CONFIGURATION ON HYBRID PLATING TO IMPROVE INTERNAL FIXATION ON FEMUR BONE MODEL

NAFISAH ARINA HIDAYATI, MOCH. AGUS CHOIRON, SOFYAN ARIEF SETYABUDI

Brawijaya University, Mechanical Engineering Department, Malang, Indonesia

DOI: 10.17973/MMSJ.2018_06_2017120

e-mail : nafisah@ub.ac.id, agus_choiron@ub.ac.id, sasbudi@ub.ac.id

This study presents a stress analysis of hybrid plating constructions on femur fracture. The bone screw mounting configurations have successfully modeled with ANSYS Multiphysics/LS-Dyna v.18.1. The bone model was achieved from the CT-scanning of the human femur bone. The interactions between femur bone and hybrid plating were observed. Locking compression plates with 8 holes for bone screws were used. Applied axial compression load has developed stress distribution at all segments. Locking screws endured the bending forces and generated bending moment. Stress concentrations were noticeable at the screws neck. Nonlocking screws have produced a lower stress but bearing to be loosed since has small angular rigidity due to unthreaded screw heads. The most stable bone screw configuration was model A with N-L-N-L L-N-L-N pattern. The alternating sequence of screw configuration resulted in lower stress distribution at all segments, has small screw displacements and enduring lowest stress at each segment, especially femur bone.

KEYWORDS

Femur fracture, hybrid plating, configuration, stress, locking compression plate, internal fixation, bone screw.

1. INTRODUCTION

Failure in a bone can be due to trauma or severe injury, muscle fatigue, bone degeneration (osteoporosis) and so on [Kutz 2003]. Femur bone is the largest and strongest bone in the human body that connects the lower body on the hips and lower limbs on the knees. Femur bone has a long cylindrical shape with a high strength so it takes enormous energy to break it. In general, a femur fracture is caused by direct trauma such as a car accident or a fall.

Fixation plate has been used in many fracture cases by implant it in the body through surgery. This procedure restores the fracture bone position back to its original position and maintains it during the fracture healing period [Cronier 2010, Szypryt 2009]. Locking plate might be made of stainless steel or titanium with a certain number of screws attached to it. This construction allows the plate to support the load and body weight as well as maintaining its stability by making a connection between a broken bone [Amalraju 2012, Cronier 2010]. The new system on plating techniques was introduced that is locking compression plate (LCP) which provides a threaded or flat screw hole in the adjacent position. This plate makes the implant much more versatile which can be used for locking screws and nonlocking screws [Szypryt 2009, Niemeyer 2006]. The distance between the plate and the bone also affects stability and fracture healing process [Ahmad 2007]. Therefore, the most difficult thing about healing broken bones with locking plate fixation is to obtain and maintain the tightness of screws while maintaining its stability.

Fracture fixation by using locking plate results in more stable bonding and better bone development. The use of bone screw that retained entirely on the bone-plate can cause the plate to be lifted so as interfere the stability of the bone connection. Therefore, variations or combination of locking screws and nonlocking screws on the plate called hybrid plating are used [Gardner 2006]. Several studies on femur fracture with analysis of the effect of mounting have been performed experimentally or modeled with finite element analysis [Freeman 2010, Doornink 2010, Nourisa 2015]. The use of nonlocking screws indicates a more significant bone healing effect. This is because the plate and screw stay in position, but nonlocking screws provide space to the bone to move or growing [Egol 2004, Smith 2007, Szypryt 2009]. Variations of bone screw mounting are mostly performed on hollow cylinder models with the screws that produce the highest strength in axial, cyclic and torque [Egol 2004, Rowe-Guthrie 2015].

The hybrid plating interaction with the configuration of mounted bone screw by using realistic bone model has not yet been extensively studied. To approximate the actual condition of fixation in the fractured bone, it is very important to make hybrid locking plate model using the real bone model. The screw mounting and load occurred would adjust to the geometry of the bone. Therefore, the analyzing of the bone model influence on the fixation process is needed. Investigation on the effects of screw configuration was conducted with a deep analyzing on the interfragmentary strain that is an indicator of the healing process. In this study, LCP and locked screw type were used [Nourisa 2015]. During loading, the femur bone and plate fixation will experience stretching (strain) and suffer the load in the form of stress. The generated stress will also affect the bone healing process. The purpose of this study was to know the effect of bone screw configuration on hybrid plating by using 3D bone model, which is focused on the stress distribution that developed on plating construction. The real bone model is obtained from the CT-scan of human femur bone that is then processed to become CAD data. Further, locking plate fixation modeling is employed software finite element analysis software, ANSYS Multiphysics/LS-Dyna v.18.1 [ANSYS 2017].

