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The Influence of Fin Thread Implant Design on Stress Distribution Comparative FEA Study

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Abstract

Background: one of the requirements of long term dental implant success lies within the implant structure and bone-implant interface ability to cope with functional stress. Dental implant ability to withstand different occlusal loads optimizes implant-supported prosthesis function, minimize stress over the surrounding bone, improve osseointegration and reduce the required period for implant loading. One of the areas of research on implant geometry is the thread design. Threads increase initial bone contact, enhance implant stability, maximize implant surface area with subsequent improvement of osseointegration. Recently, Fin Thread (FT) and Modified Fin Thread designs (IBS®) have been introduced. These designs on TiG5 dental implant did not seem to receive adequate attention in the current literature. Methods: four dental implant models (Modified Fin Thread, Fin Thread, V-shaped and Buttress designs) of TiG5 were tested using FEA for stress distribution using normal and extreme static occlusal loads on 0, 15 and 25° angles. Results: Modified Fin Thread (MFT) design and Fin Thread (FT) design showed almost uniform stress distribution compared to other models under normal occlusal load. However, MFT design showed better stress distribution with no cortical bone involvement in overloaded occlusal stress (200 and 400N) respectively. Conclusion: Modified Fin Thread Design of Ti G5 seems to be the more suitable dental implant model in terms of stress distribution in normal and over occlusal load conditions. MFT designs need clinical studies to support this study findings on patients with long follow up periods.

Introduction:

One of the requirements of long term dental implant success lies within the of the implant structure and implant-bone interface ability to cope with functional stress. That is why studying the mechanical aspects of dental implants and their influence on load transfer to the surrounding bone became one of the cornerstones in dental implant research in the last decade (1, 2). Thus, most of published researches focuses on the dental implant design and its influence on the success of dental implant surgery (3). Implant design is the three dimensional implant structure with related characteristics. It plays a major role in distributing various occlusal loads to the surrounding biological tissue (4). Implant design relates to micro vs macrothread design; implant pitch depth and width; length of dental implants and the density of the surrounding bone (5-9). The influence of different implant designs has been considered in relation to immediate bone reaction, the period of osseointegration and ability to withstand different functional loads (10, 11). One of the areas of research on implant geometry is the study on dental implant thread design. Threads increase initial bone contact, enhance implant stability, maximize implant surface area with subsequent improvement of osseointegration. They also influence stress distribution around the dental implant during function (10). Different thread designs have been and still currently provided by different dental implant companies to improve implant performance and longevity. Recently, Fin Thread (FT) and Modified Fin Thread (MFT) design have been introduced (IBS®). This design, which utilisez TiG5 has not been adequately covered in the literature.

Aim of the study:

Is to compare between the impact of newly introduced Fin Thread (FT) and Modified Fin Thread (MFT) design with both V and Buttress shaped designs on the surrounding bone, using different degrees and loading angles.

Methods:

Four 3D dental implant models (TiG5) were analysed during the loading process. The 3D implant models (TiG5) inserted in a simplified 3-D model of a mandibular section of bone with a block of dimensions (16 × 26 ×18 mm) respectively. This bony section is composed of a spongy center surrounded by the cortical bone of 2 mm. All implants were investigated for the effect of threads shape on the stress distribution within the implant and surrounding bone model. The mechanical properties of the implant model and the bone were shown in Table (1).

The four implant models were constructed using Auto-Cad Software 2016 with different thread types (FT, MFT, V-shape, buttress designs). The latter two designs, which were used in most of the studies, considered as control models. The length used for the four implant designs was 9 mm with a maximum implant width 4 mm at the crystal end of the implant. The apex of the implant body ranged from 0.9 mm to 2.5 mm. The pitch was 1 mm for all of the four models. The width of the thread was 0.5 mm for V-shaped and Buttress designs, whereas it was 0.1 mm for the Fin thread and Modified Fin Thread designs. The thread angle in both V shaped and Buttress designs was 30^{o}. The four implant models with their dimensions are shown in Fig.(1). The Finite Element Analyses (FEA) were carried out using ANSYS Workbench 17.0. The finite element model is shown Fig.(1). The physical interactions at implant-bone interfaces during loading were taken into account complete IBC. Numbers of nodes and elements of bone and implant elements of the 4 models with indication to the implant model geometry type are shown in Table (2).

