress over the surrounding trabecular bone was noticed near the tip of the first and second dental implant thread.

Conclusion: Reasonable levels of stress were reported in the suggested design in both models. However, it would be justifiable to choose the TiG4 model for the suggested tissue level implant with the exclusion of a 4/9 mm dimension to ensure minimal stress over the surrounding cortical bone.

Keywords: Tissue-level Dental implant, Modified reverse buttress design, Stress distribution, TiG4, TiG5

INTRODUCTION

Biomechanics in dental implant prosthetics witnesses continuous development to improve the outcome of dental implant treatment. The focus of this development is to enhance osseointegration and ensure hard- and soft-tissue integrity around the implant prosthesis.[1-5]

The developments in the dental implant are usually implemented on two widely used dental implant materials; commercially pure Titanium (TiG4), and Titanium alloy (Ti-6Al-4V), also known as TiG5. This Titanium alloy contains 6% aluminum and 4% vanadium.[6]

One of the directions in dental implant research is stress distribution around the implant. The stress distribution is strongly related to the geometry of implant and loading type.[3,7,8] The shape and size of threads play a critical role in this aspect. Each of the available thread designs has its advantages and disadvantages.[6] There is, however, a tendency to consider deeper thread with a larger pitch to improve both implant stability and stress distribution.[7,9]

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Another direction through which implant treatment can be improved is the adoption of the minimally invasive concept. Minimally invasive dentistry is a well-embraced concept in contemporary dental practice,[10] dental implantology is no exception. This drives most dental implant companies to adopt soft-tissue dental fixture design in the esthetic zone.

A tissue-level dental implant maintains the integrity of the gingival tissue, especially in second-stage surgery.[11-15] It minimizes the trauma over the soft tissue during the need for second-stage surgery if surgery is needed. Furthermore, it utilizes the longer threads to enhance the primary stability.

Gingival tissue around the neck (soft tissue part) of the dental implant is very important to protect the implant-bone interface from bacterial invasion. This protection is offered through firm mechanical contact with the neck of the implant. It is crucial to maintain the health of this tight soft-tissue collar. If the implant does have a soft-tissue part, this may evade the soft tissue and trauma after following the steps of prosthetic parts insertion.[16,17]

This is why it is used in the aesthetic zone. However, tissue-level implant in other jaw regions is not widely adopted.[13,18] That is why the suggested design can be used in the full arch.

The aim of the study was to test the stress distribution around a newly suggested design for tissue-level dental implant.

MATERIAL AND METHODS

This tissue-level dental implant was designed by the first author and tested on a 3D model of both Titanium Grade 4 (TiG4) and Titanium Alloy (TiG5). The software used to create this 3D implant was Autodesk Inventor 2021 [Figure 1a].

The design represents a modified reverse buttress dental implant with longer, deeper threads, and larger pitch. Furthermore, it adds a soft tissue part to the body of the implant with a concavity in its circumference. The dimensions of the suggested design are standardized with a thread depth, which increases up to 0.7 mm near the dental implant apex. The thread width of 0.1 mm and the thread pitch is 0.7 mm. Each thread has a (30°) face angle.

Nine suggested diameters/lengths: (3.5/11, 4/11, 4/9, 4.5/11, 4.5/9, 5/11, 5/9, 5/7, and 5.5/7 mm). These implant dimensions cover the required implant lengths and sizes for the full upper and lower dental arches.

A mandibular molar region with 2 mm cortical thickness was the model region for testing. This 3D mandibular segment model assumed a 1 mm distance between the implant and both buccal and lingual margins. Both, the bone model and the suggested dental implant were integrated employing Autodesk Inventor 2021. A sample of the model within the simulated bone is illustrated in [Figure 1b].

All the materials used in this study were assumed to be linearly elastic, isotropic, and homogeneous. The Young's modulus and the Poisson's ratio for the implant, cortical, and trabecular bone materials are provided in [Table 1].[1,31]

This study simulates cortical bone coverage. The occlusal uncovered soft tissue part is 2.2 mm in height. ANSYS Workbench 2020 R2 was used for meshing and analysis.

A bonded contact between implant and bone is used as a fully osteointegration between implant and bone was considered. The average number of nodes and elements was 772926 and 456442, respectively.

The static loading analysis was used in this study. The effect of mastication is simulated by applying a vertical 70N load, and 500N in the Bucco-lingual plane, at an angle of 25° measured from the implant axis as shown in [Figure 2]. The distal and mesial surfaces and the base of the mandible are taken as fixed supports. The equivalent Von Mises stresses and strains caused by the loading forces were analyzed.