2. FEMUR FRACTURE MODELLING

2.1 Material and Dimension

The fractured femur used in this study was human bones material. The model of femoral bone is obtained from cadaver through CT scan process which is then converted into CAD data and can be used for further analysis. Several methods have been developed to produce a 3D bone model that can be used in the analysis with finite element software [Isaza 2013, Francis 2012, Masood 2013]. Fig. 1 shows the reconstruction of the femur through CT-scan. From CT-scanning, DICOM data was obtained in the form of slicing pictures of the bone with a very small gap to generate a volume. The slicing pictures next processed into NRRD DICOM data using 3D Slicer software which is then converted into a 3D model using EMBODI3D. Final obtained data are .stl that can be altered in CAD software (Solid Work 2014 Student Version) and could be response data for ANSYS.

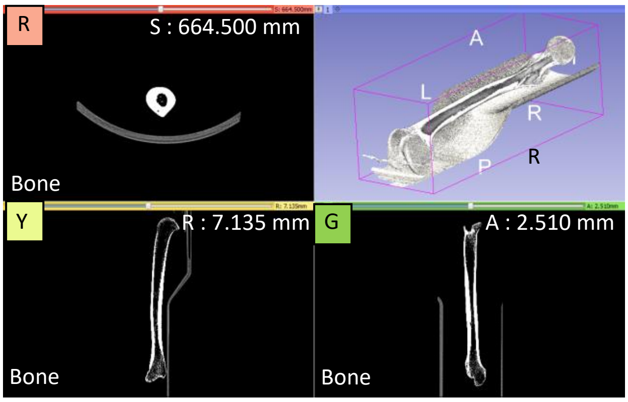


Figure 1. Reconstruction of the femur bone geometry from CT-scan data in 3D Slicer (free version). The red window is for axial view, yellow window is sagittal view, green window is coronal view and the blue window shows the 3D object.

The data of material used in this femur fracture modeling with plate fixation is shown in Tab. 1. Femur bone material was adult human femur bone, while for locking plate and bone screw was made from SS 316 L. For the sake of simplification, femur bone was modeled as a solid cortical bone. Fracture gap was 2 mm in the middle of diaphysis (femur shaft) [Claes 1997, Claes 2002, Smith 2007, Steiner 2014]. It is recommended that the number of the mounted bone screw should not be less than three to maintain axial rigidity and torsional rigidity [Stoffel, 2003]. While mounting many bone screws also does not give any significant effect on the strain that will conduce to the fracture healing process. Conversely, this situation increased the surgery and mounting processes [Nourisa, 2015]. The distance between the plate and the bone also affects the stability and the bone healing process. According to the AO procedure, a surgical management process from diagnosis to aftercare for fracture, the plate is situated on the lateral side of the bone [AO Foundation 2017]. The position of the bone with the plate was set at a distance of 2 mm to provide blood supply so as to support the bone healing process [Szypryt 2009, Rowe-Guthrie 2015]. In addition, it maintains connection stability where axial stiffness and torsional rigidity are optimal [Stoffel 2003, Nourisa 2015].

The type of locking plate used in this study was locking compression plate (LCP) with 8 bone screw holes as shown in Fig. 2. To create hybrid plating model it is required to combine two types of screw that are locking screw and nonlocking screw with specification as depicted in Fig. 3 [Synthes, 2002]. Nevertheless, to simplify the screws geometry, it was modeled as a cylindrical shape without threads. Tab. 2 presents the configuration of bone screws were used in this study.