Loads and boundary conditions:

All materials were assumed to be isotropic, homogenous and linearly elastic. The bone implant interfaces were assumed to be 100% osseointegrated. The sides and bottom of cortical and cancellous bones were set to be completely constrained, there is no relative movement assumed within the integrated parts. This makes them share the same nodes. Static loading was applied to evaluate the implant-bone model. Each of four implants was examined under normal masticatory compressive loads (30N vertical load, 70N in 30 degrees with vertical axes, and 10N transverse load) (12). In addition, they were assumed to be under overloaded forces of 200N and 400N as maximum applied load (13) at 0, 15 and 25 degrees on vertical axes. The laoding was applied on the top middle node of each of the studied models. Linear static analysis was performed. The meshing and finite element analysis software was ANSYS version 17.2. 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). In the hand, increasing the number of elements leads to a reduction of sharp angles that are artificially created through the geometric model construction process (by the mesh), thus reducing artificial stresses that occur through the improvement of actual geometry representation.

Results:

The study simulation performed according to two assumptions. The first assumption is the application of normal masticatory forces. The second assumption based on applying extra forces of 200N and 400N, in three different angles of (0, 15, 25) degrees to the vertical axes. Fig. (2) (a) shows the colour distribution from maximum to a minimum. Red refers to maximum stresses, while blue refers to minimum stresses. The minimum stress in most of the dental implant surface is noticed in MFT design. This is followed with FT design with a relatively higher level of stress in part f the cervical area. V-shape and Buttress designs, on the other hand, show the same level of stress, which has been noticed in FT design, but over most of the dental implant surface. It must be noted, however, that the stress remains within the lowest level in both of those designs. Fig. (3) (a, b, c and d) shows the stress distribution in the four implant models within normal masticatory forces. It could be seen that the minimum stresses occurs in the MFT and FT models with almost uniform distribution, whereas the stress increases on both V- shape and Buttress design with relatively higher stress over part of the cervical third of V- shape modle. The stress in the latter two designs, however, remains within the lower levels of the coloured scale.

Similarly, the stress on the surrounding bone was the least in MFT. FT showed hardly noticeable stress on the cortical bone compared to V-shaped and Buttress designs. In the latter designs, the stress seems to be concentrated over the cortical bone (of the simulated model) and tend to concentrate on one side of the implant. The area of stress tends to decrease toward the apical implant area. However, it remains mostly within the blue zones of the coloured scale

Fig.(4a and 4b) show the cross-sections of the Ansys implant-mandible model, of the MFT model of (200N and 400N respectively) in force applied on 15 degrees inclination of the model. Fig. (4c and 4d) show the 200N and 400N forces at 25-degree inclincation of the model respectively. The stress trend of the MFT model in four loading conditions is similar and within the lower blue scale. This implies that the stress distributed evenly in all cases.

Fig.(5a and 5b) show the cross-section of the Ansys implant-mandible model, of the FT model of (200N and 400N) on 15-degrees implant inclination. In 5b the stress increases on the cervical third of the implant with slight cortical involvement. However, it remains within the blue colour scales. In figure 5c and 5d with 25 degrees implant inclination with the same forces applied. As the angle increase, the stress appears to affect almost the entire implant structure and with wider involvement of cervical bone.

V-shape model shows alsmost similar stress load distribution on the entire model with cortical bone bone involvement. However, the level of the stress remains within the blue scale Fig.(6a and 6b) show a cross-section of Ansys implant-mandible model, of the v-shape model of (200N and 400N) 15-degree force, whereas Fig. (6c and 6d) show the stress of 200N and 400N with 25-degree respectively. It is obvious that not only the stress appears on almost all the implant in both angles and forces, but it is transmitted to the surrounding cortical plate in one side on a larger area compared to FT design.

