International Journal of Engineering & Technology, 7 (4.26) (2018) 123-127

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effects of Screw and Plate Positions in the Dual Plating of Distal Humerus Fixation

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Abstract

Bone fractures are one of the common effects of road accident. Osteosynthesis is a surgical procedure to treat the fractures of the bones by inserting implant to restore the fracture bones to its original position and immobilizing the restored region to allow proper growth of bone. One of the main problems of an internal fixation surgery is the ability of implants to retain the original position of humerus bone without any other complications during the fractured bone development. Thus, the purposes of the study was to analyze the biomechanical effects of screw and plate positioning at the distal humerus bone. The static analysis is carried out to evaluate the effect of mechanical characteristics and stress distribution in the humerus bone by using computational design and analysis software (CATIA) and Materialise Interactive Medical Image Control System (MIMICS) software. Thus, the analysis resulted to stress/strain distributions and displacement of the humerus bone and dual plate implant respectively. Different positioning of screws shows more significant results compared to positioning of dual locking plate regarding to the stress distribution and displacement of locking plate implant which can lead to disturbance towards the growth of bone.

Keywords: *Screw and Plate Positions, Dual Plating Fixation, Stress distribution, Displacement, Finite Element Analysis*

1. Introduction

There are many road traffic accidents occur around the world that have caused fatality and serious or minor injuries to the victims. The effects of the injuries always related to the fractures of bones and other related health problems. The fraction of bones will cause a disaster to the victim as the capabilities of the person to perform works become highly limited. Therefore, the amount of time required for a full recovery will take several months or even years depending at the type of fracture the victim possessed. If bone fracture occurs in any major part of the arm such as humerus bone, the movements of the whole arm must be restricted to prevent any further dislocation of fractured bones at the part involved [1,2].
Finite element analysis (FEA), is a numerical tool that can give a precise prediction of a component’s response subjected to different kinds of loads and boundary conditions. This numerical tool is used generally for quantification and simulation of structures and systems. Problems of heat transfer, stress analysis of a body, fluid flow and other related engineering field problems have been solved by finite elements. The data obtained from this analysis is reliable and applicable for further development of a new product design or systems by enhancing the design for a better impact. Finite element (FE) model is constructed based on computed tomography or other available sources of images [3].
In order to restrain the movement of the highly fractured bones, osteosynthesis or internal fixation surgery must be applied [4]. This surgery will resist the movement of the fractured parts by stabilizing and joining the ends of the fractured bone by implanting mechanical devices such as biocompatibility metal plates, pins, rods, or screws [5]. The implant design of plate and screws positioning are important components in keeping the stability of distal humerus bone. This purpose of the study is to develop the finite element models of humerus bone and to analyze the biomechanical effects of screw and plate positioning at the distal humerus bone using the dual plating technique. A 3D model of humerus bone is extracted from a CT-based image and dual plate implant with screw is designed in this study. The project focused on (i) the development of humeral 3D model bone obtained from the CT-scan data with 4 sets of model configuration of plate and screw positioning and (ii) to analyse the effects of screw and plate positioning to the humerus bone.

2. Materials & Methods

2.1. Materials Properties

Cortical (compact) bone is used as the type of material for the three-dimensional solid humerus bone. The cortical bone represents almost 80% of total human skeletal mass [6]. Titanium alloy (Ti-6AI-4V) is the chosen material for the dual locking plate and implant screws. Titanium alloy has the best biocompatibility for human tissues and able to resist material corrosion in human body. Titanium alloy also has the best mechanical properties for the internal fixation implant which are high toughness and stiffness, great tensile strength, light weighted and easy to be modified. These materials are set to be isotropic, homogeneous and linear elastic solids materials [7,8]. Table 1 lists the mechanical properties of each material.