Descriptive statistics were used to demonstrate the stress level over both cortical and cancellous bone around the nine dental implants in both TiG4 and TiG5 models.

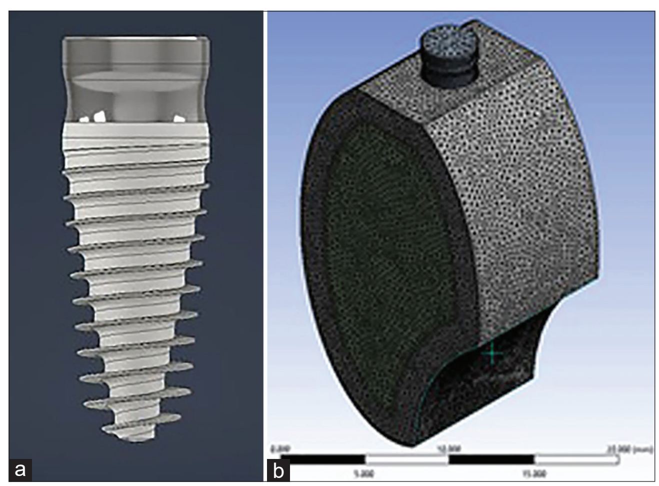

Figure 1: The implant/bone model. (a) 4/9 implant, and (b) the finite element analysis of the model.

Table 1: The material properties used for finite element analysis.

Material	Young's Modulus (MPa)	Passion ratio
Cortical bone	13400	0.3
Trabecular bone	1370	0.31
TiG4	105000	0.37
TiG5	114000	0.33

RESULTS

[Table 2] demonstrates the differences between both materials in terms of maximum stress value. TiG4 and TiG5 were close in the maximum level of stress over the cortical bone in the lower occlusal load condition. TiG5 demonstrating slightly higher stresses. Stress values in both models are, also, comparable among all implant dimensions.

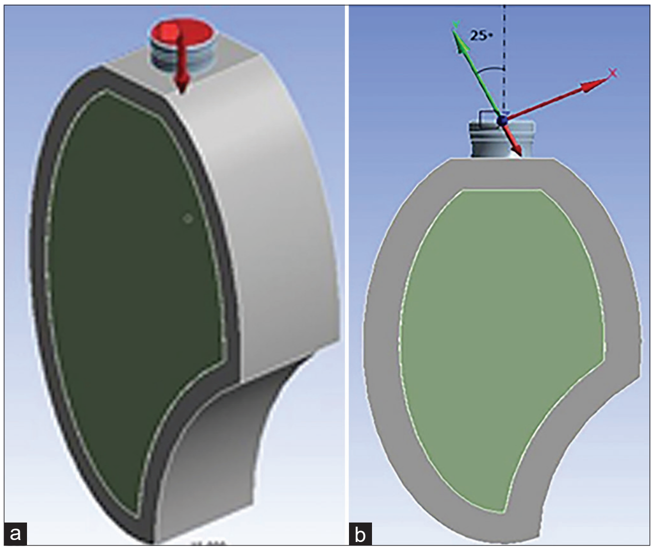

Figure 2: The applied loads, (a) 70N axial Load, and (b) 500N load being inclined 25° from the vertical axis and applied in Bucco-lingual direction.

On the other hand, the higher load condition shows obvious differences in maximum stress values between the two models. Maximum Von Mises stress is higher in the TiG5 model in all implant dimensions. The highest stress value was reported in the implant 4/9 mm dimension in both models.

Higher load condition also clarifies the difference among implant dimensions. The maximum stress is lower in 4.5/11 mm in both models. However, greater implant diameters (5/9 mm, 5/7 mm, and 5.5/7 mm) reported comparable values in both models.

It can be seen that the TiG5 model has the highest stress values in both lower higher load conditions over the cancellous bone. In lower load conditions, both dental implant models (TiG5 and TiG4) reported comparable values. All dental implant dimensions in both models did not show significant differences among different dimensions.

In higher occlusal load, however, TiG5 shows noticeably higher stress values over cancellous bone compared to TiG4 in all dental implant dimensions. In contrast to the cortical bone case, the implant 3.5/11 dimension recorded the highest stress value compared to other dimensions followed by the 4/9 mm dimension in both dental implant models. Apart from a 4/9 mm implant, the stress level over cancellous bone in both dental implant models in higher load conditions tends to decrease with the increase in dental implant diameter.

