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Research Report

Stress Distribution Around Two Dental Implant Materials with New Designs: Comparative Finite Element Analysis Study

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ABSTRACT

Background: The introduction of modified thread designs is one of the research areas of interest in the dental implantology field. Two suggested Buttress and Reverse Buttress thread designs in TiG5 and TiG4 models are tested against a standard TiG5 Fin Thread design (IBS®). **Purpose:** The study aims to compare stress distribution around the suggested designs and Fin Thread design. **Methods:** Three dental implant models: Fin Thread design, and newly suggested Buttress and Reverse Buttress designs of both TiG5 and TiG4 models were tested using FEA for stress distribution using static (70N, 0°) and (400N, 30°) occlusal loads. **Results:** The main difference between the suggested Buttress design and Fin Thread design lies in the overload (400N, 30°) condition. Maximum Von Mises stress is less in Buttress design than Fin Thread design. On the other hand the level of Von Mises stress over the buccolingual slop of the cancellous bone in Fin Thread design liess within the lowest stress level. The suggested Reverse Buttress design, on the other hand showed almost uniform stress distribution in both TiG4 and TiG4 models with maximum Von Mises stress higher than the elastic modulus of cancellous bone in overload (400N, 30°) condition. **Conclusion:** The suggested TiG4 Buttress design might have a minor advantage of stress level in cases of stress overload. In contrast, Fin Thread design shows minimal stress over the buccolingual slop of the cancellous bone. The suggested Reverse Buttress design might be more suitable for the D1 bone quality region with the advantage of almost uniform stress distribution.

Keywords: Dental Implant; Fin Thread Design; modified buttress thread design; modified reverse buttress design; stress distribution.

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INTRODUCTION

The influence of dental implant design and its mechanical properties on the ability of implant-bone interface ability to cope with functional stresses is one of the cornerstones in dental implant research.[1,2] This is reflected by the number of published research that focuses on dental implant design as one of the factors that influence the success of dental implant surgery.[3]

Dental implant design is defined as a three-dimensional structure. This structure has been extensively studied concerning its influence on occlusal load distribution to the surrounding jaw bones.[4-6] This includes micro and macro thread design; thread shape, pitch, and depth; dimension of the dental implant, and the surrounding bone density.[5,7-11] Dental implant design has, also, been, considered in terms of bone reaction through the period of healing, osseointegration, and bone remodeling.[12, 13]

Macro-thread design is one of the implant geometrical criteria that affect the way occlusal force transmission to the surrounding bone, as well as, play a role in primary implant stability.[12] Different designs have been provided by dental implant manufacturers. This inspires different researchers to study those designs to reach the best geometrical thread design criteria for the best dental implant treatment outcome.

Recently, Fin Thread design has been introduced utilizing the features of TiG5. This type of dental Introduction of modified thread designs is one of the research areas of interest in the dental implantology field. Two suggested Buttress and Reverse Buttress thread designs in TiG5 and TiG4 models are tested against a standard TiG5 Fin Thread design (IBS®). The study aims are to compare stress distribution around the suggested designs and Fin Thread design.

MATERIALS AND METHODS

Two suggested implant designs, Buttress and Reverse Buttress, designs in TiG5 and TiG4 models have been analyzed for stress distribution against a standard Fin Thread design (IBS®). Three-dimensional Finite Element Analysis has been carried out in both normal and overload conditions. The 3D implant models were inserted in a simplified 3Dimensional model of mandibular bone section with (16 × 26 ×18 mm) respectively. The implant models to be tested share the same dimensions (Ø 4x9 mm).

The bony section consists of a core of cancellous bone encircled by a 2 mm thickness of cortical bone. The three implant models will be studied for the influence of the thread design on occlusal stress distribution on the surrounding bony model. The properties of the implant models and the bone section are shown in Table 1. The construction of the implant models was performed with 2016 Auto-Cad Software. The three implant models are shown in Figure 1.

Load and boundary conditions: the study is based on the assumption that all materials are homogenous, isotropic with elastic linearity. Bone- Implant Contact has been considered as optimum with 100% osseointegration. There is no movement within the suggested model parts, which makes those parts share the same nodes. Node and element numbers for bone and implant in the 3 selected models are shown in Table 2.