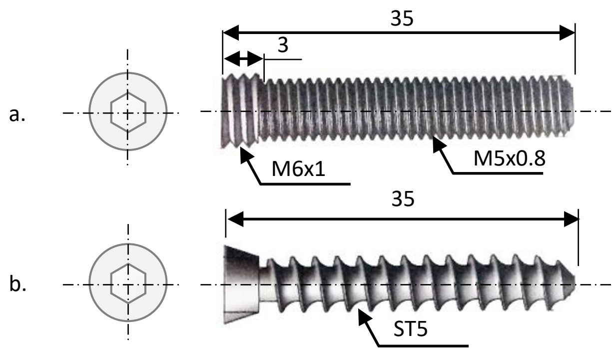


Figure 3. Dimensions of bone screw; (a) locking screw (b) nonlocking screw [Synthes 2002] (in mm)

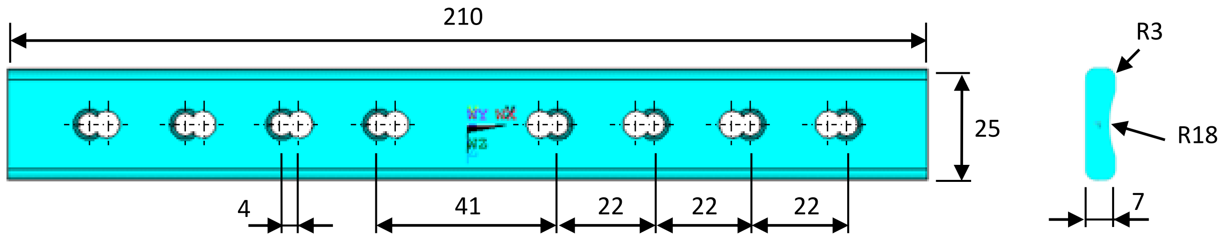
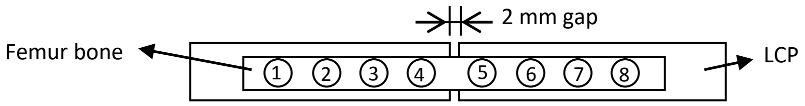


Figure 2. Dimensions of LCP plate with 8 screw holes configuration (in mm)

	Femur Bone [Dhanopia 2017]	Locking plate - Bone screw [Amalraju 2012]
Modulus elasticity (GPa)	17.4	193
Yield strength (MPa)	115	290
Tensile strength (MPa)	133	485
Compressive strength (MPa)	195	570
Poisson ratio	0.39	0.30
Density (kg/m^3)	1950	8000

Table 1. Mechanical properties of hybrid plating materials



Model	Screw configuration	Preview
A	N-L-N-L L-N-L-N	○ ● ○ ● ● ○ ● ○
B	N-N-L-L L-L-N-N	○ ○ ● ● ● ● ○ ○
C	N-L-L-N N-L-L-N	○ ● ● ○ ○ ● ● ○
D	N-L-L-L L-L-L-N	○ ● ● ● ● ● ● ○

● Locking screw (L) ○ Nonlocking screw (N)

Table 2. Construction of hybrid plating with the bone screw configuration (4 models)

2.2 Femur Fracture Modelling

2.2.1 Mesh Generation

Femur fractures with hybrid plating models were created based on the design geometry. To simulate the fracture of the femur, the femur was cut in the middle with a gap of 2 mm. This gap plays a direct role in the bone healing process by callus formation [Claes 1997, Claes 2002, Smith 2007, Steiner 2014]. Discretization of geometry for analysis process employed finite element software was carried out by meshing geometry used SOLID elements 187 as shown in Fig. 4. SOLID Element 187 is a 3-D higher order of element type which has 10-nodes with quadratic displacement behavior. The nodes having three degrees of freedom at each node that is translations in the nodal x, y, and z directions. This type of 3-D element was very suitable for meshing irregular models [ANSYS 2017]. The final result of meshed geometry is shown in Fig. 5 with the size of the finer elements in the parts of contact areas or on uneven surfaces. This is done to get a better approach function of element shapes.

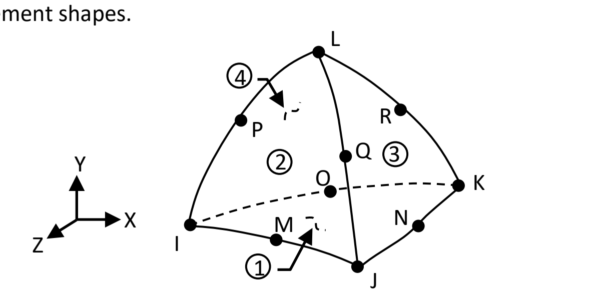


Fig. 4. Geometry of SOLID187 elements. I, J, K, L, M, N, O, P, Q and R are denoting the node numbers at their corresponding position. 1, 2, 3 and 4 represent the surface coordinate systems which are related to the surface load [ANSYS 2017]

