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Effect of Dental Implant Micro-thread Designs on Stress Distribution In Bone-Implant Interface

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ABSTRACT

Dental implants have been used in replacing broken or damaged teeth. There are failures after the operation was done due to lack of primary stability. Through improving the design of the dental implant, primary stability can be achieved. The aim of the study is to analyse the stress distribution at bone-implant interface due to different micro-thread designs. Five types of two-dimension micro-thread shapes dental implant embedded in bone cube are modeled in ANSYS APDL R3. The micro-thread shapes are Straight, Square, V-shaped, Buttress and Reverse Buttress. The models are meshed using element Quad 8-node 183. 106.066N of horizontal force and vertical force are applied on each model to find out the stress distribution pattern and peak Von Mises stress. The study found that micro-thread shapes changed the stress distribution on implant and bone. The peak Von Mises stress was located at the first micro-thread. Cortical bone took large portion of stress compared to cancellous bone. Square micro-thread has the best stress distribution pattern.

Keywords: Dental implant; micro-thread; thread; finite element analysis; stress distribution

INTRODUCTION

Due to esthetical and high success rates, dental implants have been used in replacing lost or damaged teeth through osseointegration (Degerliyurt et al. 2010; Ovesy et al. 2019; Croitoru & Popovici 2017; Bicudo et al. 2016; Dhatrak et al. 2018). These dental implants are made by gold and slowly being replaced by biocompatible titanium due to its strong bending fracture resistance (Gupta et al. 2015).

There are many factors that will affect the success rate for the dental implant and one of them is primary stability. Dental implant experiences various amounts of forces during occlusion and the forces will form stress distribution around implant-bone interfaces. Therefore, primary stability must be achieved for a good start and followed by secondary stability. Primary stability can be achieved by the compression of the surrounding bone with the implant after the implantation while secondary stability can be achieved by the bone remodeling and regeneration during initial healing (Bicudo et al. 2016). If primary stability is not achieved, the dental implant will experience micro-movement and break eventually.

However, there are also some cases of dental implant failure each year because of low primary stability. The key factors that will affect the primary stability are macro-design and micro-design of the dental implant. Macro-design of the dental implant included length, diameter, pitch and thread shape while micro-design is the collar design and surface design for the dental implant (de Carvalho et al. 2018; M. L. da C. Valente et al. 2017). These marco and micro-designs of the dental implant will affect the stress distribution at bone-implant interface (De Andrade & Carvalho 2017). Overstressing on the bone will leads to dying of bone cell which is bone resorption and lastly dental implant loosening.

Due to space limitation in mandibular and maxillary bone, small diameter dental implant was being used to replace teeth. Dental implants that have diameter less than 3.5mm are considered as small diameter implant while standard diameter ranging from 3.75 to 4.1mm (Bordin et al. 2017). A small diameter implant has less contact surface with bone so high stress will be more concentrated in certain point (Wu et al. 2016; Ogle 2015; Pellizzer et al. 2018).

To further increase the stability of dental implants, micro-design such as surface properties of dental implants are being studied by researchers. Surface treatments such as machining, acid etching, sandblasting and anodizing are being applied on dental implants and tested. Carlos Nelson Elias (2008) found that different surface treatments caused the changes in surface roughness and wettability of dental implants. These properties changed the removal torque of dental implants and bone growth. Conrado Aparicio (2011) also found the importance of surface treatment toward the stability of dental implants. Conrado Aparicio tested a few types of surface treatments and proposed a new surface treatment to accelerated bone tissue regeneration.

There are many researches that analyzed the effects of different macro-design of dental implant while less researchers were found regarding the effects of the micro-design of the dental implant. The objective of the study is to analyze the stress distribution of 5 different micro-thread designs with the same thread design under vertical and horizontal loading in bone model using 2D FEA.

METHODOLOGY

All models were created using ANSYS APDL R3 for numerical analysis. 5 different micro-threads with dimensions of 10mm length of implant body and 4mm diameter titanium dental implants model were constructed. The shapes of micro-threads included were Straight micro-thread (no micro-thread), Square micro-thread, V shaped micro-thread, Buttress micro-thread and Reverse Buttress micro-thread while the pitch and depth for micro-thread were 0.2mm. The micro-threads were at the first 2mm of the dental implant body while the rest of the body was 0.8mm pitch and 0.4mm depth V-shaped thread as a constant for 5 dental implant model. The dental implants were embedded in a 25mm x 50mm bone model with 2mm thickness of cortical bone. The models then undergo finite element analysis in the same software. All materials were assumed as homogenous, isotropic and linear elastic. A 106.066N of vertical force and 106.066N of horizontal force acted at the middle of the head of the dental implant models to simulate 150N of chewing force acted 45° to the dental implant (Macedo et al. 2017). The contact of bone-implant interface set as 'bonded'. The same 'bonded' contact also applied at cortical bone and cancellous bone connection. All sides of the bone model were fixed in X and Y directions. The force will only affect small area around dental implant-bone interface so by fixing the large bone model will not affect the final result.

