Stress Shielding Prediction of Unicortical and Bicortical Screws: A Finite Element Analysis

*Anis Amira Mat Zuki, Fauziah Mat, Khairul Salleh Basaruddin**,*
Ruslizam Daud, Masniezam Ahmad
Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Arau, Perlis, MALAYSIA
**khsalleh@unimap.edu.my*

Fauzan Djamaluddin
Department of Mechanical Engineering, Faculty of Engineering, Hasanuddin University, Gowa, INDONESIA

ABSTRACT

The stability in an implant fixation plays a vital role in ensuring proper formation and remodelling process of the fractured bone. Failure in implant fixation is commonly associated with short- and long-term instability of the bone-implant interface. The bone-implant interaction creates a complicated mechanical interplay that might influence the stress distribution and hence the biomechanical performance stability of the implant fixation. Furthermore, implant screw parameters namely thread size, geometrical design and material properties become additional factors that affect the bone-implant interaction. The purpose of this study was to investigate the effect of unicortical and bicortical screws' parameters on the screw-bone interaction mechanism. To evaluate the stress transfers between screw and bone, the stress parameters namely stress transfer parameters (STP) was employed. A two-dimensional (2D) finite element model of full treaded screw was simulated while varying the parameters of the screw: two types of material (stainless steel A316 and titanium alloy Ti-6Al-4V), screw length and screw pitch. It was found that the lower in elastic modulus results to the higher stress transfer between implant-bone interface. As the titanium have lower elastic modulus, it gave higher values of STP which help to transmit and distribute stress better compared to the stainless steel. While the effect of varying screw pitch between two types of screws shows that STPs values of fully threaded bicortical screws shows significant result for finer pitch size that may advancing bone remodelling process at the early stage.

ISSN 1823-5514, eISSN 2550-164X
© 2023 College of Engineering,
Universiti Teknologi MARA (UiTM), Malaysia.
https://doi.org/10.24191/jmeche.v20i2.22052

Received for review: 2022-06-23
Accepted for publication: 2023-02-27
Published: 2023-04-15

Keywords: *Unicortical; Bicortical; Implant Fixation; Stress Transfer*

Introduction

Fracture fixation device such as internal fixation is one of the leading ways that surgeons used to treat the fractures of the femur bone. The purpose of the fixation implant is to restore the bones' structure and assist in the stabilization of the fractured bone in accordance with the types of fractures while bone regenerates. Failure of implant fixation usually occurs due to short-term and long-term instability of the bone-implant interface. Implant material properties [1]-[2] implant geometry [3]-[4] and configuration [5]-[7] external loading [8], and interfacial bonding [9] are among the factors that affect the stability of the implant-bone interface.

In order to enhance secondary bone healing and prevent bone resorption, a suitable fixation that generates the sufficient amount of strain in the newly formed bone tissue is vital to allow a controlled interfragmentary movements along the bone's axial direction [10]. However, when implant fixations were introduced into bone, the implant is stiffer than the surrounding bone which consequently undergoes changes in shape and stiffness. This affects the mechanical environment in the bone which is supposed to be an active participant of the fixation process. Proper bone formation and remodelling process would not occur without suitable implant type and placement technique used for improving mechanical stability, thus causing the implant placement to fail.

For an internal fixation screws system, there are two types of screws: (1) bicortical, and (2) unicortical. Bicortical screw is known as a screw-type that can penetrate both sides of cortical bone cross section. Meanwhile, unicortical can only penetrate through one side of cortical bone cross section. Screws can be considered as the gold standard for internal fracture fixation [11] as it is responsible for retaining the stability of the implant [12]. Bone-implant screw interface plays a significant role in providing fixation stability on the formation of bone. To transmit stress between the implant and the tissue around the bone, the screw parameters have a major influence in determining the primary implant stability. Screw material, core diameter, outer diameter, thread depth, pitch, length, and number of threads engage to the bone are important characteristics that could affect the construct strength.

The result from Ros et al. [13] shows that loosening rate of the Wagner Standard Cup was significantly related to a lack of bone coverage of the acetabular cup as result from a poor design that delay osseointegration since it is crucial to maximise the contact area between the implant and the bone as the mechanical stability of the acetabular component depends on proper implant positioning. Other than that, thread depth and width of the screw could also clinically influence implant insertion and surface area; however, thread depth had a more significant impact on the effective stress distribution then thread width [3], [13]. The previous studies show that continuous stress transfer between bone-screw interaction can be enhanced by increasing the number of screw thread and thread diameter and reduce the core diameter [14]-[15]. Moreover, the thread depth and width also influenced the implant insertion and surface area where it has significant effect on the stress distribution [3]. The result from previous study related to implant dentistry shows that von Mises stresses are inversely proportional to thread depth which will result in maximizing the necessary area for osseointegration and providing good initial stability [16]. Contact surface area at the bone-screw interface also can be increased by increasing the pitch of the screw thus increasing the number of threads per inch. Increasing the pitch increase the number of threads engaged in bone thus increasing the amount of bone chips and debris engaged between the threads [17] .

Santos et al. [18] highlight the importance of screw length by using bicortical and unicortical to determine the stability of the implant fixation with a different type of plate system in vitro study. According to the previous in-vitro study [5], the bicortical has greater stability where it can make a connection between plate and bone interface with the distal cortex of the bone. However, the bicortical are more invasive than unicortical screws because according to the Wu et al. [19], the unicortical fixation is a surgically less complex operation, can theoretically cause less damage to surrounding soft tissues and avoids the complications associated with incorrect screws size. While the result from an experiment demonstrated that the bicortical fixation resulted in higher pull-out strengths for 40 cadaveric human proximal phalanges than unicortical, but recommended unicortical fixation for diaphyseal fractures, as the pull-out strength of unicortical screws at the mid-diaphysis was significantly higher than bicortical screws [20]. Despite the wealth of literature available in the field, there still lack of study regarding transmission of stress and strain between an implanted screw and the surrounding bone as previous research only focused on in-vitro study.

