Mechanical Characterization of Dental Implant Due to Biomechanical Loading

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Abstract. The presence of dental implant has totally altered the force transfer from crown to the surrounding bone and the oral mechanical environment. This leads to abnormal bone remodelling. The high stiffness of the implant decreased the physiologic loading of the surrounding bone. This situation is described as stress shielding. Stress shielding is the common cause of failure in the fixture of dental implant. There are various implant geometries that have different impacts on the stress shielding effect. The aim of this study is to analyse the effects of implant length to stress shielding by using finite element method. 3 different lengths of dental implant models (6mm, 8mm and 10mm) are drawn using ANSYS APDL 2019 and a shear force of 30N is applied to the implant to examine the stress distribution of the implant and surrounding bone. Stress transfer parameter (STP) is computed and compared for each dental implant. This study found that by increasing the length of the dental implant, the maximum Von Mises stress decreases. The stress shielding effect also decreases when the length of dental implant increases.

1. Introduction

Scientists and researchers had realized that the important roles that stress and strains plays in the development and transformation of human bone. It is a valid theory that the adaption of human bone is depends on the changes in biomechanical environments. A well know German anatomist by the name of Julius Wolff has proven that there is a relationship between the distributions of bones and mechanical loading through physiological experiments. [1] From the point of view of biomechanics, biomechanical loading plays a crucial role in bone remodelling to a genuine shape. The presence of dental implant alters the force transfer from the crown to the surrounding bone. In this situation, abnormal bone remodelling may happen, whereby the mandible skeleton is self adapted to new forms.

In implant dentistry, screw loosening is a common condition that involved the abutment screw or the prosthesis screw. Failure of the screw or implant body are the consequences of screw loosening. There are several factors that affect the screw loosening such as the design of the screw, the preload of the screw, the connections of the screw and more. [2] Continuous screw loosening may eventually lead to fracture of the screw. Another factor that contributed to screw loosening is the stress shielding effect. Stress shielding will cause bone resorption and lastly leads to dental implant failure. Dental implant that placed into jawbone cause differences in stiffness between implant and bone. This causes more mastication forces experienced by the implant body than the surrounding bone and causes shield shielding.

Stress shielding effect analyses using stress transfer parameter (STP). This parameter is calculated using the effective stresses at implant threads and surrounding bone. [3] This approach is widely used
to analyse the stress shielding effect of orthopedic screws in femur bone while the study of applying this approach to dental is less. The objective of this study is to analyse the stress distribution and stress shielding effects of different dental implant length under shear loading onto dental implant using 2D FEA.

2. Experimental Procedure

2.1. Bone-implant model
2-D bone-implant model is idealized as a perpendicularly insertion of the implant into cortical bone region and trabecular bone region. 3 dental implant models with different length (6mm, 8mm and 10mm) are drawn in this study. The thickness of the cortical bone was 1.0 mm with underlying volume of trabecular bone. The average cortical bone thickness was taken as in the dentate mandible. The principle dimensions of this fixture modelled for this study is based on the design that are currently in the market. The minor and major diameter of the implant are 3.8 mm and 4.8 mm respectively and kept constant at all time. The diameter of top abutment is 6.5 mm. The pitch of the thread also kept constant at 1 mm. Figure 1 shows the bone-implant model generated.

![Bone-implant model](image)

Figure 1. Bone-implant model

2.2. Simulation set-up
The bone-implant model is generated using Mechanical APDL 2019. The type of titanium of the screw is Ti-6Al-4V. [4] It is the most commonly used titanium alloys because of its low density and excellent corrosion resistance. The dental implant was test under 30 N of shear force. Shear force is applied to the top of the implant to analyse of the effect of geometric and material screw parameters to their stress transfer to bone respectively. The contact between the bone and implant set as “bonded”. Same contact is applied to cortical and trabecular bone too. The bone model is fixed in X and Y direction in the simulations. The form of thread used for this model is standard V-thread. All materials were assumed as homogenous, isotopic and linear elastic. The simulations of this 2-D model were performed by using Mechanical APDL 2019. Table 1 show the material properties used for cortical bone, trabecular bone, and dental implant.
2.3. Stress Transfer Parameter (STP)

The level of stress shielding is measured as the ratio between the stress in the bone and its underlying stress in the thread. [5] The low STP will indicates poor stress transfer from the thread to the bone which is the sign of stress shielding. $\sigma_b$ is stress in the bone between the bottom of the abutment and the screw thread. Meanwhile $\sigma_t$ is stress in the midpoint of the first screw thread. $\sigma_{bi}$ is stress in the bone between consecutive screw thread and $\sigma_{tj} = $ Stress in the midpoint of consecutive screw thread. N is number of screw threads. This STP value indicates how much the design of the screw contribute to stress shielding effect.

$$STP, \alpha = \frac{\sigma_b}{\sigma_t}$$  

$$STP, \beta = \frac{\sum_{i=1}^{N} \sum_{j=1}^{2} \sigma_{bi}}{\sum_{i=1}^{N} \sum_{j=1}^{2} \sigma_{tj}}$$

$$STP\ TOTAL = STP\ \alpha + STP\ \beta$$

| Boundary condition   | Elastic Modulus (GPa) | Poisson’s ratio |
|----------------------|----------------------|-----------------|
| Cortical bone        | 13                   | 0.30            |
| Trabecular bone      | 1                    | 0.30            |
| Implant-abutment     | 115                  | 0.36            |

Figure 2. Parameters studies of stress shielding analysis [5]
3. Results & Discussion

Figure 3 shows the maximum Von Mises stress along the thread for different length of implants. All the line graphs were following the same trend which is the maximum Von Mises stress decreases along the length of the thread at the first half section. This is due to the stress decreases as it located further away from the concentrated force which is at the top of dental implant. However, there is an increase of stress occurs in the distal region. This is due to the nature of the fixed interface and pull-out resistance of the screw. The maximum stress of the 10mm length dental implant was the lowest compared to the other length of the dental implant models in any distances from the surface following by 8mm and 6mm. This trend showed that stress of 10mm dental implant model was distributed more evenly and more stable.