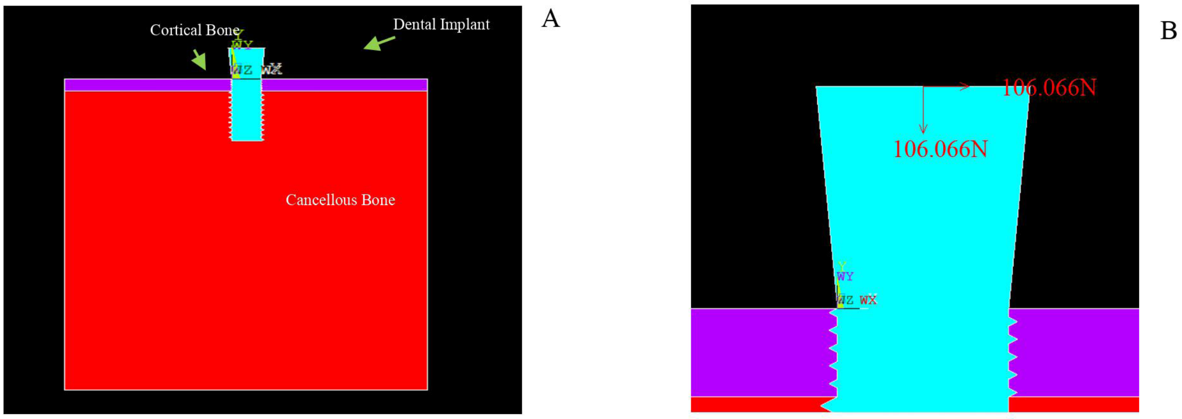

FIGURE 1. A: Dental implant and bone model. B: Types of load applied

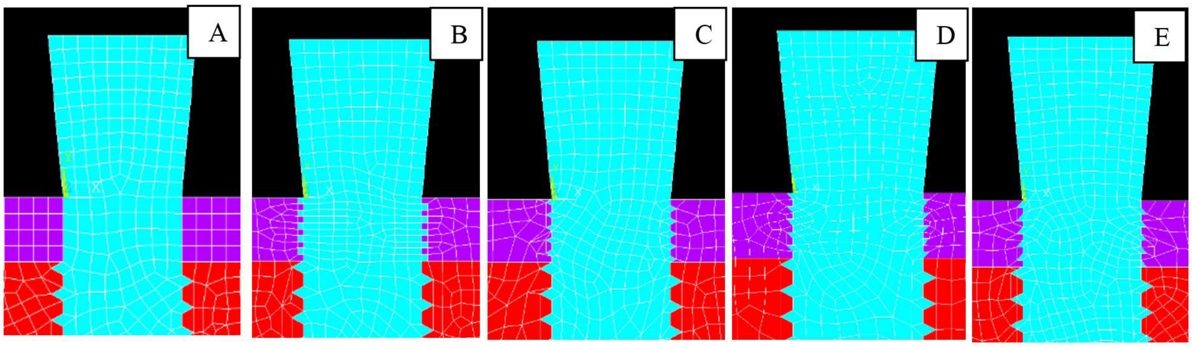

FIGURE 2. Five types of micro-thread designs A: Straight B: Square C: V-shaped D: Buttress E: Reverse Buttress

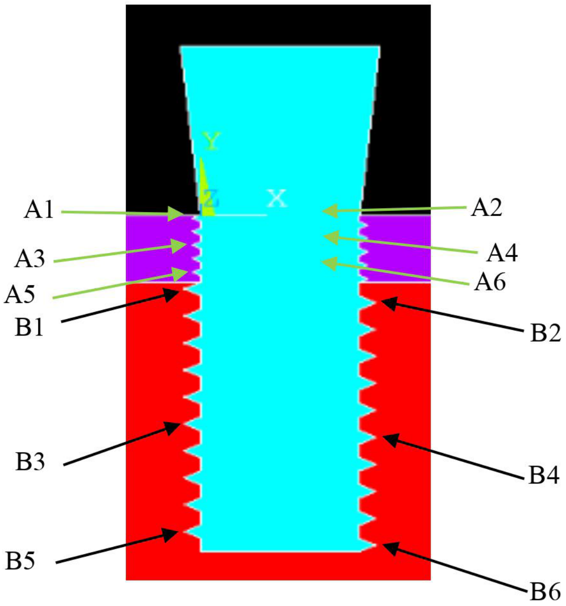

FIGURE 3. Point selected for analysis

The Young Modulus and the Poisson's ratio of the materials were shown at the table below (Coelho Goiato et al. 2014; Chatterjee et al. 2019).