Fully threaded screws commonly used as an internal fixation compared to partially threaded screws to produce optimal compression and absolute stability. Meanwhile, Downey et al. [15] compared performant of partially and fully threaded lag screw and suggest that fully threaded lag screw perform better than partially threaded lag screw in shear and superior in the initial stiffness and failure strength. Sayyed et al. [21] stated that fully threaded cancellous bone screw with higher numbers of threads may have better purchase in the porous metaphyseal bone of distal tibia and increase the pull-out strength thereby leading to better outcomes, thus become optimal internal fixation device for use in elder patients with complications. Compression experimental results showed that fully threaded screws demonstrated significant improvement in stability of fixation of a medial malleolar fracture compared to partially threaded isometric cancellous screws [22]. As such, multiple published data have studied the strength, flexibility, and maximum insertion torque of partially threaded cancellous screws and dental implant. But the bone-screw interaction of fully threaded bicortical and unicortical in internal fixation application are not well defined. Therefore, it remains questionable whether the fully threaded unicortical or the bicortical is more practical for patients in terms of stability and fewer surgical complications.

Other than geometry, the material of the implant also plays a vital role in the stability of the bone-implant interaction. According to the Fouda et al. [17], an implant with carbon hydroxyapatite (C/HA) contribute to the greatest stress along with the fracture site and increase stress 16% than stainless steel implant. Defective material will not only result to early fatigue and breakage but contribute to the increased corrosion and increase tissue reaction. However, most of the implant from available manufacturing are made from stainless steel and titanium.

The stress distribution between bone-implant can be measured by mechanical stimuli that develops around it to stabilize the interaction between bone-implant ant thus ensuing bone remodelling process. Various mechanical measures have been used to evaluate the bone remodelling process such as stress transfer parameters (STP) and strain energy density transfer parameter (SEDTP). One example of study used STP to determine the effect of different types of half pins on STP during osseointegration [23] while others used to evaluate the effect of thread profile on stress transfer in a magnesium fixation [11] and material [24]. While Chun-Li Lin [25] used SED to investigate the interactions for implant placement of dental implant. Therefore, by understanding the mechanic interaction between implant and bone of screws contact for improving its stability may promoting better osseointegration process.

These situations demonstrate that at the bone-implant interaction, it experienced stress shielding response where normal mechanical stress of bones reduced, resulting in bone loss in the region of implants [26]. Even though loosening of the screw has been well reported in the literature, there are still lacking regarding the bone-screw interaction involving the reduction of stress shielding and bone remodelling of fully threaded cortical screw as most of previous study focused on partial thread screw and dental implant. In vivo, a loss of compression between implanted screws and bone is unavoidable, especially with lag screws.

Implants should be constructed in such a way that the stress shielding effect is minimized. Without an appropriate implant design that increases primary reliability, the necessary bone development and remodelling mechanism will not be triggered, and implant placement may fail. Analysis of stress distribution can provide information on the consequences of implant characteristics. This is important for effective bone healing and avoids unnecessary secondary or revision surgery. Therefore, the aim of this study is to determine the effects of fully threaded cortical screw parameters such as material, pitch size and screw length on stress transfer parameters in order to improve implant stability and thus promoting the better formation of a direct interface between bone and implant.

Methods

The risk of loosening can be reduced by optimizing screw geometric and material features in a way that produces and distributes stress equally between bone and around screw threads. In this study, the effect of screw parameter on stress transfer was simulated using a 2-D finite element model. An axisymmetric screw-bone model was generated using ANSYS APDL to observe stress transfer of the fully threaded cortical screw configurations for the varied parameter such as material, size of pitch and length of screws as shown in Table 1. Two materials have been used in this study which are stainless steel A316 and titanium Ti-6Al-4V ELI. The effect of pitch, the size of screws pitch was varied with 0.50, 1.00, 1.25, 1.50, 1.75, and 2 mm. The thread profile, major and minor diameter of the screw were kept constant. The screw length was varied from 6 mm to 27 mm to investigate the effect of length on stress transfer between the implant and the bone. The unicortical (U) screw refers to the shorter screw while the longest screw was set as a bicortical (B) screw as unicortical fixation only engaging the near cortical bone to hold the reduction. On the other hand, the bicortical fixation always engage with both the near and far cortical bones [19]. Rectangular shape of screw thread was used in this study as it shown to give a uniform surface stress distribution [26]-[27].

Table 1: Parameters of cortical screw

Material properties		Pitch size (mm)	Thread profile	Minor diameter (mm)	Major diameter (mm)	Screw length (mm)
Stainless Steel A316 [29]: E=190GPa V=0.31	Titanium Ti-6Al-4V ELI[28]: E=110GPa v=0.31	0.5-2	Rectangular	0.5	1.0	6.00-27.00

The 2D model was constructed by 3 mm homogeneous cortical bone layers at upper and bottom of cancellous bone and 20 mm cancellous bone region as listed in Table 2. The model was considered as linear elastic and isotropic for simplification purposes to allow the model to focus on the influence of the screw parameter [11].

Table 2: Material properties of bone

Bone	Material properties	Thickness (mm)
Cortical	E=17 GPa, v=0.33	3 [12]
Cancellous	E=1G Pa, v=0.35 [30]	20 [12]

The placement and the design of screw were mimic the bicortical and unicortical screws as shown in Figure 1. The axisymmetric screw-bone displacement was constrained in x-axis direction but allowed in y-axis direction. Fixed boundary condition was applied to the one side of the model (right) and the bottom. The contact between screw and bone are assumed to be bounded to simulate a perfect contact between screw and bone [11]. It was also considered that the contact between cortical and cancellous bone was bounded. A vertical load of 80 N was subjected in the y-direction on the top surface of the screw's head to simulate pull out process [14].