In all dimensions for both models, the higher level of stress over the surrounding cortical bone lies at the surface of

Table 2: Maximum Von Mises stress levels in both 70N, 0°, and 500N, 25°, for both TiG4 and TiG5 models.

	70N 0°		500N 25°	
Implant measurement	**Cortical_strss TiG4**	**Cortical_strss TiG5**	**Cortical_stress TiG4**	**Cortical_stress TiG5**
3.5_11	15.722	15.496	104.71	104.06
4_11	15.252	14.96	100.78	99.486
4_9	20.121	20.021	296.74	291.09
4.5_11	6.6429	6.5834	47.542	46.696
4.5_9	8.7569	8.6645	61.063	60.933
5_11	9.1763	9.0681	89.124	87.128
5_9	6.2956	6.2788	71.84	71.611
5_7	7.4732	7.4314	64.079	62.972
5.5_7	9.9694	9.8451	62.656	62.036
	70N 0°		**500N 25°**	
Implant measurement	**Cancellous_stress TiG4**	**Cancellous_stress TiG5**	**Cancellous_stress TiG4**	**Cancellous_stress TiG5**
3.5_11	0.40658	0.39653	4.4622	4.3757
4_11	0.32604	0.31854	3.619	3.5551
4_9	0.51543	0.51361	4.0905	4.078
4.5_11	0.22876	0.22281	2.374	2.3151
4.5_9	0.26301	0.2576	1.4814	1.4467
5_11	0.26704	0.25972	1.6023	1.5561
5_9	0.23509	0.23014	1.2532	1.2083
5_7	0.32607	0.31526	1.1964	1.1511
5.5_7	0.3056	0.29625	1.4704	1.4064

the cortical bone, whereas the maximum stress over the surrounding trabecular bone was noticed near the tip of the first and second dental implant thread [Figures 3 and 4].

DISCUSSION

The study hypothesis suggested that the tissue level implant with the modified reverse buttress design will provide an acceptable level of stress over the surrounding bone in an overload condition. Modification in the reverse buttress thread includes decreasing the face angle and increasing the thread depth and pitch.

Reducing the dental thread face angle aims to minimize the shear forces over the surrounding bone. Increasing both thread depth and pitch makes the modified reverse design as close as possible to square design. It has been suggested that such design provide better stress distribution in inclined dental implant situation.[9,19]

Besides, this modification on the reverse buttress design increases the primary stability in the soft bone region.[9] It is important to achieve better primary stability and stress distribution, especially in tissue-level implants. The soft-tissue part could be subjected to unwanted pressure during the healing period.

Furthermore, the design is characterized by a concavity of the gingival part throughout most of its circumference to increase the biological width and allow the soft tissue to drape more coronally.[20] This concavity, which starts at the junction between the intra-bony and the gingival parts utilizes the modified platform switching concept. This provides better preservation of the crestal bone.[5]

In this study, two types of loading conditions were studied to realistically assess the stress state of the implant/bone system,[21,22] and compare the effect of implant size (diameter and length) on stress distribution in bone.

The pattern of stress distribution over cortical and cancellous bones in both loading conditions is comparable to studies that adopt root shape dental implant design.[23,24] There is an obvious difference between stress levels in cortical and cancellous bone. This is attributed to the difference in density and the modulus of elasticity.[24] The highest level of stress in overload condition was reported with implant dimension (4/9 mm).

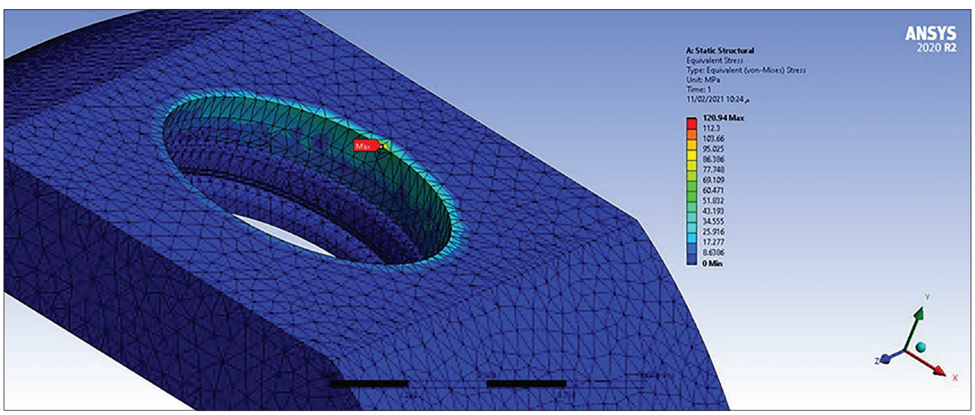

Figure 3: Pattern of stress over the cortical bone.