Linear and static loading were applied on the top middle node of each of the studied implant modes. Each of the four implants was examined under normal masticatory compressive loads (vertical 70N) and overload load force 400N with 30° angulation over the vertical axis.[15,16] Finite Element Analyses (FEA) were performed with ANSYS Workbench (Ver. 16).

Both sides and bottoms of the surrounding bone were completely constrained. The top surface of the implants was the area of the applied load. Static structural analysis was done using ANSYS 16 software. Mesh density was carefully considered at the curved parts of the geometry. Also, increasing the number of elements reduces artificially created sharp angles during implant designing. This will reduce artificial stresses.

RESULTS

The study simulation was performed according to two assumptions. The first assumption is the application of normal masticatory forces (70N, 0°). The second assumption is based on applying extra forces of 400N, in 30° degrees to the vertical axes. Cortical bone and cancellous bone sections have been separated in the figures to provide detailed information on stress level and distribution.

Figure 2 shows Von Mises stress distribution for the three implant designs for TiG5 with 70 N, 0°. Reported stress over the cortical bone for Fin Thread is the lowest compared to the Buttress and Reverse Buttress, with relatively wider stress distribution around the implant neck.

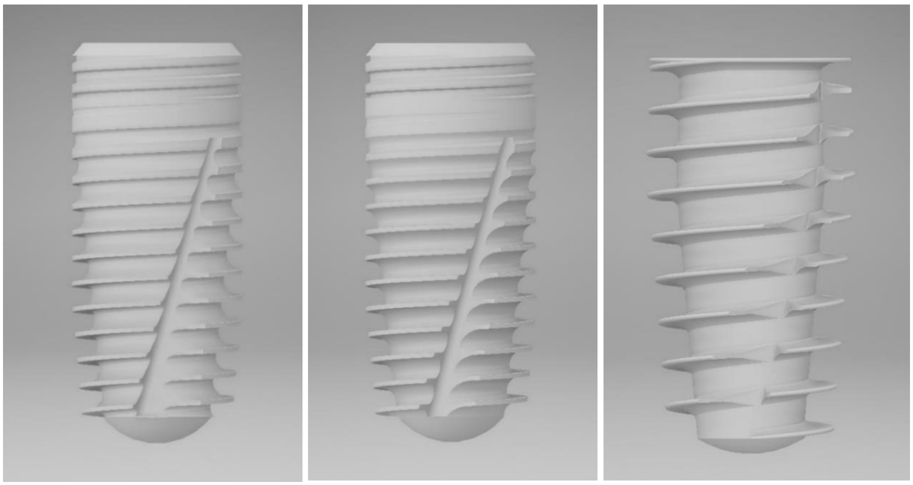

Figure 1. Implant designs, a: Buttress, b: Reverse Buttress, c: Fin Thread.

Table 1. Mechanical properties of the implant models[14]

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

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
Fin Thread (FT)	23,077	73,077

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However, both Fin Thread and Buttress designs showed less stress compared to the Reverse Buttress design.

On the other hand, the maximum Von Mises stress over the surrounding cancellous bone is relatively lower in Buttress design than Fin thread, despite the area of stress distribution over the Fin thread is smaller compared to Buttress design. Maximum Von Mises stress on both Buttress and Fin Thread designs is far lower than elastic modulus for both cortical and cancellous bones.

Reverse Buttress appears to have the highest Maximum Von Mises stress level compared with the previous designs, despite the almost uniform stress distribution