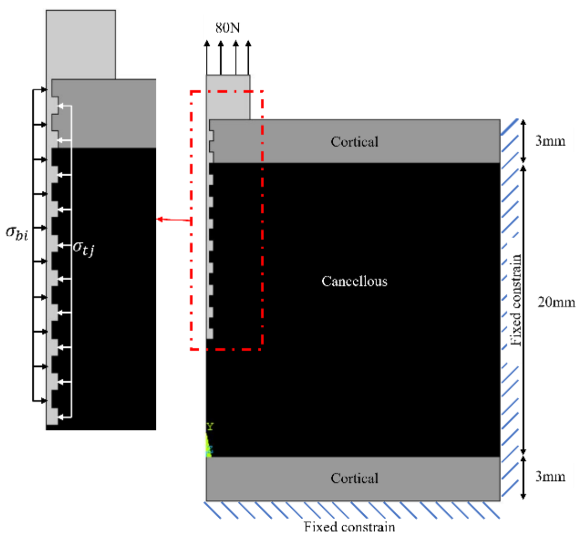


Figure 1: 2D of screw–bone interaction model

The convergence test was used to determine the optimum mesh size of the model for accurate calculation with reasonable computational time. Figure 2 shows the maximum equivalent stress obtained from the simulation at different number of elements. The result shows that the maximum of equivalent stress rapidly increases from 13426 to 84133 of element numbers until it steadily increases to 148783 of element numbers. From there, the increment of maximum equivalent stress of the element number from 84133 to

148783 was small compared to others number of elements. Thus, 84133 number of elements was used to simulate in screw-bone interaction models effective number for meshing due to small increment about 1% to the following element number. The number of element and element type were configured at 9678 and plane 183 solid elements with 8-node quadrilateral, respectively.

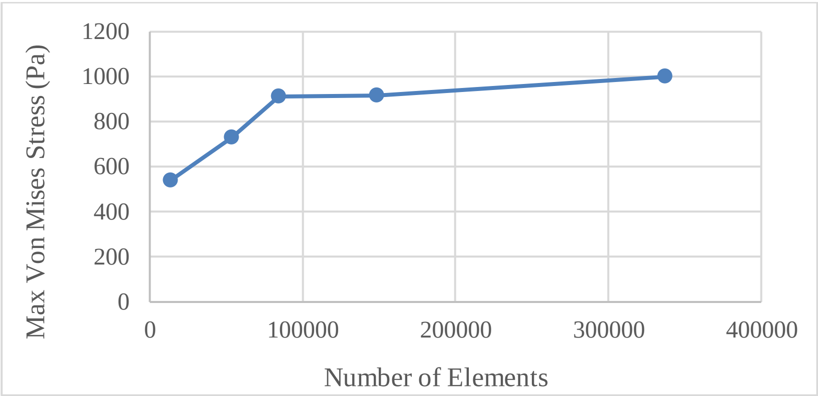


Figure 2: The convergence test between number of element and maximum equivalent stress with element meshing model

To characterize this stress transfer, stress transfer parameters (STP) was applied to evaluate the load transfer between the bone and the screw fixation. STP is defined as a ratio of von Mises stress transferred to bone, σ_b versus the stress in the adjacent screw thread, σ_t [30]. The STP of mechanical stimuli between screw and bone is computed after the simulation using following equations [31]:

$$\mathrm{STP} = \sum_{i=j=N}^{i=j=N} \frac{\sigma_{bi}}{\sigma_{tj}} \tag{1}$$

where σ_{bi} is average von Mises stress (bone) and σ_{tj} is average von Mises (thread).

Table 3 summarizes the range of screw pitch and the length of the screw used in this study. Length of screw for different pitch have been grouped into 6-8, 9-11, 12-14, 15-17, 18-20, 21-23, 24-25, 26-27. The groups were selected to avoid incomplete or partial thread at the end of each screw. For example, in the group length of 6-8 mm, each screw has different length for different pitch namely 0.50, 1.00, 1.25, 1.50, 1.75, and 2.00 mm. For pitches 0.50, 1.00, 1.50, and 2.00 mm, the thread completes at 6 mm of length while at pitch 1.25 and

1.75, its complete at 6.25 mm and 7 mm, respectively. The length of screw from 6 mm to 23 mm is in cancellous zone, whilst 24 mm to 27 mm is in cortical zone.

Table 3: Screw's length and pitch

Group of length (mm)	Pitch (mm)					
	0.50	1.00	1.25	1.50	1.75	2.00
6-8	6.00	6.00	6.25	6.00	7.00	6.00
9-11	9.00	9.00	10.00	9.00	10.50	10.00
12-14	12.00	12.00	12.50	12.00	12.25	12.00
15-17	15.00	15.00	15.00	15.00	15.75	16.00
18-20	18.00	18.00	18.75	18.00	19.25	18.00
21-23	21.00	21.00	21.25	21.00	21.00	22.00
24-25	24.00	24.00	25.00	24.00	24.50	24.00
26-27	26.00	26.00	26.25	27.00	26.25	26.00

Results and Discussions

Effect of cortical screw materials on STP

Figure 3 presents the results of STP value obtained for two types of screw material namely stainless steel A316 and titanium alloy Ti-6Al-4V. Pitch, core diameter and thread diameter were kept constant with 0.5 mm, 0.5 mm and 1 mm, respectively. Based on the results obtained for both of materials, the highest STPs values of titanium is 0.4852 gained by the 26-27 mm group of length. While, from the group of length 6-8mm to 24-25 mm, the graph shows fluctuated trend with maximum, minimum, and average value are 0.4483, 0.3255 and 0.3712, respectively.

The similar trend observed for stainless steel A316. For stainless steel A316, the most significant value of STP is 0.3369 at 26-27 mm group of length. STPs values fluctuated at the maximum of 0.3106 with the lowest of 0.2246 and 0.2611 of average. Compared to the stainless steel A316, titanium alloy shows higher values of STP. The minimum and maximum STP value for stainless steel of all pitch are 0.0516 and 0.4985, respectively. While the minimum and maximum STP value for titanium alloy are 0.07782 and 0.5537, respectively.

For the same group of length and pitch, it is found that the STP percentage differences resulted in an 6.4% to 85.4% increased between the SS A316 and the titanium. Among the groups observed, the largest different between the two types of material is the 12 mm group of length where the titanium has higher value of STP compared to the stainless steel. STP value of stainless steel 0.0887 while STP value of titanium is 0.1645 with percentage different 85.4%. This indicates that titanium alloy Ti-6Al-4V gave better load transfer between the bone and the screw fixation compared to stainless steel A316 based on STP values. The similar observation is found in previous research where it compares effect of pins materials on average STPs, it found the percentage difference of the STP value is 0 to 23.5% between stainless steel and titanium alloy of half pin uniaxial external fixation [30].