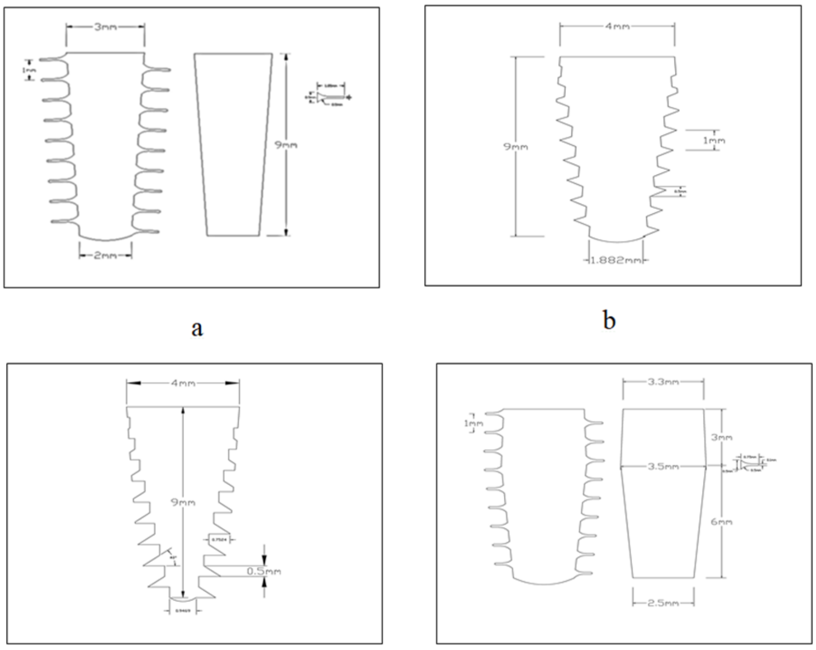
Fig. (7), on the other hand, shows less stress over the surrounding cortical bone compared to V-shape design. It also shows less stress on overall implant structure. The influence of doubling the force does not seem to greatly influence the stress distribution within or around the dental implant. There was a very small effect of increasing the load and inclination angle. The stress in this thread design appears to be more on the apex of the implant.

Discussion

This study took in consideration the utilization of FT and MFT designs to TiG5 elastic modulous in relation to the cortical and cancellous bones' elastic modulous for stress distribution. Titanium Grade 5 (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 widely used in dental implants, 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 (14). This study compares the influence of FT and MFT designs (IBS®) on occlusal stress distribution with two widely used models (V-shaped and Buttress thread designs) employing TiG5 for the four used models.Various conducted research has shown that each thread design has its advantage regarding different aspects of dental implant success (9, 15, 16). This might be related to the different influence imposed by each design characteristics on different loading periods, osseointegration time and the quality of bone (11, 17, 18). However, to the best of the authors' knowledge, this is the first paper compared between Fin thread design (as a modification of square thread design) and other widely used dental implant thread designs. The study showed that both MFT and FT designs have smaller area of stress on the dental implant alone compared to V- shape and Buttress designs, although the areas of stress shown on all implant models remains within the lower scale of the colour zones (green to blue scale). This might be attributed to the thin thread, which impose minimum stress on the surrounding bone. It seems that the TiG5 strength enabled the designer to minimize the width of the thread to a minimum level taking the advantage of the differences between this Titanium and jaw bone's elastic modulous. It is agreed that maximum stress appears on cortical bone in both V- shape and Buttres designs and square thread design, although to less extent (19, 20). This has been attributed to the increase stress imposed by macro thread design on the cortical bone (21). In this study the FT model has shown some stress over the surrounding cortical bone when subjected to occlusal force overload on a more inclined implant. FT and MFT design showed the least stress in both implant models with or without the simulated bone structure during normal masticatory load. The percentage difference in elastic modulous between TiG5 and bone (1/10) has been utilized in longer and thinner thread design. The width of the thread in MFT and FT designs is around 1/10 the width of the bone between threads. This made the implant and the bone act as if they are a one unit. This has been found more evident in MFT. Despiste the inconclusive evidence from in vitro studies regarding dental implant geometry in terms of thread design, it has been suggested that thread depth increases functional bone-implant interface and the advantage of better mechanical stability and better primary stability (22, 23). It is, also more critical in terms of stress distribution than thread width (20). Furthermore, Zarei et al found that smaller thread implant with shorter pitch length can cause more bone stress (4). On the other hand, other researchers argued that smaller pitch might distribute force better, as it provides a higher surface area. Moreover, a shallower pitch might facilitate implant insertion in dense bone (24). However, larger pitch with deeper and thinner thread could offer the same advantage (3). This might explain the superiority of stress distribution in MFT and FT designs over V-shape and Buttress designs. This is more evident in the Modified Fin Thread design. It should be noted, however, that the stress remains within the minimum levels in all four models. Based on the result of this current study, Modified Fin Thread Design showed the best stress distribution in both normal and excessive occlusal load compared to other designs. The fin thread design characteristics allow the dissemination of forces to the surrounding bone, which might result in better implant-bone interface tolerance to occlusal load. The results of this study might overcome the shortage in the literature regarding the suitable criteria for square thread geometry (20)**.** This study showed that MFT design has almost similar stress distribution when the applied force was on 15° and 25° in normal and extreme static load. This might suggest that this design a suitable choice for dental implant design based on FEA. The limitation of this study is similar to other FEA studies, it assumes bone homogenously, elasticity, even muscle action, complete level of osseointegration and static occlusal load. However, it has been suggested that different degrees of osseointegration might not affect the level of stress distribution level (25). Furthermore, the affordability of such studies and their reasonable ability to predict the biomechanical environment within the oral cavity. Thus they can be useful as a useful guide for clinical studies (20).