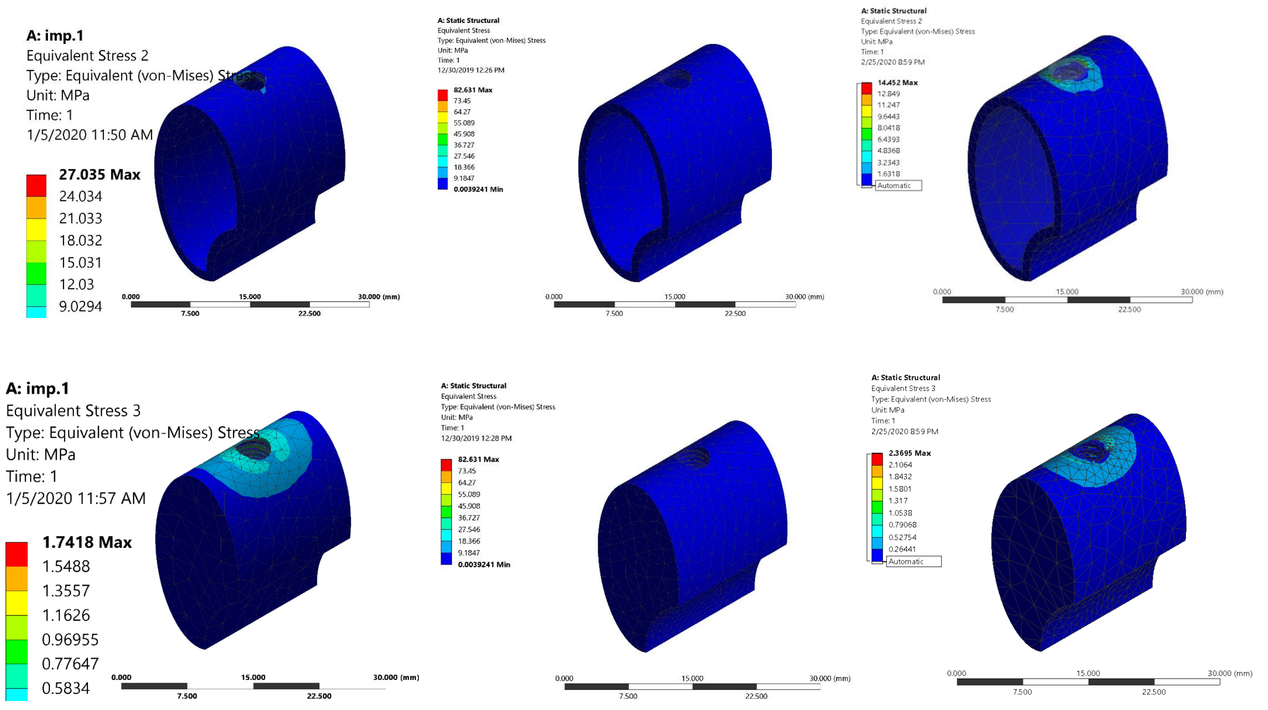

Figure 2. Stress distribution for TiG5 implant (70 N) masticatory forces, 0° on in Buttress design (LT), : Reverse Buttress (middle), and Fin Thread (RT) for compact bone (upper row), and spongy bone (lower row).