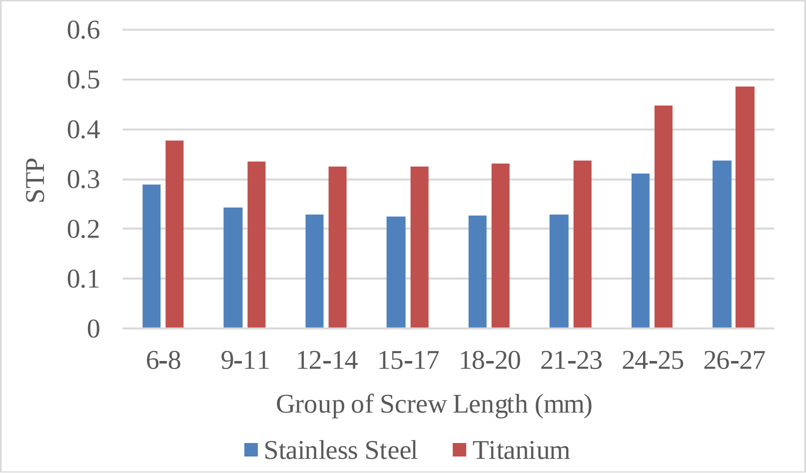


Figure 3: Effect of screw materials on the average STPs

The present study found that a screw material with a lower Young's modulus results in improved load transfer, as evidenced by the calculated stress-transfer parameter (STP) values. This finding is consistent with previous research on the bone-implant fixator stress-strain behaviour under three-point and four-point bending, which found that the STP of stainless steel was lower than that of titanium due to the fact that stainless steel has a higher elastic modulus than titanium for both bending loads at a constant pitch [32]. Another study on nails and canals also found that a titanium nail (with a modulus of 110 MPa) resulted in lower gap deformation and provided a higher contact force, resulting in a higher frictional force against the applied load, in comparison to a stainless steel nail (with a modulus of 200 MPa) [33]. Furthermore, previous research on cancellous screws has reported an average 20-35% increase in stress transfer upon reduction of the elastic modulus of the screw material from 105 GPa to 40 GPa [12], [29]. This suggests that a lower Young's modulus results in better STP values.

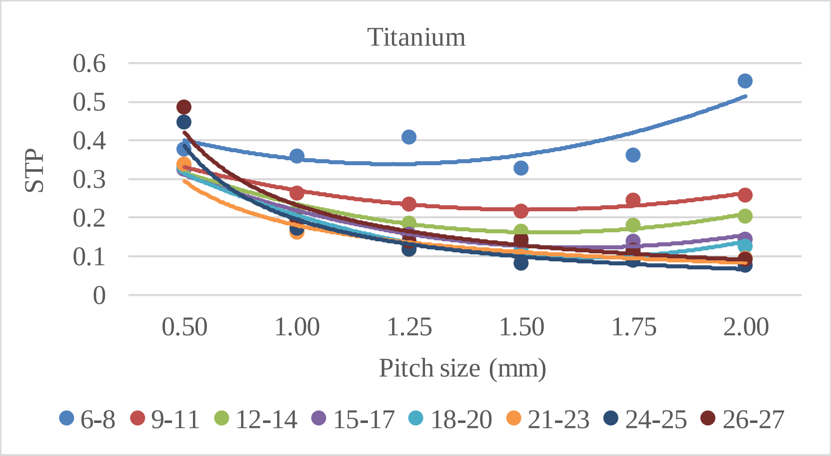
Effect of varying cortical screw pitch on STP

Figure 4 presents STPs values on two types of materials for different pitch. The results show similar trends of the STPs values for all pitch of the stainless steel A316 and titanium alloy. The STPs values of all group length show the same trends where the highest STP is at the finer pitch size before STPs values start to decrease as the size of pitch increased except for group length of 6-8 mm. The result shown similar pattern as that of Hosseinitabatabaei et al. [34], where simulated 4 years healing process to observe the effect of maximum stress parameter and STP by varying screw pitch from 1.5 mm to 2.5 mm and the results shows that by decreasing screw pitch size would improve the screw performance and reduce the effects of stress shielding. However, at the group length of 6-8 mm, the STPs values start to increase simultaneously as the size of pitch increased. Among of all the pitch, the highest STPs values is found at the shortest group of length of 6-8 mm for both of materials at the 2 mm of pitch size.

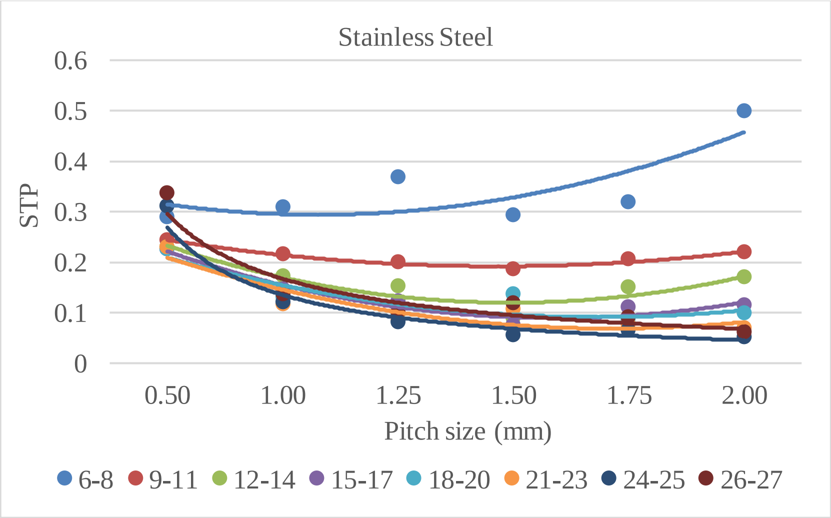
Considering the above, the stress transfer performance is optimized with the appropriate combination of screw pitch and material thus reducing the undesirable stress shielding effect of the implant to the surrounding bone. This is consistent with the previous findings which suggest that using a less stiff screw and reducing the pitch of the screw would improves the stress transfer from screw to bone, and consequently diminishes the risk of stress shielding [14], [25]. Study by Fatin et al. [29] also found that implant with high elastic modulus may cause severe stress concentration, which may weaken the bone and lead to the deterioration of the implant-bone interface.