Conclusions:

Stress distribution in the four dental implant models was within the acceptable level in vertical and angled implants. However, Modified Fin Thread designs showed minimum stress compared to V-shape, Buttress and Fin Thread dental implants. Modified Fin Thread Design of Ti G5 seems to be more suitable model in terms of stress distribution in normal and over occlusal load conditions. MFT designs need clinical studies to support this study findings on patients with long follow up periods.



a b

c d

Fig.(1): Implant designs and their dimensions, a: Fin Thread,b: V-shape, c: buttress, d: Modified Fin Thread.

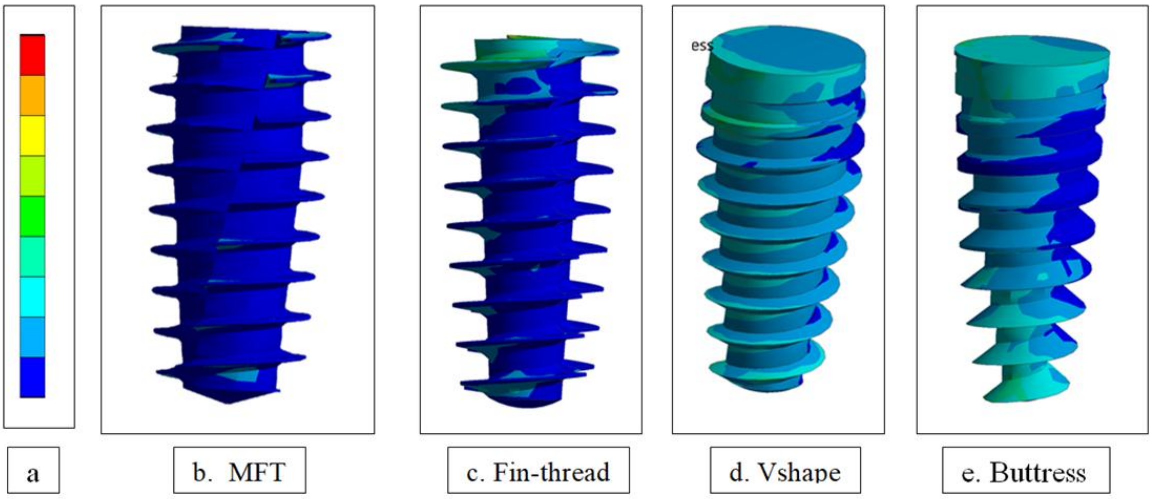


Fig.(2): Stress distribution in the four implant models of 200N (15 degrees) force.