TABLE 1. Material properties

Material	Young's Modulus E (MPa)	Poisson's ratio (v)
Titanium	110000	0.33
Cortical Bone	14700	0.3
Cancellous Bone	1470	0.3

The element type selected was Quad 8 node 183 and the numbers of elements and nodes for each model were shown in the table below.

TABLE 2. Number of nodes and element for different micro-thread shape

Model	Elements	Nodes
Smooth	10191	30982
Square	10299	31304
V-shaped	10238	31115
Buttress	9825	30067
Reverse buttress	10492	31869

RESULT

Results were evaluated at the tips of the micro-threads and threads for all dental implant models at bone-implant interface. As smooth micro-thread (no micro-thread) didn't contain any tips at micro-thread section, the von Mises stress of 6 points are selected from the cortical bone sections as reference points to compare with other micro-thread designs.

Figure 4 showed the stress distribution of different micro-thread design implants. The von Mises stress was visualized on the model from dark blue (least stress) to red (highest stress). The peak von Mises stress was located at the middle of the head of the dental implants for each model where the forces were applied on for all micro-thread design implants model. However, the present study was only concerned at the implant-bone interface and the peak von Mises stress found at the areas excluded from stated were ignored. Therefore, the peak von Mises stress that mentioned below only referred to the implant-bone interface for each dental implant model.