An orthopaedic screw implant is a crucial aspect of a patient's physical and psychological recovery, as well as their rehabilitation and rehabilitation regimen. The ability of an orthopaedic screw to transmit stress uniformly between the threads and the surrounding bone determines its biomechanical compatibility. As elastic modulus decreases, the stress parameters such as STP was increased. This indicates that decreasing elastic modulus help to transmit and distribute stress better than higher elastic modulus in implant-bone contact.

A study on material of dynamic hip screw during fall and gait loading found that smaller elastic modulus materials help to induce less stress on the implant and decrease stiffness of implant during loading [2]. Finite element analysis on dental implant also showed by using low modulus would result in lower flexural resistance [1]. Similarly results found on research using viscoelastic finite element modelling where it stated that reducing the elasticity of screw will reduce the amount of the stress shielding of the screws [35]. Furthermore, an vivo study on sheep from previous research on dental implant found that by using small size of screw pitch showed the greater surface area and better stress distribution thus may improve primary stability in cancellous bone [36]. Experimental study of screw on synthetic bone also demonstrated the screws pitch as one of the important parameters on holding power as finer thread was reported gave greater purchase compared to coarse thread pitch [17].



(a)



(b)

Figure 4: STP on two types of material: (a) titanium, and (b) stainless steel, for different pitch size

Figure 5 shows the effect of screws length on the constant pitch size. The graph of all pitch shows same pattern where the STPs values start to decrease from 6-8 mm of group length until 21-23 mm (unicortical screw region) before STPs values start to increase at the 24-25 mm until 26-27 mm of group length (bicortical screw region). This trend also shows that it is anticipated that with appropriate combination of screw pitch, screw length and material able to improve the performance of the stress.

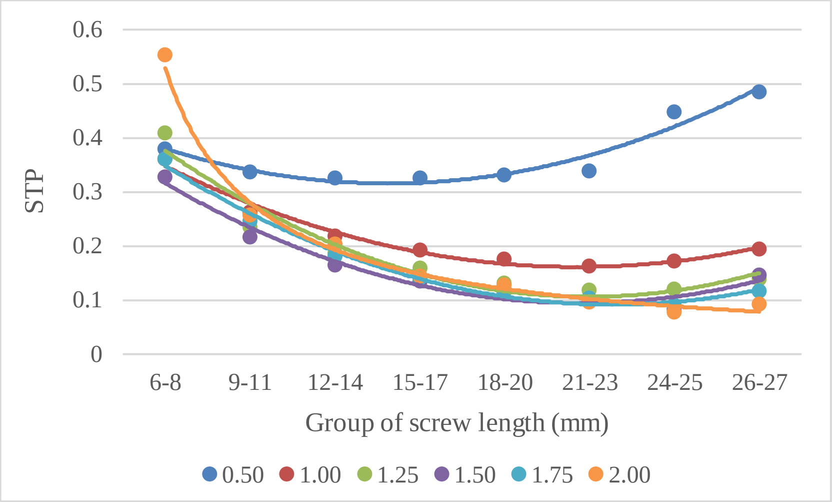


Figure 5: STPs on constant pitch and material for different length

The results in Figure 5 demonstrate that there is a significant difference in STP values for a pitch size of 0.5 mm when compared to other pitch sizes, particularly at higher screw lengths. This variation is attributed to the significant difference in the number of threads, as group lengths between 6 mm-8mm until 21-23 mm are classified as unicortical screws, while group lengths between 24-25 mm and 26-27 mm are classified as bicortical screws, as depicted in Figure 6. To avoid incomplete or partial threading at the end of each screw, the screw lengths for different pitches were grouped accordingly. This finding is in line with previous research, which suggests that decreasing the modulus of elasticity of screws, increasing the number of threads per screw, decreasing the pitch of screws, and decreasing the diameter of the screws shaft can all contribute to reducing stress shielding and loosening of the screws [35].

Ricci et al. [37] stated that bicortical lag screws offer better benefit regarding quality of bone at the end of the screw as compared to unicortical lag screws. Experimental results of bicortical and unicortical placement at proximal tibia fractures shows that bicortical screw present a mechanically superior construct than unicortical screw placemen as it significantly outperformed unicortical screw placement in stiffness and maximum load [38].

The mean load to failure of unicortical fixation also was lower compared to bicortical plate fixation in transverse metacarpal fracture models subjected to cyclic loading [39]. Others study also shows that specimens fixed with bicortical locked plating gave increased in stiffness during torsional loading when compared to unicortical locked fixation [40].

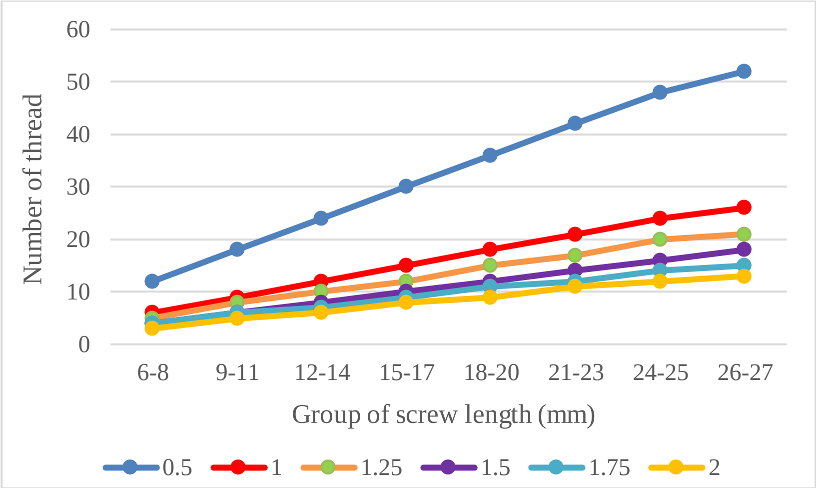


Figure 6: Number of threads on constant pitch and material for different length

However, the experimental study on synthetic bone shows that the stability of temporary screws length depends on the bone thickness where 2 or 1 mm of cortical thickness coupled to cancellous bone was deemed sufficient enough to achieve mechanical stability [41]. Another study presents the comparison between unicortical and unicortical plate and screw fixation of metacarpal fractures. It showed that unicortical can act as standard method of fixing metacarpal fractures due to the reason it requires less technically demanding and quicker producer [19]. Unicortical fixations also demonstrated higher stability against bending loads of the forearm, and potentially decreased refracture risk following plate removal [40].