Table 1: Mechanical properties used in Finite Element model

Material	Elastic Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
Titanium Alloy (Ti-6AI-4V)	114	0.3	795	860
Cortical Bone	17.2	0.33	163	121

2.2. Designing Parallel & Anti Parallel Locking Plate Models

Two types of distal humerus plate used for study are dorsolateral locking plate (DLP) and medial locking plate (MLP), are designed in CATIA software. The implants were designed by referring to the actual implants used in the previous research article. The dual parallel plate orientation has been chosen over perpendicular plate. This is to establish optimal amount of compression forces between implant and the fractured bones thus increasing the implant stabilities and resulting a better bone growth while restoring the previous geometry of the original humerus bone [9]. The dual implant of the distal humerus bone was designed by following the standard size of the humerus bone which is apparently to be medium sized human bone. In this project, two sets of dual locking implant models were designed and instrumented into the distal humeral models, which are parallel, DLP-MLP model and anti-parallel, as illustrated in Fig. 1. The length of MLP implant for both models is the same which is 100 mm in length. The length of each DLP implant differentiates the parallel and anti-parallel models as the specification of parallel DLP implant is 80 mm in length while the length for anti-parallel DLP implant is 100 mm. The implants and screws were designed and created using CATIA software. The screws used to secure the DLP-MLP model are 3.5 mm diameter of cortex screw and 2.0 mm diameter of locking screw. The amount of screws used for DLP-MLP implants for parallel plate model are 8 cortical screws and 6 locking screws while for anti-parallel plate model, the screws used for the attachment of implant to the humerus bone are 7 cortical screws and 6 locking screws. The threads of the screws were omitted to simplify the models.

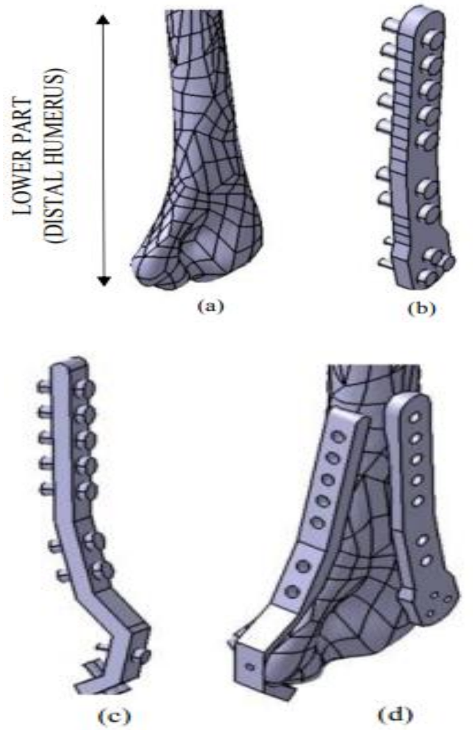


Fig. 1: 3D model of (a) Distal Humerus Bone (b) Dorsolateral Plate (c) Medial Lateral Plate (d) Assembly of Dual Plates

2.3. Pre-Processing Finite Element Analysis

A 3D solid humerus bone was used as the geometry of this finite element case study. The solid geometry will be attached with two sets of dual locking plate implant which are parallel DLP-MLP implant and anti-parallel DLPMLP implant. Common surgical techniques were simulated to instrument the DLP-MLP implant into the distal humeral bone models. The two sets of dual locking plate is then divided into two new conditions by varying the positioning and amounts of cortical screws at the humerus bone. Dual parallel plate orientation have been chosen over perpendicular plate to determine the effects of plate and screw positioning for the internal fixation of distal humerus bone fracture. The plate consists of combination of medial and lateral plate to ensure optimal compression between the implant and the fractured bones. The total number of elements and nodes contained in the parallel DLP-MLP model is 120096 and 29316 respectively while for anti-parallel DLP-MLP model, it contained 129947 elements and 31043 nodes.

2.4. Loading and Boundary Condition

After the assembly process of locking plates and three-dimensional humerus bone model has been constructed. The simulation of finite element analysis was simulated in CATIA V5 software. All bone models and implants has been set to linear elastic isotropic material properties. The contact behaviour of implant plates/humerus bone has been defined as surface to surface contact and the contact behaviour between screws/humerus bones has been assigned as a bolt tightening contact which the tightening force of cortical screws has been set to 50N. This contact behaviour allow user to attach the implants without the presence of actual designed bolt/screw with the desired tightening force. All of the contact elements were assigned as deformable elements and the frictional forces between implants and humerus bone were neglected to simplify the simulation process and results
A set of bending forces was applied to the humeral shaft model to simulate and test the effects of high impact distributed forces towards the locking plate implant. The implant functioned as a support to maintain the original position of humerus bone at the attached region. Downward (Y-axis) direction of forces was applied approximately 10 cm from the end tip of the locking plate implant. The distributed forces were applied to 4 sets of screws and plates configuration [10]:

a) Parallel plate endings; the placement of the farthest screws at the different level. (PD)
b) Anti-parallel plate endings; the placement of the farthest screws at different level. (AD)
c) Anti-parallel plate endings; the placement of the farthest screws at same level. (AS)
d) Parallel plate endings; the placement of the farthest screws at the same level. (PS)