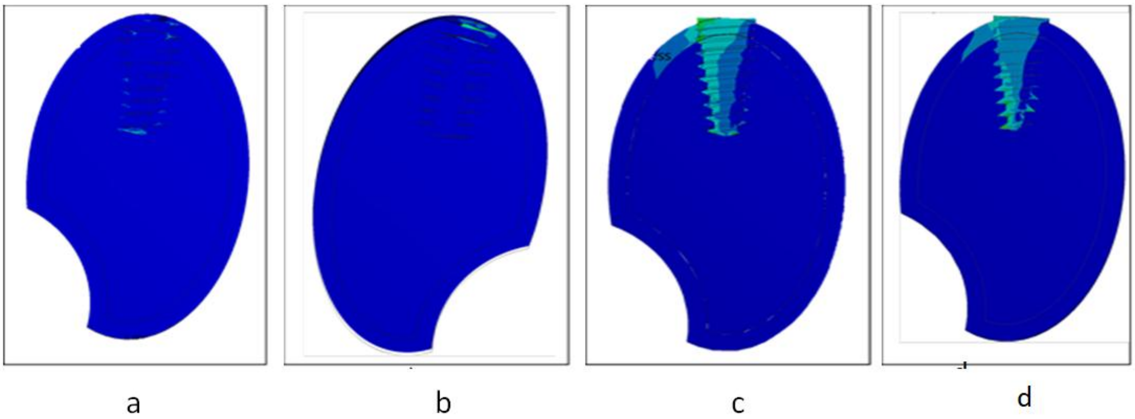


Fig.(3): Cross section of the implant-bone model showing stress distribution in normal masticatory forces. A: MFT, B: FT, C: V-shaped, D: Buttress

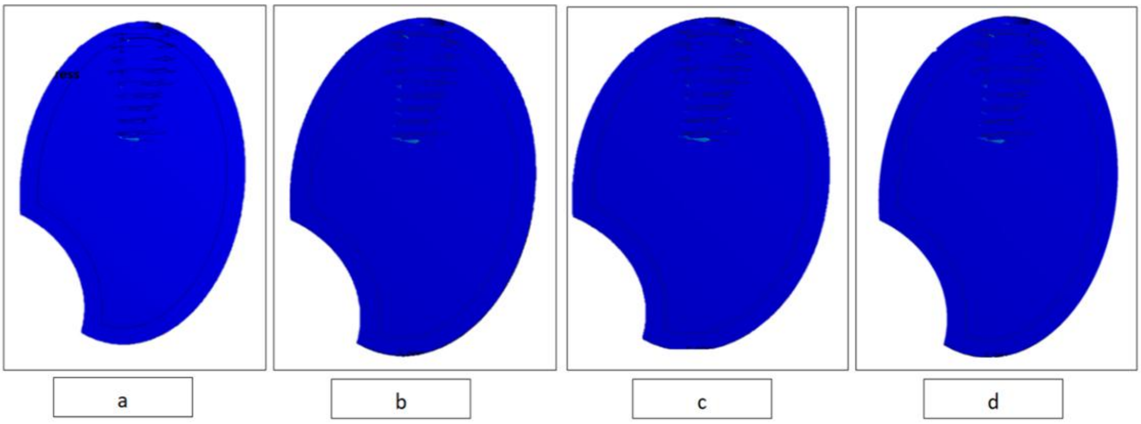


Fig.(4): A cross-section of Ansys implant-mandible model of the MFT model.

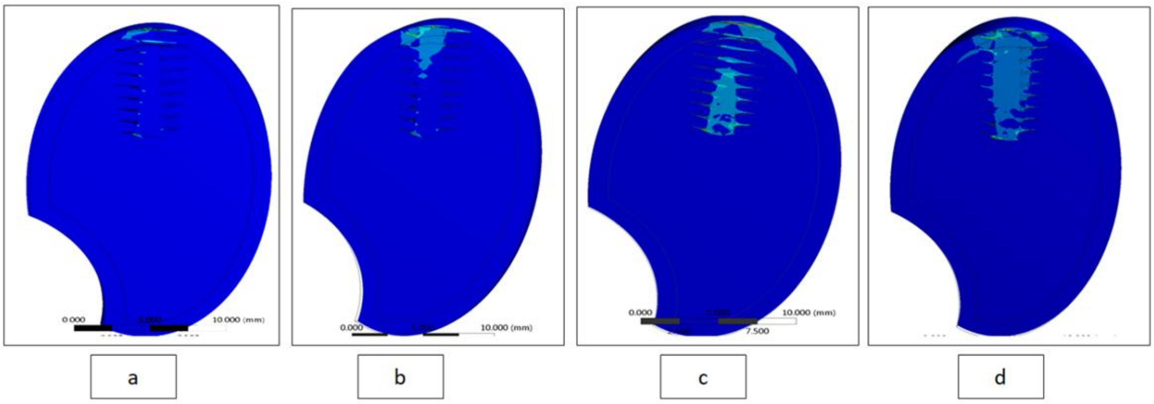


Fig.(5): A cross-section of Ansys implant-mandible model of the Fin-shape model.