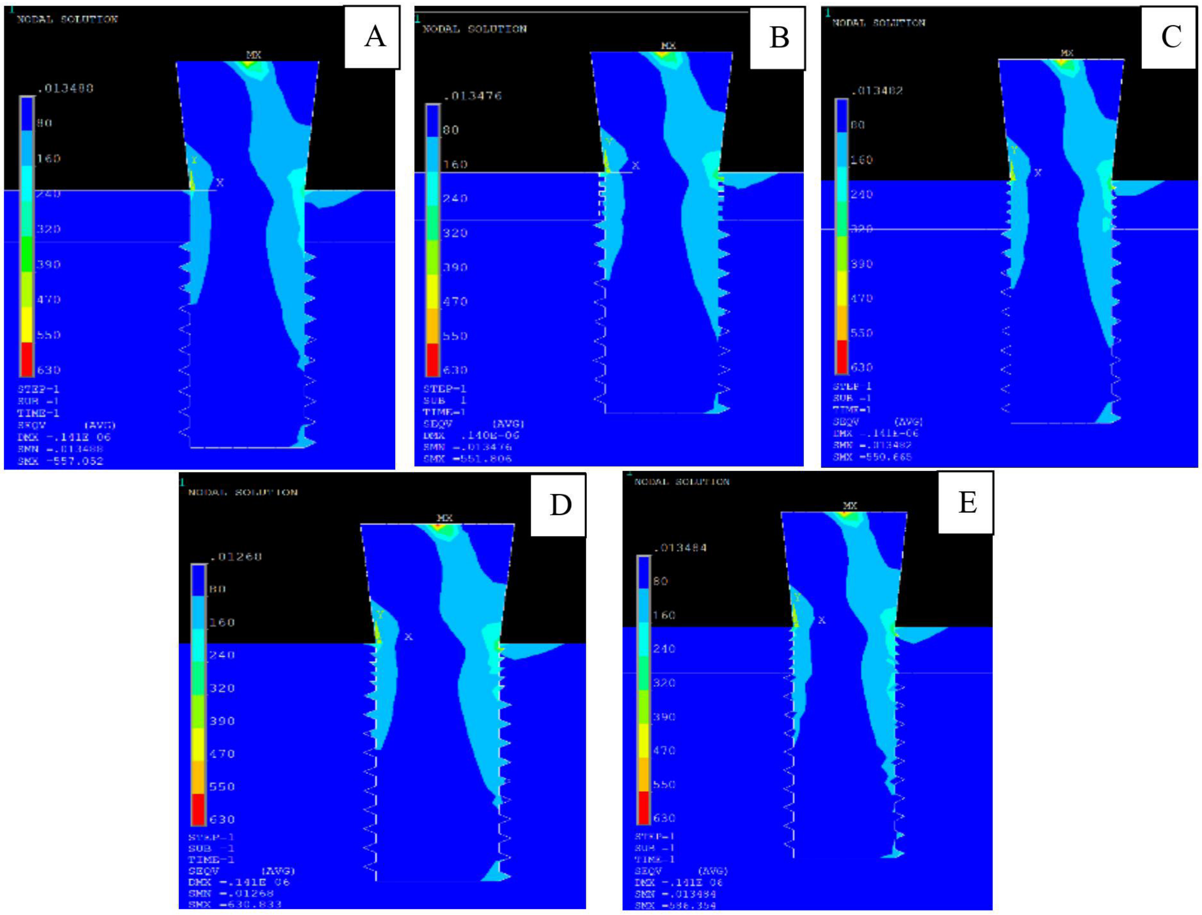

FIGURE 4. Stress distribution for 5 types of micro-thread shape. A) Straight. B) Square. C) V-shaped. D) Buttress. E) Reverse Buttress

For cortical bone section, in screw interface, the peak von Mises stress are located at the first micro-thread for every dental implant model which at point A2. At point A2, V-shaped micro-thread implant model produced the highest von Mises stress which is 502MPa while straight micro-thread produced the least von Mises stress which is 290MPa. The same situation was found at the bone interface. The highest von Mises stress was also located at point A2 while among all micro-thread designs, the highest was Straight micro-thread which is 237MPa.

The lowest von Mises stress within cortical bone for screw interface was found at point A6 of Square micro-thread design. Square micro-thread also generated the lowest von Mises stress for point A3, A4, A5 and A6 while the highest for all these points was Straight micro-thread design. On bone interface, the lowest von Mises stress was found on point A5 which is 14MPa.

For cancellous bone section of screw interface, among the highest von Mises stress produced for every model, reverse buttress micro-thread model was the highest which was 189MPa at point B6 while the lowest was the reverse buttress micro-thread which was 29MPa. The differences of von Mises stress between 5 micro-thread designs were not significant since the stress experienced by the bone was small compared to the screw body.

Although smooth micro-thread had the lowest peak von Mises stress compared to other model in both cortical and cancellous bone section, the von Mises stress along the implant body also higher compare other models. Due to absence of micro-thread along the cortical bone, the von Mises stress decreased gradually along the implant body while the values for the von Mises stress on each point was higher compared to other models. On the other hands, square micro-thread generated the lowest von Mises stress along the implant body compared to other models. This is because the contact area on the interface of implant body and bone model were highest among all models. Therefore, the stress can be more evenly distributed along the implant body. Figure 5 below showed von Mises stress for all points at implant and bone interfaces.