Stress and strain distribution

Referring to Figure 7, it shows the von Mises distribution in unicortical (6-8 mm) and bicortical (26-27 mm) fully threaded screw profiles for both materials. The figure shows that the maximum amount of stress occurs in the head for the 6-8 mm length group with 793.14 (titanium) and 865.76 (stainless steel). Moreover, large stresses are noticed in screws where the thread is placed next to the combined sections of cortical and cancellous bone. This is because the screw's head being secured to the cortical surface, which compresses the bone between the head and the first thread [29]. Also, as seen in the figure, the cortical region has higher stress than the cancellous region.

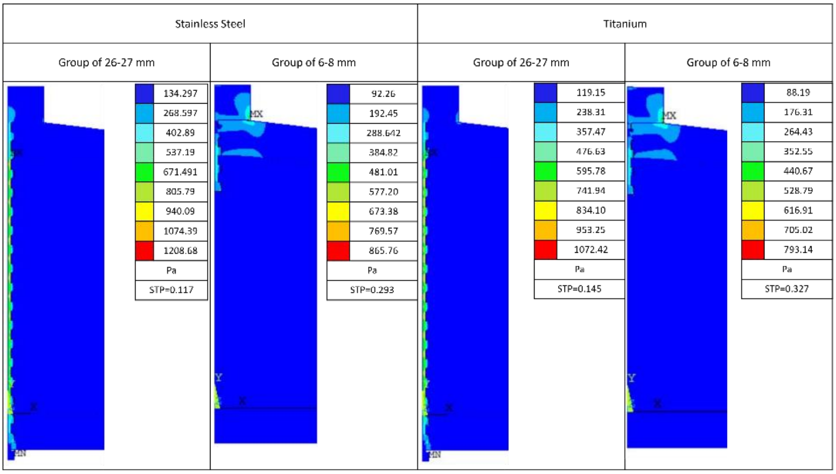


Figure 7: von Mises stress distribution on varied screw length with different material

While, at group of length 26-27 mm, the maximum stress happened at the screw region with 1072.42 (titanium) and 1208.68 (stainless steel) while at the surrounding of the bone, the highest stress values are 119.15 (titanium) and 134.297 (stainless steel). It also shows that the highest concentration stress occurs in the screw thread region, adjacent to the joined portions of cortical and cancellous bone. The stress from the head of screw start to significantly increases and well distributed until at the thread in cancellous region before it reduces in stress value in the thread at the far cortical region. However, the stress value in the bone is lower in comparison with those of the screw for both type of screw.

Titanium screws Ti-6Al-4V ELI has a maximum von Mises stress of 1072.42 Pa while maximum von Mises of stainless-steel screws A316 is 1208.68 Pa at 26-27 mm group length where titanium screw approximately 12.71% lower than stainless steel. Because the elastic young's modulus of the titanium screw (110 GA) is substantially smaller than that of the stainless-steel screw (190 GPa). The titanium screw Ti-6Al-4V ELI model results in a lower von Mises stress, which is advantageous since greater mechanical stimuli conveyed to bone will possibly bring about much less pressure shielding as STP values shows in Figure 3.

Furthermore, it showed that the screw in group of 26-27 mm had the largest contact area with the bone and at the same time the maximum von Mises stress occurred in the surrounding bone for both materials. This means that the longest screw length transfers the most amount of stress to the surrounding bone through the bone-screw interface as shown in Figure 7. These findings are in line with those found in the literature, where critical stress seems to yield at the thread location [11] and material with elastic modulus of 45 GPa produce lower stress compared to 193 GPa of elastic modulus [30].

The limitation still existed in this finite element simulation which can be improved in future studies. Specific situations are considered such as material properties of bone, bone thickness, and contact condition that may not exactly reflect the real situations. The material properties in this study were assumed as linear elastic, homogeneous and isotropic. Another assumption was the contact between bones and screws were perfectly bonded. Furthermore, the outcomes of this study were based only on the 2D cross-section of the model. These simplification purposes to allow the model to focus on the impact of the screw parameters.

Conclusion

The bone-implant screw contact is critical in providing fixation stability during bone growth. The screw parameter is important in transmitting stress between the implant and the tissue around the bone. In the application of internal fixation, the interaction of fully threaded bicortical and unicortical is not clearly defined. Therefore, in this study the results demonstrated low in elastic modulus of fully threaded bicortical and unicortical will provide better stress transfer and distribution to the bone. As in this study, titanium alloy Ti-6Al-4V provide improved biomechanics compared to stainless steel A316 as it has lower elastic modulus. The effect of varying screw pitch and screw materials between two types of screws shows that bicortical gave better performance at pitch of 0.5 mm, followed by 1.00 mm and 1.25 mm. This mean bicortical screws produce significant and strong stress transfer when using finer pitch size. For unicortical (9-11 mm until 21-23 mm of group length), the most optimum values of stress parameters were at pitch of 0.5 mm and followed by 1.00 mm however unicortical screw with 6-8 mm of group length shows contrast result where the optimum stress transfer happened at pitch of 2 mm, followed by 1.25 mm. The results of this study may provide better understanding of the impact of fully threaded cortical screws parameters such as material, pitch size and screw length on the formation of a direct interface between bone and implant. By gaining a greater insight into these factors, it may be possible to improve implant stability during the early stages of healing, thereby promoting optimal healing outcomes.