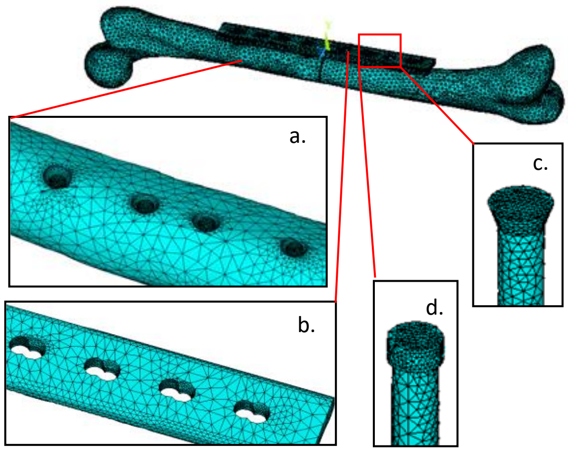


Fig. 5. Meshed volume on femur fracture with internal fixation model; (a) femur bone, (b) locking plate, (c) locking screw and (d) nonlocking screw.

2.2.2 Boundary Condition

The boundary condition is a condition that is applied to each structure parts during loading which produces equal opposed reactions. The given boundary conditions were bolt pretensions, constraints, contacts, and load. Pretension bolt is the applying of initial tightening force when a screw or bolt is mounted. Pretension bolt serves to clamp the two joined objects so that the friction between objects is being restricted and to reduce the effect of loading on the bolts [Predictive Eng. 2001]. Pretension was applied to the element of the screw threaded shaft. At the locking screw, pretension was attached to the threaded shaft and head. While at the nonlocking screw, pretension was only attached to the threaded shaft. The applied pretension load was 1000 N with site as shown in Fig. 6 [Gervais 2016]. The blue vector indicates the direction of pretension tangential force.

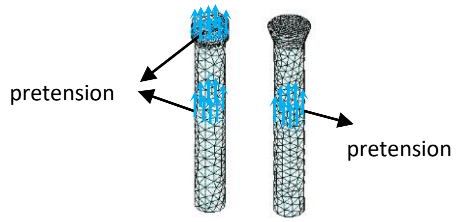


Figure 6. Bolt pretension in locking and nonlocking screws

The contact areas between component parts were subjected to boundary conditions in the form of contact. The developed contact areas might have occurred were bone screws with the holes in the locking plate and bone screws with the femur bone. Friction coefficients of 0.15-2.0 were applied to every contact sites. Constraints or resistances to displacements were provided to meet the actual condition of the human body while standing and on the move. Fig. 7 shows constraints and loading at given conditions. The end of the femur was fixed supported, hence all dof constrained [Dhanopia 2007, Masood 2013]. The amount of applied load was 75 kg (750 N) which works as pressure on the head of the femur (red color) [Dhanopia 2007]. Once the boundary conditions all completed, femur fracture with internal fixation model could be executed to achieve the results.

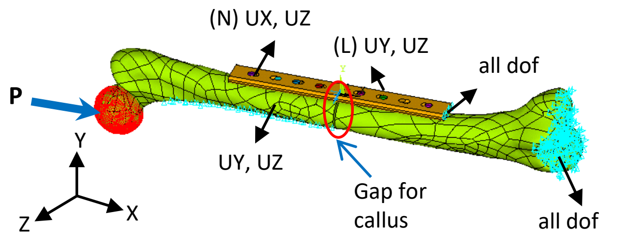


Figure 7. Boundary conditions applied on femur fracture with internal fixation. UX, UY, and UZ means constrained displacements in X, Y, and Z direction, respectively, and all dof means all degree of freedom is constrained.

3. RESULTS AND DISCUSSION

3.1 Simulation Results

The modeling in the femoral fracture case with internal fixation was performed through ANSYS Multiphysics/LS Dyna with non-linear static analysis. The load P was given statically on the head of femur which is the normal adult body mass. With the applied load and boundary conditions, it produced stress distribution in the structure. Fig. 8 demonstrates the stress distribution occurred in the models. The models with screw mounting configuration pointed out a different plot of stress distribution. The applying load on the femur head has produced tensile stress distribution for all segments of internal fixation. The stress contour plot appeared to be concentrated on locking screw mounting area for all the models as depicted in Fig. 9. In general, it can be seen that the sequence of stress distributions from the highest to the lowest value were occurred in the region of locking screw, locking plate, nonlocking screw, and femur bone.