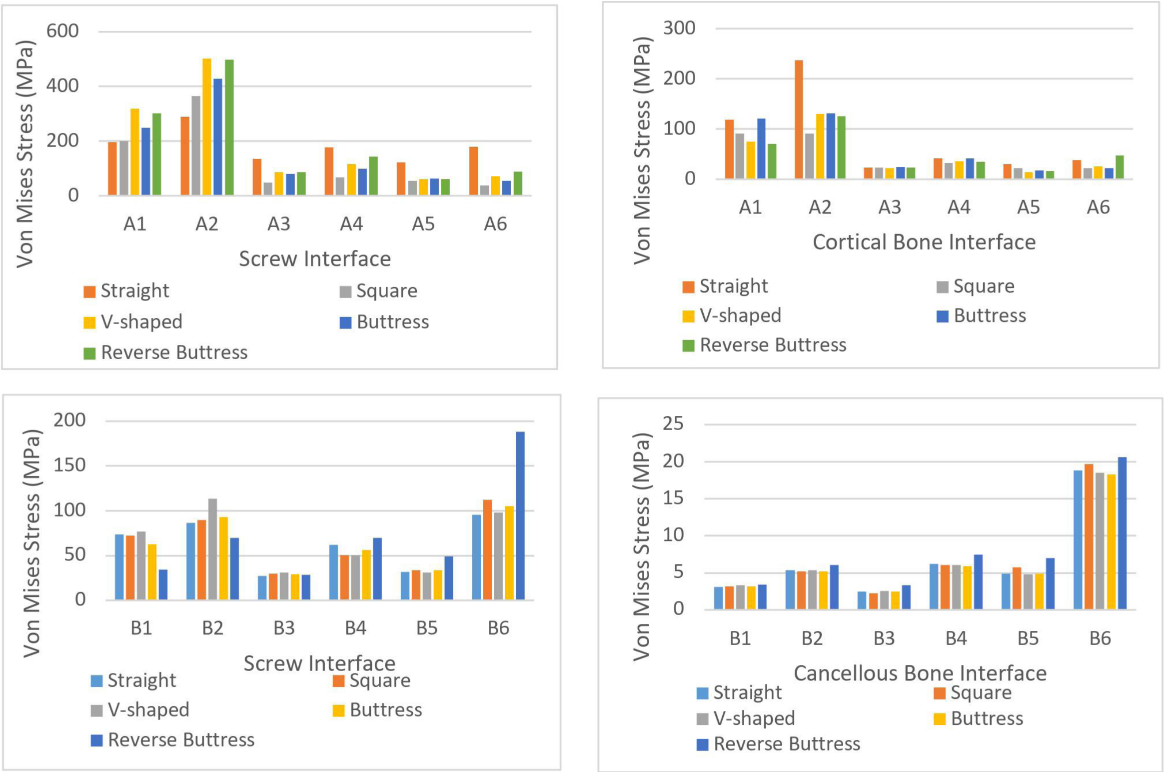

FIGURE 5. Von Mises stress of screw and bone interface for cortical bone and cancellous bone; A) Screw interface at cortical bone. B) Bone interface at cortical bone. C) Screw interface at cancellous bone. D) Bone interface at cancellous bone

DISCUSSION

Finite Element Analysis (FEA) is a strong and effective tool to simulate complex engineering problem and widely being accepted by researchers in predicting mechanical behavior of dental implants for different boundary condition. FEA also saves times and costs compared to traditional experiments (Yamanishi et al. 2012). So, by using FEA, the stress distribution can be found and visualized in this study.

The peak von Mises stress were found at the first thread of the right side of every implant model. This result is similar with some researchers (Duan et al. 2018; Hernandez-Rodriguez et al. 2015; Santiago Junior et al. 2013; Lofaj et al. 2015). In this study, the horizontal force applied on models acted to the right side of the model and caused the stress concentrated at the first thread of the right side of the models. The micro-thread sections for each model contributed higher percentage of the total stress generated compared to the thread section of every models. This showed that the existence of micro-threads affected the stress distribution on the dental implants.

Dental implant design played a significant role in implant stability and osseointegration process [10]. Michele Cali (2018) found that thread shape does not significantly influence the stress distribution. In the research of Pankaj Dhatrak (2018), the stress distribution of different thread design was found by using FEA and experiment. Suchat Aumnakmanee (2018) ran FEA of 4 different thread designs under compressive forces and sheer force. In their studies, they both found that reverse buttress are the worst for thread design while V-shaped was the best profile. Thread geometry increases the contact area between bone and dental implant for better stress distribution (Ogle 2015). With the increase in contact area, micro-movement can be reduced and stability of the implant can be improved (Narendrakumar et al. 2018).

Micro-thread design on dental implant can be found on recent dental implant. It can utilizes the cortical bone in distributing stress and increasing bone-implant contact area for better osseointegration (Javed & Romanos 2010; Azcarate-velázquez et al. 2019). More contact areas between dental implant and bone can stimulate more bone growth and increase stability (Y. Li et al. 2019). Wenzhi Niu (2017) found that the present of micro-thread can significantly reduce bone loss around the dental implant. It also can reduce the peak shear stress. These results were similar with the study of Zhi Heng Jin (2019) who studied the effect of micro-thread through FEA. These results are similar to the author's study. In author's study, the effect of micro-thread on stress distribution found to be significant. Different micro-thread shape generated different peak von Mises stress and stress distribution pattern. The stress distribution pattern was affected the most on the cortical bone part and less significant in cancellous bone because cortical bone distributed large portion of the stress compared to cancellous bone.

Most of the researchers analyzed the effect of macro-design such as thread design, diameter and connections. Only a few researchers or none study about the effect of micro-thread designs on stress distribution at bone-implant interface. To the best of author's knowledge, no recent study was found that related to the micro-thread designs and their effects at bone-implant interface. This study can be a fundamental understanding on the effect of micro-thread design.

CONCLUSION

The stress distribution analysis was performed on 5 different micro-thread designs dental implant embedded under bone model. With the results from the simulations, following conclusions can be drawn.

1. Micro-thread designs will affect the stress distributions along the implant body.
2. Maximum von Mises stress for different micro-thread profiles was found at the first threads of the dental implant.
3. Square micro-thread generated the least von Mises stress along the implant body compared to other micro-thread designs. Therefore, Square micro-thread was recommended to apply on dental implant.

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DECLARATION OF COMPETING INTEREST

None

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