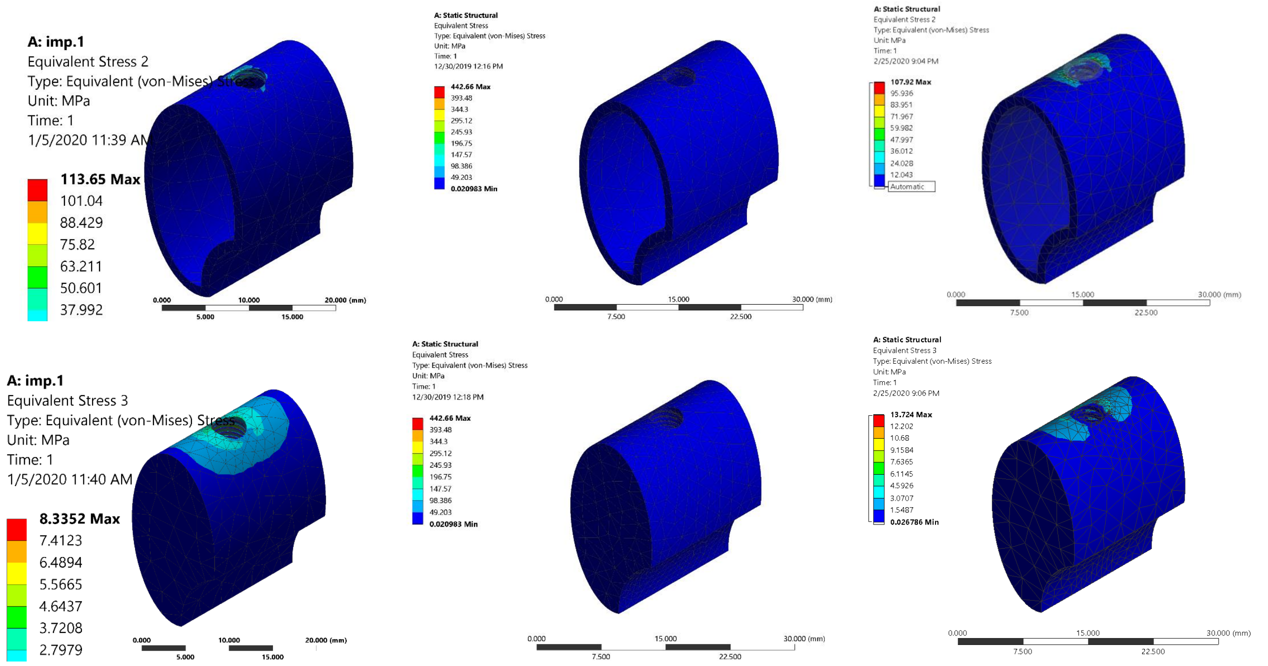

Figure 3. Stress distribution for TiG5 implant in (400 N) masticatory forces 30° on in Buttress design (LT), : Reverse Buttress (middle), and Fin Thread (RT) for compact bone (upper row), and spongy bone (lower row).

over both cortical and cancellous bones. The maximum Von Mises stress applied on cancellous bone in this design remains less than the average yielding point of the cancellous bone.

In Figure 3, all TiG5 dental implant designs are subjected to 400N, 30° occlusal load. The figure shows comparable Maximum Von Mises stress levels on both cortical and cancellous bones for both Buttress and Fin Thread designs. However, the area of distributed stress over the compact bone in Fin Thread design is relatively larger. In contrast, the area of stress distribution over cancellous bone is smaller in Fin Thread. This area differs between Fin Thread and Buttress designs. Bucco-lingual slop does not show the same distribution pattern of stress. The stress in Fin Thread design remains almost within the minimum Von Mises stress in buccolingual slops.