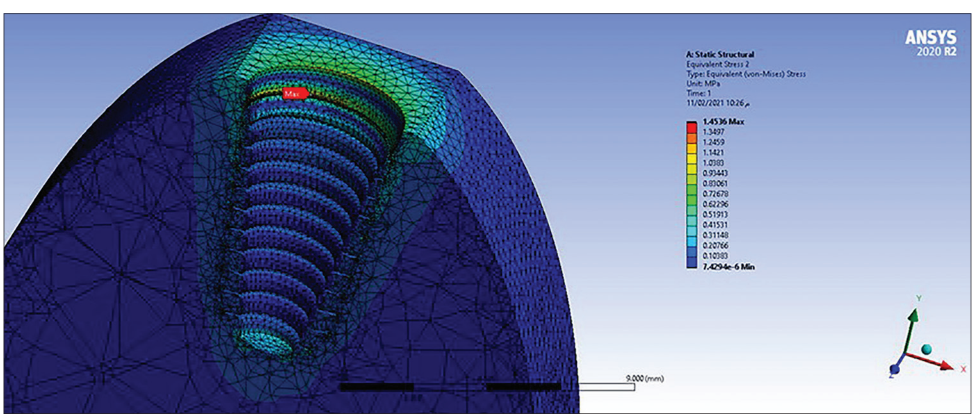

Figure 4: Pattern of stress over the cancellous bone.

It is difficult to compare this study results with other studies. There is no standardization in different loading conditions and loading angles.[25-27] Furthermore, there is paucity in the published studies that compare the level of stress between different dimensions within the same design. Dental implant companies seem to be discrete in providing details of their design shortages.

It can be assumed that according to the level of maximum stress, the suggested design has reported reasonable levels of stress. This is evident through the difference between the reported maximum stress and the elastic modulus of both cortical and cancellous bones. Besides, it showed comparable results to similar studies.[27]

This study's findings have shown a comparable stress pattern with a previous study, which was conducted by another research team led by the same first author. The previous study suggested a bone-level dental implant with a modified reverse buttress design.[1] However, implant 3/13 mm (TiG5 model) in the previous study reported the highest level of stress in cortical bone 500N, 25° condition.[1]

In the current study, the highest level over the cortical bone in 500N, 25° condition is reported in 4/9 mm dental implant. It shows double the level of stress around the 3.5/11 mm implant. However, 4/9 mm implant remains 4 times less than the elastic modulus of the cortical bone.

The comparable results in both studies could suggest that similar implant dimensions impose comparable stresses over the surrounding bone, especially with similar basic thread design features. In both studies, the thread pattern is of a reverse buttress design, and the modified face angle is 30°.

Reversed buttress thread design transfers the stress applied in a single area into isolated areas near the tip of the thread. This raises the nonlinear stresses on the surface of the implant to be greater in the valley between the thread pitch in comparison with stresses at the thread tip.[26]

Similar to other dental implant designs, the balance in implant length and diameter needs to be considered in dental implant design for better stress distribution, regardless of the presence of soft-tissue part of the fixture. The stress distribution is related to the intraosseous dental implant geometry. This could be the reason behind the focus of most studies on the submerged part of dental implant prosthesis.[24,28-30]

Like other FEA studies, in the present analysis, the interface between the implant and the surrounding bone was fully bonded, but in clinical conditions, this is not always the case. Furthermore, some elements, such as the crown, that were not included in this model, may produce different effects on stress/strain patterns. Therefore, the existing models are unable to produce absolute and real stress and strain values in the jawbone/implant framework of the actual model. However, such simplifications are considered to be adequate for comparative analysis. For future works, Friction may also be taken into account in models to accurately simulate the clinical environment. Hence, the new implant design should be tested experimentally and compared clinically with the existing designs.

CONCLUSION

Reasonable levels of stress were reported in the suggested design in both models. However, it would be justifiable to choose the TiG4 model for the suggested tissue level implant with the exclusion of a 4/9 mm dimension to ensure minimal stress over the surrounding cortical bone.

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Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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