Based on the common surgical practices, dual locking plates should vary in length to avoid any early or late peri implant failure effects. Peri implant failure effect is a failure of bone occurs around the area of the implant after an internal fixation or osteosynthesis process has been carried out. This implant failure will slowly degrade the composition of bone, thus resulting total failure of implant. There are lack of scientific evidence and test carried out to support this claim. Therefore, this case study has been conducted to analyse the stress analysis of the finite element model consisting the assembly part of distal humerus bone and locking plate implant. Thus, the main manipulated variable of this study is to evaluate the influence of plate and screw positioning on the tendency of peri-implant fractures. A set of 100N, 200N, 300N and 400N of forces were applied vertically (Y-axis) onto the horizontal positioning of the finite element model of humerus bone with being clamp at the end of the distal end of the bone (X-axis), as shown in Fig. 3.

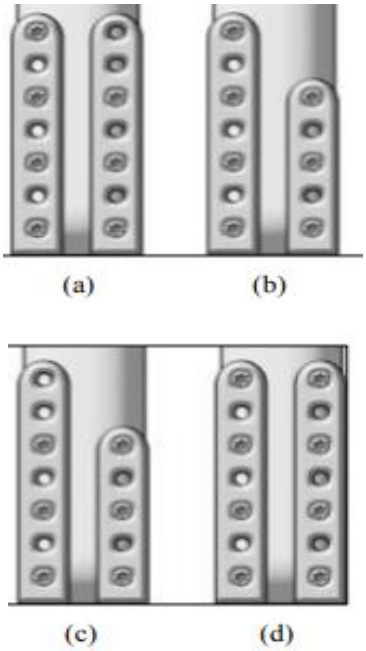


Fig. 2: Screws and plates configuration (a) PD, (b) AD, (c) AS and (d) PS

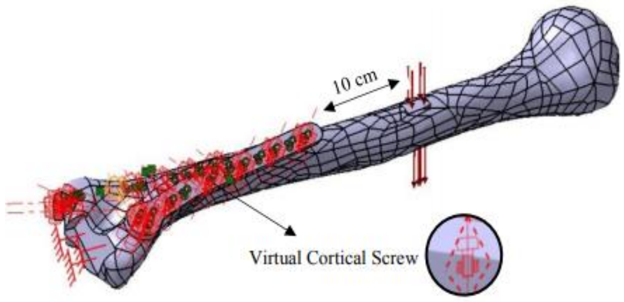


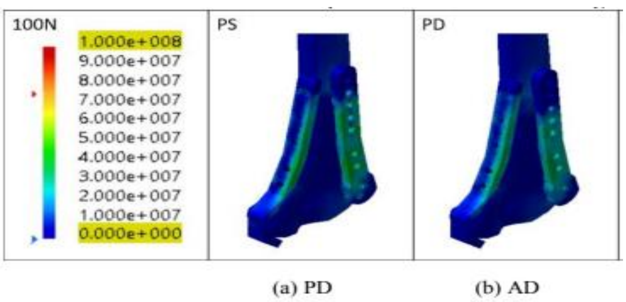
Fig. 3: Loading and boundary condition of distal humerus bone

3. Results & Discussions

Results of the effects of screw and plate positionings in the dual plating of distal humerus fixation were discussed in the resulting stress distribution and total displacement.

3.1. Stress Analysis of Dual Plating Implants

The maximum von Mises stress distribution after DLP-MLP fixation under several of loading applied are shown in Fig. 4 for 100 N force. The maximum stress was indicated as 74.46 MPa at (PS) implant model and the lowest maximum von Mises stress value was 42.86 MPa at (PD) implant model. The stress was concentrated at the DSL implant from (PD) configuration to (AS) configuration and at the PS implant configuration the distribution of stress was small but highly concentrated at the implant distal region. This indicated that after some time peri implant failure of bone degrading might occur at the highlighted regions.