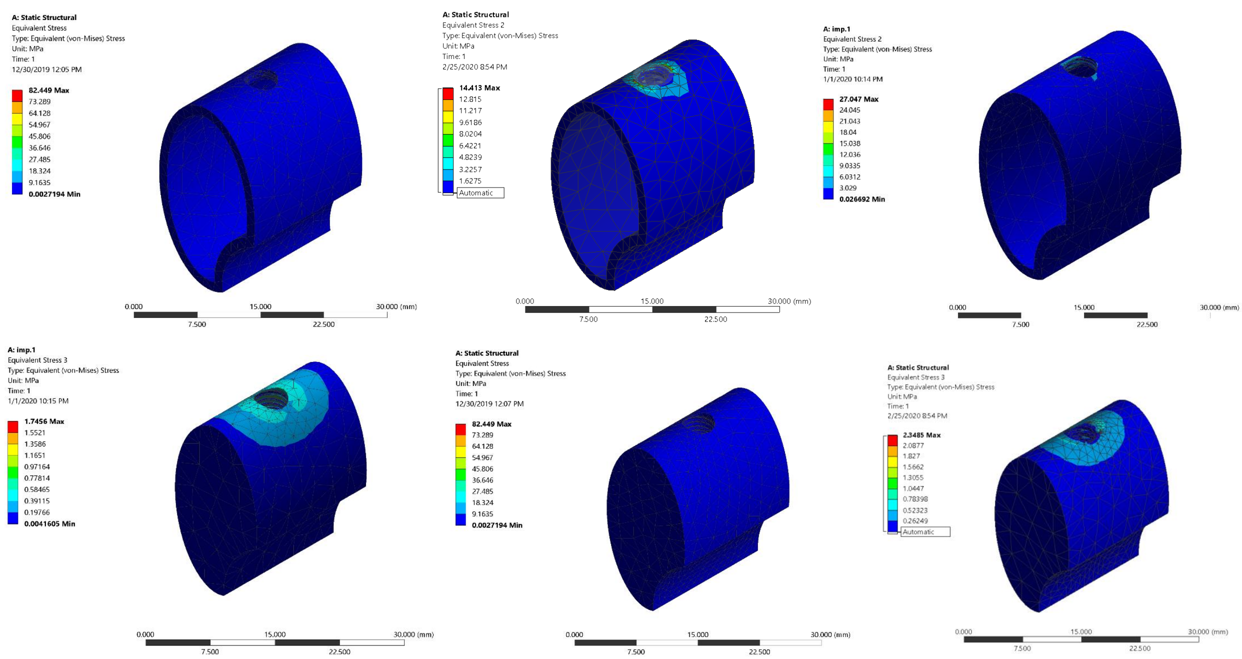

Figure 4. Stress distribution for TiG4 implant (70 N) masticatory forces, 0° on in Buttress design (LT), : Reverse Buttress (middle), and Fin Thread (RT) for compact bone (upper row), and spongy bone (lower row).

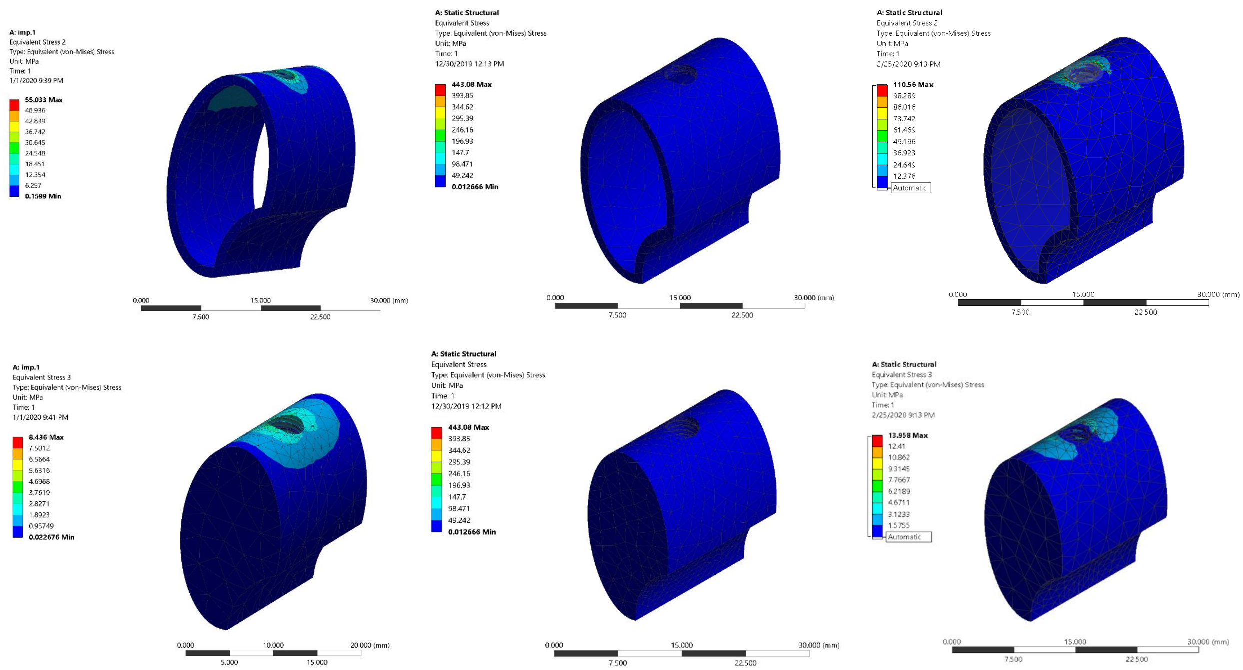

Figure 5. Stress distribution for TiG4 implant in (400 N) masticatory forces 30° on in Buttress design (LT), : Reverse Buttress (middle), and Fin Thread (RT) for compact bone (upper row), and spongy bone (lower row).