Contributions of Authors

It is confirmed that all authors were fully involved in the study and preparation of the article and that the material within has not been and will not be submitted for publication elsewhere. We have read and concur with the content in the article.

Funding

This work was supported by the "Fundamental Research Grant Scheme (FRGS)" [FRGS/1/2018/TK03/UNIMAP/02/22] from Ministry of Higher Education (MOHE) of Malaysia

Conflict of Interests

Fauziah Mat has received a research grant from "Ministry of Higher Education (MOHE) of Malaysia". The authors confirm that there is no conflict of interest regarding the publication of this manuscript.

Acknowledgement

The authors would like to be obliged to Universiti Malaysia Perlis and Ministry of Higher Education (MOHE) of Malaysia for providing laboratory facilities and financial assistance under FRGS/1/2018/TK03/UNIMAP/02/22.

References

[1] A. Korsel, "3D Finite Element Stress Analysis Of Different Abutment Materials in Screw, Implant and Cortical Bone," *Egyptian Dental Journal*, vol. 66, no. 1, pp. 415–421, 2020.

[2] N. S. Taheri, A. S. Blicblau, and M. Singh, "Comparative study of two materials for dynamic hip screw during fall and gait loading: Titanium alloy and stainless steel," *Journal of Orthopaedic Science.*, vol. 16, no. 6, pp. 805–813, 2011.

[3] H. S. Ryu, C. Namgung, J. H. Lee, and Y. J. Lim, "The influence of thread geometry on implant osseointegration under immediate loading: A literature review," *Journal of Advance Prosthodontics*, vol. 6, no. 6, pp. 547–554, 2014.

[4] Q. Wu, Y. Zhang, S. Wang, R. Liu, and G. Liu, "Different Lengths of

Percutaneous Transverse Iliosacral Screw in Geometric Osseous Fixation Pathway : A Finite - Element Analysis," *Indian Journal of Orthopaedics*, no. 0123456789, 2022.

[5] G. J. G. Quintero, "Biomechanical Evaluation Of Hybrid, Bicortical And Unicortical, Screw Configurations For Internal Bone Plate Fixation Of Long Bone Fracture: An In-Vitro Study Of Porcine Femur Bone Models," Thesis, 2017.

[6] M. Zhu *et al.*, "Initial stability and stress distribution of ankle arthroscopic arthrodesis with three kinds of 2-screw configuration fixation: A finite element analysis," *Journal of Orthopaedic Surgery and Research*, vol. 13, no. 1, pp. 1–7, 2018.

[7] B. Zhang, J. Liu, Y. Zhu, and W. Zhang, "A new configuration of cannulated screw fixation in the treatment of vertical femoral neck fractures," *International Orthopaedics*, vol. 42, no. 8, pp. 1949–1955, 2018.

[8] L. E. Butignon, M. de A. Basilio, R. de P. Pereira, and J. N. A. Filho, "Influence of Three Types of Abutments on Preload Values Before and After Cyclic Loading with Structural Analysis by Scanning Electron Microscopy," *International Journal of Oral & Maxillofacial Implants*, vol. 28, no. 3, pp. e161–e170, 2013.

[9] S. Xie, K. Manda, and P. Pankaj, "Effect of loading frequency on deformations at the bone–implant interface," *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, vol. 233, no. 12, pp. 1219–1225, 2019.

[10] H. K. Uhthoff, P. Poitras, and D. S. Backman, "Internal plate fixation of fractures: Short history and recent developments," *Journal of Orthopaedic Science*, vol. 11, no. 2, pp. 118–126, 2006.

[11] E. Tetteh and M. B. A. McCullough, "Impact of screw thread shape on stress transfer in bone: a finite element study," *Computer Methods in Biomechanics*, vol. 23, no. 9, pp. 518–523, 2020.

[12] K. Haase and G. Rouhi, "Prediction of stress shielding around an orthopedic screw: Using stress and strain energy density as mechanical stimuli," *Computer in Biology and Medical*, vol. 43, no. 11, p. 1748, 2013.

[13] V. Ros *et al.*, "High short-term loosening rates with the wagner standard cup," *Journal of Arthroplasty*, vol. 29, no. 1, pp. 172–175, 2014.

[14] G. Rouhi, M. Tahani, B. Haghighi, and W. Herzog, "Prediction of stress shielding around orthopedic screws: Time-dependent bone remodeling analysis using finite element approach," *Journal of Medical and Biological Engineering*, vol. 35, no. 4, pp. 545–554, 2015.

[15] M. W. Downey, V. Kosmopoulos, and B. B. Carpenter, "Fully Threaded Versus Partially Threaded Screws: Determining Shear in Cancellous Bone Fixation," *The Journal of Foot and Ankle Surgery*, vol. 54, no. 6, pp. 1021–1024, 2015.

[16] E. Reinaldo, S. Bonifacius, and A. Adenan, "Influence of short implant

thread pitch and depth to primary stability on D4 bone density: A laboratory study," *Journal of International Oral Health*, vol. 13, no. 5, p. 456, Sep. 2021.

[17] T. A. Decoster, D. B. Heetderks, D. J. Downey, J. S. Ferries, and W. Jones, "Optimizing bone screw pullout force," *Journal of Orthopaedic Trauma*, vol. 4, no. 2. pp. 169–174, 1990.

[18] R. R. Santos *et al.*, "Biomechanical analysis of locking reconstruction plate using mono-or bicortical screws," *Material Research*, vol. 19, no. 3, pp. 588–593, 2016.

[19] F. Wu *et al.*, "Stability of Unicortical versus Bicortical Metacarpal Fracture Internal Fixation Trial (SUBMIT): Study protocol for a randomized controlled trial," *Trials*, vol. 17, no. 1, pp. 1–7, 2016.

[20] M. Khalid, K. Theivendran, M. Cheema, V. Rajaratnam, and S. C. Deshmukh, "Biomechanical comparison of pull-out force of unicortical versus bicortical screws in proximal phalanges of the hand: A human cadaveric study," *Clinical Biomechanics*, vol. 23, no. 9, pp. 1136–1140, Nov. 2008.