Dental implants are considered as short implants when its length is less than 10mm. [6] In this study, the length of the implant chosen are 6mm, 8mm and 10mm. The models are covering short implant and normal implant. Short implants are widely used in the location with limited alveolar bone height and width. [7] So, the effect of dental implant length in stress distribution around the implant and bone should be studied carefully. This study showed that the longer the length of the dental implant, the lower the maximum Von Mises stress found in the dental implant body. This finding is similar with the research of Tao Li. [8] In the study of Tao Li, the researcher found that the maximum Von Mises stress is influenced by implant length and this phenomena in more obvious in the trabecular region of the bone. The author also suggested that the length of the implant to be more than 12mm in poor bone quality region. Z. Xing [9] also studied the effect of implant length using FEA method. The researcher also found that the stress distribution in the bone around the dental implant was affected by the length of the implant. High maximum Von Mises stress will causes the dental implant to break during daily usage. So, lower maximum Von Mises stress will ensures the stability of the dental implant in future.

Table 2 shows the STP values against thread length/number of thread configuration. It can be clearly seen that the STP $\alpha$ rises gradually as the length and the number of thread configurations increases which also means the role play of the first thread increases. The STP $\alpha$ rises from 0.2173 to 0.2450 or with the increase of 12.75% when the length is increase from 6 mm to 8 mm. While increasing the length 10 mm, the STP $\alpha$ rises from 0.2450 to 0.2674 or with the increase of 9.14%. Meanwhile, STP $\beta$ increases from 0.8361 to 1.287 or with the increase of 53.92% when the length of the thread increased from 6 mm to 8 mm. When the length is further increase to 10 mm, the STP $\beta$ increases from 1.287 to 1.7643 or with the increase of 37.09%. It shows significant increase of STP $\beta$ when the length of the thread increases. The ratio of stress parameter for the consecutive thread shows the same sign as the first.
thread of the implant, which is increasing when the thread length and the number of thread configurations increase. This is due to the stress decreases constantly away from the concentration of force at the top of the abutment. Therefore, increasing the length /number of thread results in stresses being further away from the concentrated stress region and the higher average STP for the screw below the first thread.

Figure 3. Plot of maximum Von Mises stress against distance from surface. is noticed that the average tidal stream velocity in shallow water of Malaysia is approximately 1.0 m/s. This velocity is significantly low for the minimum speed required flow speed of HATT, but it is relevant for VATT deployment. There are areas experiencing high marine current flows which include in narrow straits, between islands, around headland and entrance to lochs, bays as well as large harbours – i.e. average tidal stream velocity is between 1.0 m/s to 1.5 m/s with high potential of tidal stream energy.

Table 2. Stress transfer parameter (STP) values for the thread

| Thread length, Number of thread configurations | 6 mm, 5 threads | 8 mm, 7 threads | 10 mm, 9 threads |
|-----------------------------------------------|----------------|----------------|-----------------|
| STP, α                                        | 0.2173         | 0.2450         | 0.2674          |
| STP, β                                        | 0.8361         | 1.2870         | 1.7643          |
| STP Total                                     | 1.0534         | 1.5320         | 2.0317          |

Overall, implant with thread length of 10 mm has the highest total STP value compared to implants with 6 mm and 8 mm thread length. It can be shown that the trend of the total STP is increasing when the thread length increases. This also means that there is better stress transfer between the screw threads and the bone when the thread length and the number of thread configuration increase. Thus, the stress shielding effect declines when the length of the thread rises. The total STP increase by approximately 45.43% when the thread length increases from 6 mm to 8 mm while the total STP increase by approximately 32.62% when the thread length increases from 8 mm to 10 mm. It shows lesser escalation when the thread length increase from 8mm to 10mm

STP is widely used to describe the stress shielding effect of implant and bone surrounding in hip bone and femur bone. It is hard to find researches that using this approach to analyse the stress shielding effect in dental implant. From this study, the STP values found to be affected by the length of the dental implant. This result is similar with the research done by Kristina Haase [10]. In Kristina Haase’s research, researcher found that the stress transfer increases when the length of implant increases. This effect is then depleted slowly when the diameter of the implant from 4mm to 6mm. Similar result also found in the study of Gholamreza Rouhi. [3] Researcher ran a 2D simulation with ANSYS 12.0.1 to investigate the effects of engineering designs of bone screws on stress shielding effect. The results also showed that increasing the number of threads causes the stress shielding effect decreases. Longer implant provides more continuous stress transfer at implant-bone interface

4. Conclusion

Von Mises stresses are simulated on every thread of the implant and the surrounding bone to compute the stress transfer parameter (STP). With the increase in length of dental implant, maximum Von Mises stress decreased and the stress distribution around bone and implant more even. The total STP is
increasing as the thread length/number of thread configurations is increasing. This showed that the stress shielding effect decreases when the length of dental implant increases.

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