Interestingly, the Reverse Buttress design, still, shows almost uniform stress distribution over both compact and cancellous bones. The maximum Von Mises stress value is higher than the cancellous bone elastic modulus.

Figure 4 demonstrates Von Mises stress for the three implant designs (TiG4 model) under 70N, 0° over both compact and cancellous bones. Similar to Figure 2, both Buttress and Fin Thread designs report comparable Maximum Von Mises stresses, with a slightly wider area of stress distribution over the compact bone around the dental implant.

In contrast, Buttress designs show relatively wider stress distribution over cancellous bone compared to the Fin Thread design with comparable Maximum Von Mises stress. The area of stress distribution over the cancellous bone in the Fin Thread design model remains mostly within the same Von-Mises stress level. In Buttress design, however, there is a subtle difference between the area of the cancellous bone surrounding the implant and the surrounding area. This difference, however, seems to diminish over the buccolingual slop.

Reverse Buttress designs, as in Figure 2, gives an almost uniform stress distribution with the highest level of Von Mises stress compared to the other two implant designs. This pattern of stress distribution appears to be equal on both compact and cancellous bones.

As shown in Figure 5 the difference between Buttress and Fin Thread designs (TiG4 model) in terms of Von Mises stress is more obvious. When 400N, 30° load is applied on those two implant models, Buttress designs show less Maximum Von Mises stress compared to the Fin Thread design. However, the area of distribution is relatively less over the Fin Thread design.

Maximum Von Mises stress over cancellous bone in both Buttress and Fin Thread designs shows comparable levels, which lies within far less degree than the elastic modulus. The area of stress distribution over the cancellous bone in Fin Thread design remains confined to the mesial and distal sides of the implant and seems to decrease to its minimal level over the buccolingual slop.

The pattern of stress distribution over both compact and cancellous bones in the Reverse Buttress design (TiG4 model) is similar to what is shown in (Figure 3). The stress seems to be distributed almost equally over the surrounding bone. However, the maximum Von Mises stress over the cancellous bone is higher than the cancellous bone elastic modulus.

DISCUSSION

One of the objectives of dental implant design is to reduce the occlusal stress over the adjacent bone to be within the surrounding bone physiological limit. Otherwise, implant failure would result, as the masticatory load will exceed the yielding point of the stress of the surrounding bone.[17] In this sense, it would be logical to complement the biomechanical features of the dental implant material with the dental implant design to achieve this objective.

In the current study, both Buttress and Reverse Buttress thread designs were modified to reduce the thread face angle. This would disseminate the load on the adjacent bone.[18,19] This, also, will achieve a square-like design toward the tip of the thread. The suggested models were compared with the Fin Thread design adopted by (IBS®) as a standard model for comparison. Fin Thread design (IBS®) should have the advantage of square design with (1/9) thread to bone formula, utilizing the difference between the elastic modulus of TiG5 and cortical bone.[20]

For both Buttress design and Fin Thread design, the maximum Von Mises stress was higher on the cortical bone compared to the cancellous bone in both normal and over occlusal load situations. This finding agrees with the previous studies.[21-23] This is because of the higher rigidity of the cortical bone. Its elastic modulus is 10-7 times the cancellous bone. When oblique forces are applied to the implant, the cortical bone will act as a fulcrum. That is why the maximum stress occurs on the cortical bone.[24] This was true for both dental implant materials (TiG5 and TiG4).

The decrease in maximum Von Mises level over the cortical bone in TiG4 compared to TiG5 in Buttress design might favor the TiG4 material with this design compared to Fin Thread design. However, the Von Mises stress in Fin Thread design remains far more less the maximum physiological limit of cortical bone.

Because the majority of dental implants are manufactured from TiG4, not much attention has been given to the influence of TiG5 on stress distribution in comparison to TiG4. Different dental implant materials with different biomechanical properties might influence the occlusal stress distribution.