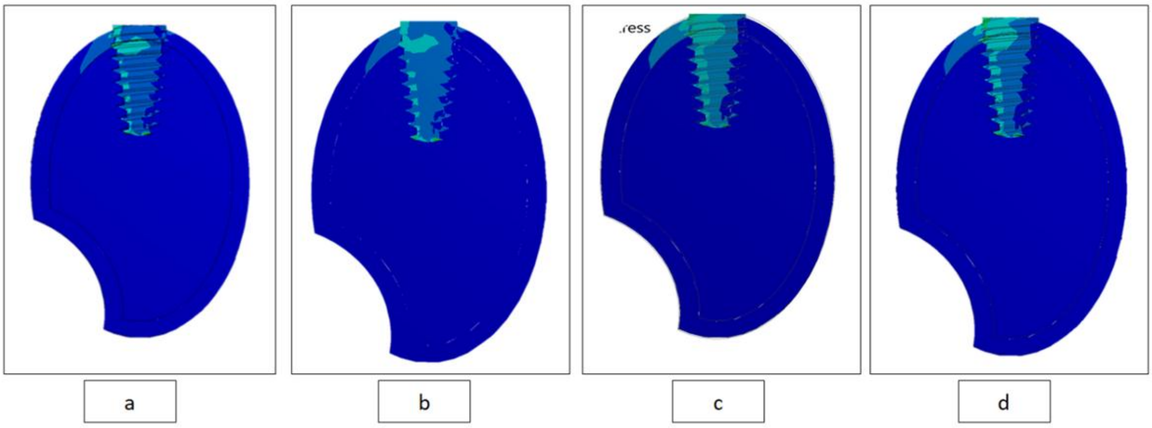


Fig.(6): A cross-section of Ansys implant-mandible model of the V-shape model.

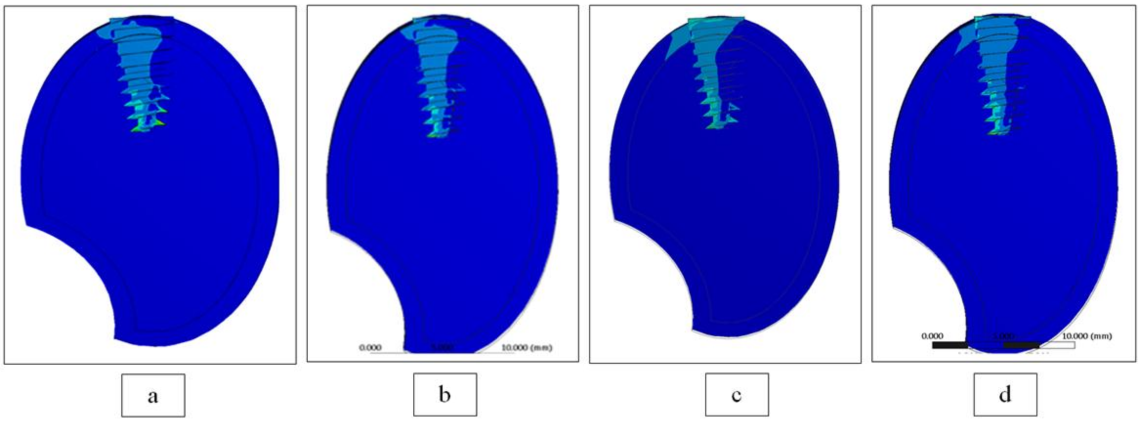


Fig.(7): A cross-section of Ansys implant-mandible model of the Buttress model.

Table (1): Mechanical properties of the implant models

Part	Poisson's ratio	Elastic modulus(M pa)
Implant	0.35	110000
Compact bone	0.3	1360
Trabecular bone	0.3	150

Table (2): lists the number of nodes and elements of the 4 implant models.

Model	No. of nodes	No. of elements
Fin shape	30.1901	101.057
V-shape	26.107	85.036
Buttress	39,135	93,529
Modified Fin Thread (MFT)	23,077	73,077

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