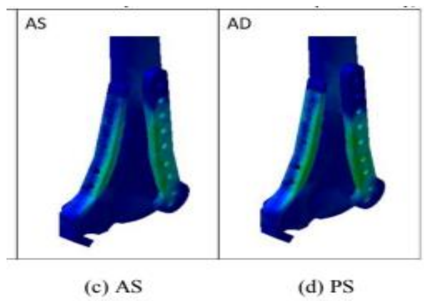


Fig. 4: 100N force applied at (PD, AD, AS & PS) implant configurations

Similar pattern was observed for the exceeding loading which are 200N, 300N and 400N loadings. The maximum stress was 160.31 MPa in (PS) implant and the lowest stress was at (PD) implant which is 84.46 MPa. Even though the stress distribution is not widely distributed but the high stress was expected to cause a high distress of pressure at the concentrated region. In 300 N loading force, the resulting maximum stress was 240.44 MPa at (PS) implant and the lowest maximum von Mises stress is 127.81MPa at (PD) implant model. This yield strength for cortical bone is at 163 MPa. Therefore, it is believed that at this point the stress caused by the applied force may triggering the bone to be fractured, but as shown from previous study [10], the presence of locking plate implant will increase the yield strength of the bone by enhancing the stability of the bone composition. Thus, as we can see the yellow-green indicator is implying the for stress at 120 MPa to 168 MPa. The high stress was predicted to disrupt the stability of implant maintaining the original positions of the humerus bone.

Results of stress distribution in dual plating fixation with 400N of loading force was presented in Fig. 5. The highest maximum stress was 317.24N and predicted at (PS) model, while the lowest maximum stress was 127.81MPa at (PD) model. The results show constant increasing results of stress analysis distributed on the distal humerus bone model and stress experienced by the DLP-MLP locking plate. These results indicate that (PD) implant configuration is not desirable for internal fixation configuration as it causes high stress impact on the bone, however the (PS) implant gives better design of screws and plates configuration for the distal humerus bone as the Von Mises stress distribution is not critical, thus ensuring low possibility of implant failure due to peri-implant failure. Therefore, (PD) implant configuration is better than other implant models' configurations. The stress was concentrated at the middle part of LLP implant and slightly at the left part of the MLP implant. The yield strength of titanium prohibited the failure deformation of the implant as the von Mises stress generated by the applied force is lower than the yield strength of titanium.

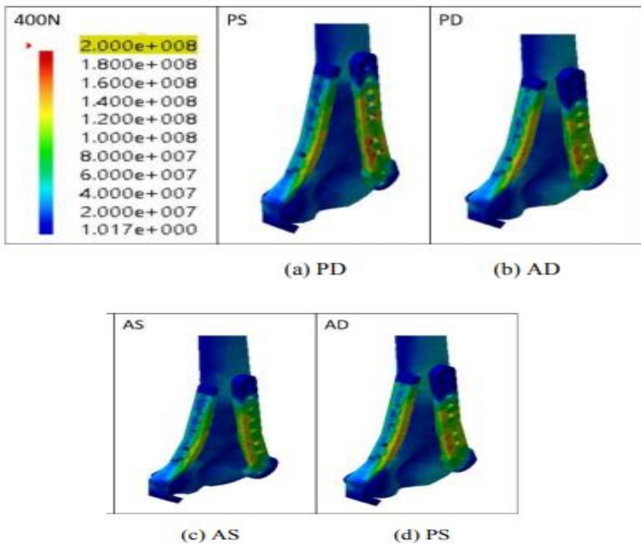


Fig. 5: 400N force applied at (PD, AD, AS & PS) implant configurations

In general, the comparison maximum von Mises stress within the dual plate positioning at different loading magnitudes was summarized in Fig. 6. Stress magnitude was increased with the increment of loading magnitude. The similar pattern throughout the loading magnitude shows that the loading magnitude not very significant to observe the effects of screws and plate positioning.