Implementing the biomechanical features of the dental implant material with the thread design seems to be out of the focus of those studies. TiG5 elastic modulus has the formula of 9/1 to the cortical, which has been considered in the design of IBS implant.

TiG5 (Ti-6Al-4V) is alloyed Titanium containing 6% aluminum and 4% vanadium. It is the strongest type of Titanium, which is why it is preferred in orthodontic mini-implants. However, it is not as popular as TiG4, despite it exhibits an attractive combination of both mechanical and physical properties, corrosion resistance, and great biocompatibility. These are considered as the gold standards dental implant manufacturing.[25]

The use of TiG5 Fin Thread design as the standard model to compare with was based on the manufacturer's assumption that this design suitably implements the biomechanical properties of the material with the surrounding bone. Of course, this is true for the cortical bone, as the elastic modulus of cancellous bone does not fit with this formula. Still, it remains applaudable, since the cortical bone has the greater burden of dental implant stress.

This study shows, however, no major difference between TiG5 and TiG4 Fin Thread design in terms of stress distribution over both cortical and cancellous bone in normal and overload conditions. This implies that the type of material might not the essential variable in stress distribution.

Despite the minor difference in maximum Von Mises stress between TiG5 and TiG4 Buttress design, the level of the maximum stress remains within a very reasonable level compared to the elastic modulus of both cortical and cancellous bones.

Based on this study, it might be concluded that decreasing the distance between threads to 0.5mm in the suggested Buttress design, compared to 9mm BS Fin Thread design, does not highly influence the level of stress distribution. The suggested implant designs took into consideration the results of studies, which found that longer dental thread and pitch have the advantage of less stress over the surrounding bone [4, 22, 26, 27] with suitable implant insertion easiness [28], in addition to better implant stability.[29, 30]

Apart from the fact that the suggested Buttress design in the TiG4 model showed a slightly favorable level of Von Mises stress over cancellous bone in overload condition compared to Fin Thread design, both showed highly acceptable levels of stress distribution in normal and overload conditions. Maximum Von Mises stress for both was far less than the physiological limit, which is an important objective to be achieved. However, it is important to refer to the fact that Fin Thread design, in the cases of an overload condition, showed minimal stress over buccolingual slop of the cancellous bone.

Despite that the Reverse Buttress design showed the highest Von Mises stress compared with the other models, the almost uniform pattern distribution might favor its use in the D1 bone quality area.[31] In this region, the level of stress is definitely within the physiological limit of cortical bone. The advantage of stress distribution uniformity might provide the advantage of using a narrow implant diameter in the lower anterior mandibular region. The uniformity of stress distribution might utilize the whole implant body. This might preclude the need for a wider implant to ensure better stress distribution

It is difficult to compare the finding of the current study with other studies. Each published study uses different design parameters, implant designs, and different load conditions. However, the published articles tend to support the advantage of square thread design over other thread designs in terms of the level of transmitted stresses to the cortical bone.[21-23] The occlusal load over the implant with square thread design in an axial direction will be compressive at the bone-implant interface area.[32] This might be the reason for many different implant companies to follow this design with different patterns.[33-35] Accordingly, Fin thread design seems to provide the maximum benefit of a square design, utilizing the strength of TiG5.

Despite published studies agreed that each design imposes different stress over the surrounding bone[13,36,37], Buttress and Fin Thread designs gave comparable results, in terms of the level and the area of stress distribution. This might be attributed to the advantage of designing the Buttress design thread to simulate the Fin Thread design. Further studies might be required to compare the suggested Buttress design and Fin Thread design with different implant parameters to ensure that the suggested Buttress design provides desirable stress distribution for different implants lengths and diameters.

CONCLUSION

No major differences between TiG5 and TiG4 in the three dental implant designs. In addition, there is no obvious difference between the suggested Buttress design and Fin Thread design in terms of the level and the surface of stress distribution. However, the suggested TiG4 Buttress design might have a minor advantage of stress level in cases of stress overload. In contrast, Fin Thread design shows minimal stress over the buccolingual slop of the cancellous bone. The suggested Reverse Buttress design might be more suitable for the D1 bone quality region with the advantage of almost uniform stress distribution.

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