[21] S. H. Sayyed-Hosseinian, F. Bagheri, M. H. Ebrahimzadeh, A. Moradi, and S. Golshan, "Comparison of partially threaded and fully threaded 4mm cancellous screws in fixation of medial malleolar fractures," *The Archive Bone and Joint Surgery*, vol. 8, no. 6, pp. 710–715, 2020.

[22] L. Parker, N. Garlick, I. McCarthy, S. Grechenig, W. Grechenig, and P. Smitham, "Screw fixation of medial malleolar fractures: A cadaveric biomechanical study challenging the current AO philosophy," *The Bone and Joints Journal*, vol. 95 B, no. 12, pp. 1662–1666, 2013.

[23] N. F. I. Ibrahim, R. Daud, M. K. Ali Hassan, N. A. M. Zain, and A. F. Azizan, "The effect of different types of half pins on stress transfer parameter during osseointegration," *Material Today Proceedings*, vol. 16, pp. 2179–2186, 2019.

[24] M. H. Khan, R. Daud, M. K. Ali Hassan, A. F. Azizan, B. Izzawati, and N. N. Mansor, "The effect of cannulated screw material on stress transfer parameter in orthotropic femur bone with Pauwels type-III fracture," *Material Today Proceedings*, vol. 16, pp. 2135–2143, 2019.

[25] C. L. Lin, Y. H. Lin, and S. H. Chang, "Multi-factorial analysis of variables influencing the bone loss of an implant placed in the maxilla: Prediction using FEA and SED bone remodeling algorithm," *Journal of Biomechanics*, vol. 43, no. 4, pp. 644–651, 2010.

[26] S. Kebdani, S. Zahaf, B. Mansouri, and B. Aour, "Numerical study of the effect of rigid and dynamic posterior attachment systems on stress reduction in cortical and spongy bones of the lumbar segments L4-L5," *Nano Biomedical Engineering*, vol. 9, no. 3, pp. 249–274, 2017.

[27] A. Dhanopia and M. Bhargava, "Finite Element Analysis of Human Fractured Femur Bone Implantation with PMMA Thermoplastic Prosthetic Plate," *Procedia Engineering*, vol. 173, pp. 1658–1665, 2017.

[28] H. Mehboob and S. H. Chang, "Application of composites to orthopedic prostheses for effective bone healing: A review," *Composite Structures*, vol. 118, no. 1, pp. 328–341, 2014.

[29] A. Gefen, "Computational simulations of stress shielding and bone resorption around existing and computer-designed orthopaedic screws," *Medical and Biological Engineering and Computing*, vol. 40, pp. 311–322, 2002.

[30] N. F. I. Ibrahim, R. Daud, M. K. A. Hassan, N. A. M. Zain, and Y. Bajuri, "Half pins stress shielding interaction behavior at implant-bone interface," *International Journal of Integrated Engineering*, vol. 10, no. 5, pp. 204–208, 2018.

[31] J. P. Paul and A. Gefen, "Optimizing the biomechanical compatibility of orthopedic screws for bone fracture fixation (multiple letters)," *Medical engineering & physics*, vol. 25, no. 5, pp. 435–436, 2003.

[32] B. Izzawati, R. Daud, M. Afendi, M. S. A. Majid, N. A. M. Zain, and Y. Bajuri, "Prediction of Stress Shielding Around Implant Screws Induced by Three-Point and Four-Point Bending," *International Medical Device and Technology Conference*, vol. 15, no. 4, p. 50, 2017.

[33] P. Y. Lee, Y. N. Chen, J. J. Hu, and C. H. Chang, "Comparison of mechanical stability of elastic titanium, nickel-titanium, and stainless steel nails used in the fixation of diaphyseal long bone fractures," *Materials (Basel)*, vol. 11, no. 11, pp. 1-11, 2018.

[34] S. Hosseinitabatabaei, N. Ashjaee, and M. Tahani, "Introduction of Maximum Stress Parameter for the Evaluation of Stress Shielding Around Orthopedic Screws in the Presence of Bone Remodeling Process," *Journal of Medical and Biological Engineering*, vol. 37, no. 5, pp. 703–716, 2017.

[35] M. Torabi, S. Khorramymehr, M. Nikkhoo, and M. Rostami, "The role of orthopedic screws threads properties on the success of femoral fracture fixation," P*roceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol.236, no. 17, pp. 095440622210947, 2022.

[36] E. Orsini, G. Giavaresi, and S. Salgarello, "Osseointegration Process : An In Vivo Comparison Study," *International Journal of Oral & Maxillofacial Implants*, vol. 27, no. 2, pp. 383–392, 2012.

[37] W. M. Ricci, P. Tornetta, and J. Borrelli, "Lag screw fixation of medial malleolar fractures: A biomechanical, radiographic, and clinical comparison of unicortical partially threaded lag screws and bicortical fully threaded lag screws," *Journal of Orthopaedic Trauma*, vol. 26, no. 10, pp. 602–606, 2012.

[38] P. J. Dougherty, D. G. Kim, S. Meisterling, C. Wybo, and Y. Yeni, "Biomechanical comparison of bicortical versus unicortical screw placement of proximal tibia locking plates: A cadaveric model," *Journal of Orthopaedic Trauma*, vol. 22, no. 6, pp. 399–403, 2008.

[39] R. Afshar, T. S. Fong, M. H. Latifi, S. R. Kanthan, and T. Kamarul, "A

biomechanical study comparing plate fixation using unicortical and bicortical screws in transverse metacarpal fracture models subjected to cyclic loading," *Journal of Hand Surgery (European Volume)*, vol. 37, no. 5, pp. 396–401, 2012.

[40] T. J. Pater, S. I. Grindel, G. J. Schmeling, and M. Wang, "Stability of unicortical locked fixation versus bicortical non-locked fixation for forearm fractures," *Bone Research*, vol. 2, no. March, pp. 1-5, 2014.

[41] D. J. Fernandes, C. N. Elias, and A. C. O. Ruellas, "Influence of screw length and bone thickness on the stability of temporary implants," *Materials (Basel).*, vol. 8, no. 9, pp. 6558–6569, 2015.