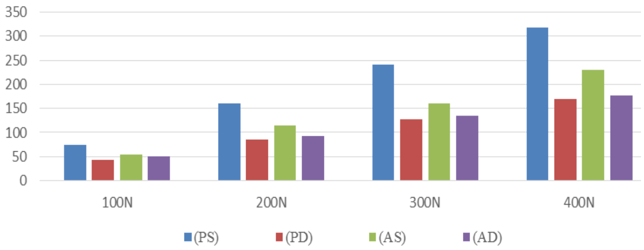
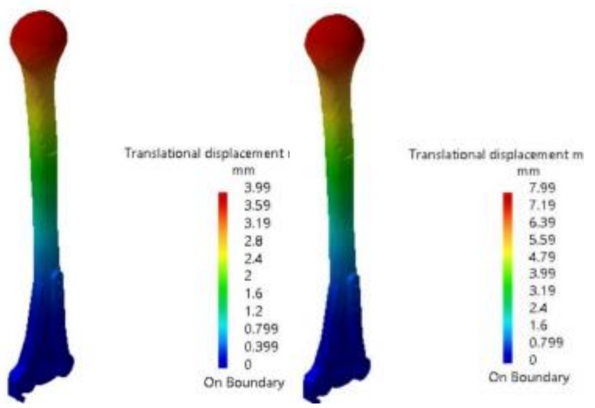


Fig. 8: Maximum von Mises stress for PS, PD, AS & AD

3.2. Total Displacements of Dual Plating Implant at Humerus Bone

Fig. 6 indicate that the highest deformation occurred at the tip of the humerus bone which is the proximal part of the bone. The deformation values are decreasing gradually along the humerus shaft of the bone and it is heading towards no significant deformation (>1 mm) at the DLP-MLP implant region. Thus, we can conclude that the stress has been resisted completely by the implant. We can also note that there is a slight deformation occurs at the proximal tip of the LLP implant which covered about 10% of the total implant length. If the total deformation of bone occurred, then it is expected that the fractures of bone will end at the slight deformation region (light blue) of the LLP implant model. The objective of this case study can be achieved by knowing the length of displacement occurred at the tip of the DLP-MLP implant. This is because the function of the dual plates is to maintain the original position of the humerus bone after the fractured humerus bone has been restored to its original position. Therefore, any significant displacement of bone at the region will caused other kinds of complications to patient. Thus, slowing or prohibiting the growth pace of the fractured humerus bone



(a) (b)

Fig. 6: Total displacement for (a) 200N and (b) 400N

Results of maximum deformation are presented in Fig. 7. Note that all DLP-MLP implant will not experiencing any extreme deformation of plates as the deformation value of the intact humerus bone is not exceeding the peak level of titanium implant deformation value. On the mechanical analysis part, between the four types of screws and plates configurations, when 100 N of force is being applied, the highest displacement of bone is 2.37mm at (PS) model and the other implant configurations shows a slight difference of displacement between each other. At 400N of loading force, the maximum deformation occurred is 9.21 at (AS) model and minimum deformation occurred by (PD) model which is 7.99 mm. From the acquired results, the values of displacement occurred at the tip of the LLM plate can be obtained by dividing the maximum deformation values of each forces by 10, thus the values displacement of 100 N, 200 N, 300 N and 400 N of force will be 0.237 mm, 0.461 mm, 0.660 mm and 0.921 mm, respectively.

Fig. 7: Maximum deformation of the humerus at implant region (10%)

According to the previous study that has been conducted [10], the fractures may occur at 250 N to 450 N load, but it is believed that the dual plate implants has enhanced the structural properties of the humerus bone, thus making it harder to break compare to normal bone. The displacement indicates that the (PD) model is the best selection of implant to ensure a stable enforcement of the fractured bone to prohibit any movements at the restored position of the humerus bone.

4. Conclusion

In conclusion, the von Mises stress distribution for four types of screws and plates configurations at the distal humerus model were determined. The parallel plate with screws at the same positioning (PD) give much higher result of von Mises stress than the other types of configurations because the placement of screws at the farthest position give the most significant influence towards the performance of dual locking plates to offer stabilizations of implant at the humerus bone. The anti-parallel plate with screws at different positioning (AD) shows the minimum point of stress for every loadings analysis which occur at the intact distal humerus bone either at the medial and lateral part of the bone. For the analysis of the displacement for each of the implant's screws and plates positioning, it shows that the minimum deformation results were shown by plates that have different positions of screws at the outermost part of implant plates while the maximum deformations occurred at the screws with same positioning. The risk of peri-implant failure is slightly affected by the positions of the dual plates, but it is crucial to vary the positions of screws at the outermost plates as it may have caused medical complications related to the osteosynthesis treatment

Acknowledgement

We thank our colleagues from Faculty of Mechanical Engineering, UiTM and Faculty of Medicine, Universiti Malaya who provided insight and expertise that greatly assisted the research.

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