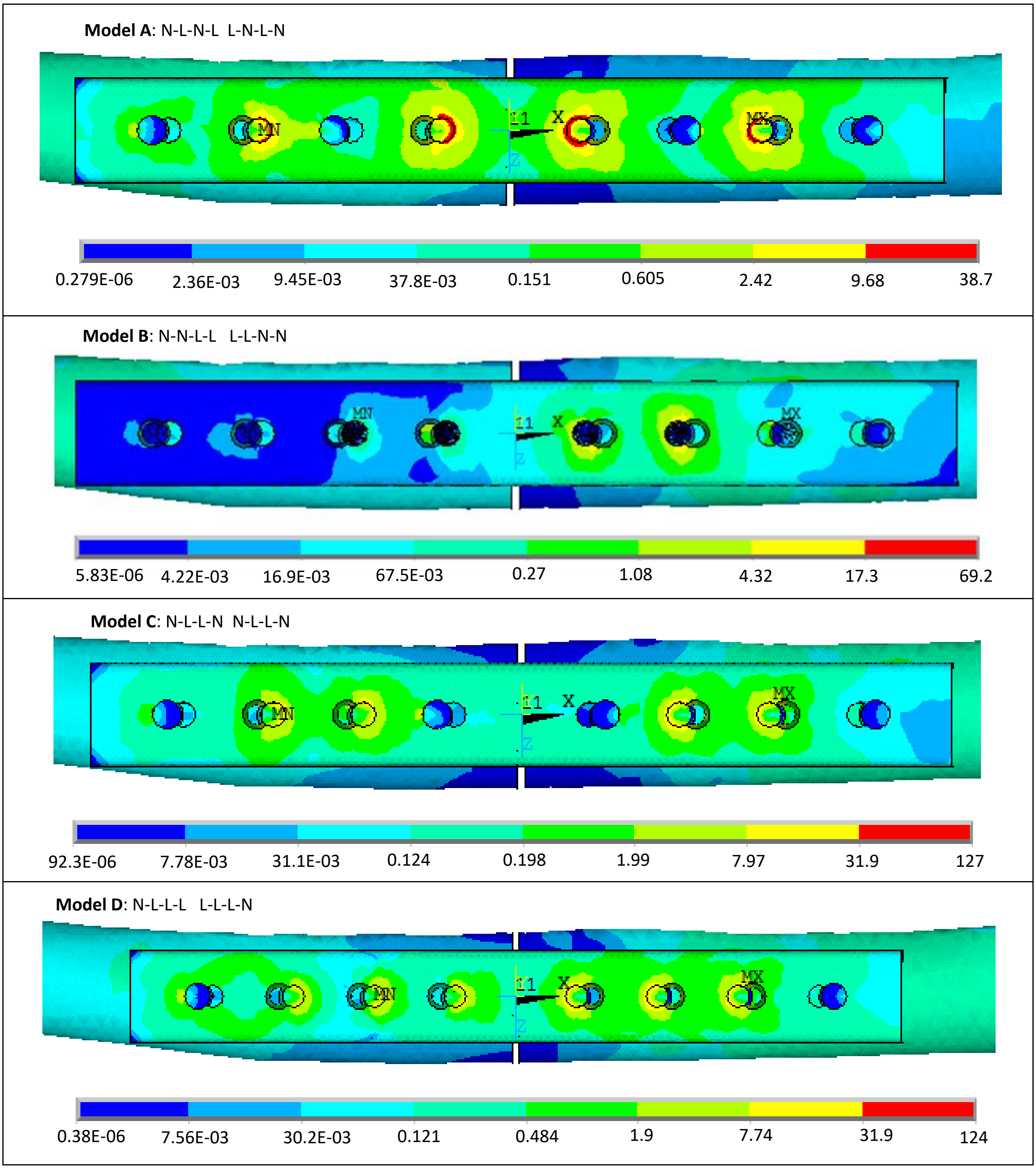


Figure 8. Stress distribution on fracture femur with hybrid plating fixation under axial loading (von Mises Stress in MPa)

Model	Stress (MPa)			
	A	B	C	D
	N-L-N-L ~	N-N-L-L ~	N-L-L-N ~	N-L-L-L ~
Locking screw	38.711	2.176	75.512	52.243
Nonlocking screw	0.326	0.453	0.948	0.517
Locking plate	19.285	10.465	15.699	17.346
Femur	3.76	69.155	127.44	123.82

Table 3. The maximum stress of the hybrid plating fixation with bone screw configuration

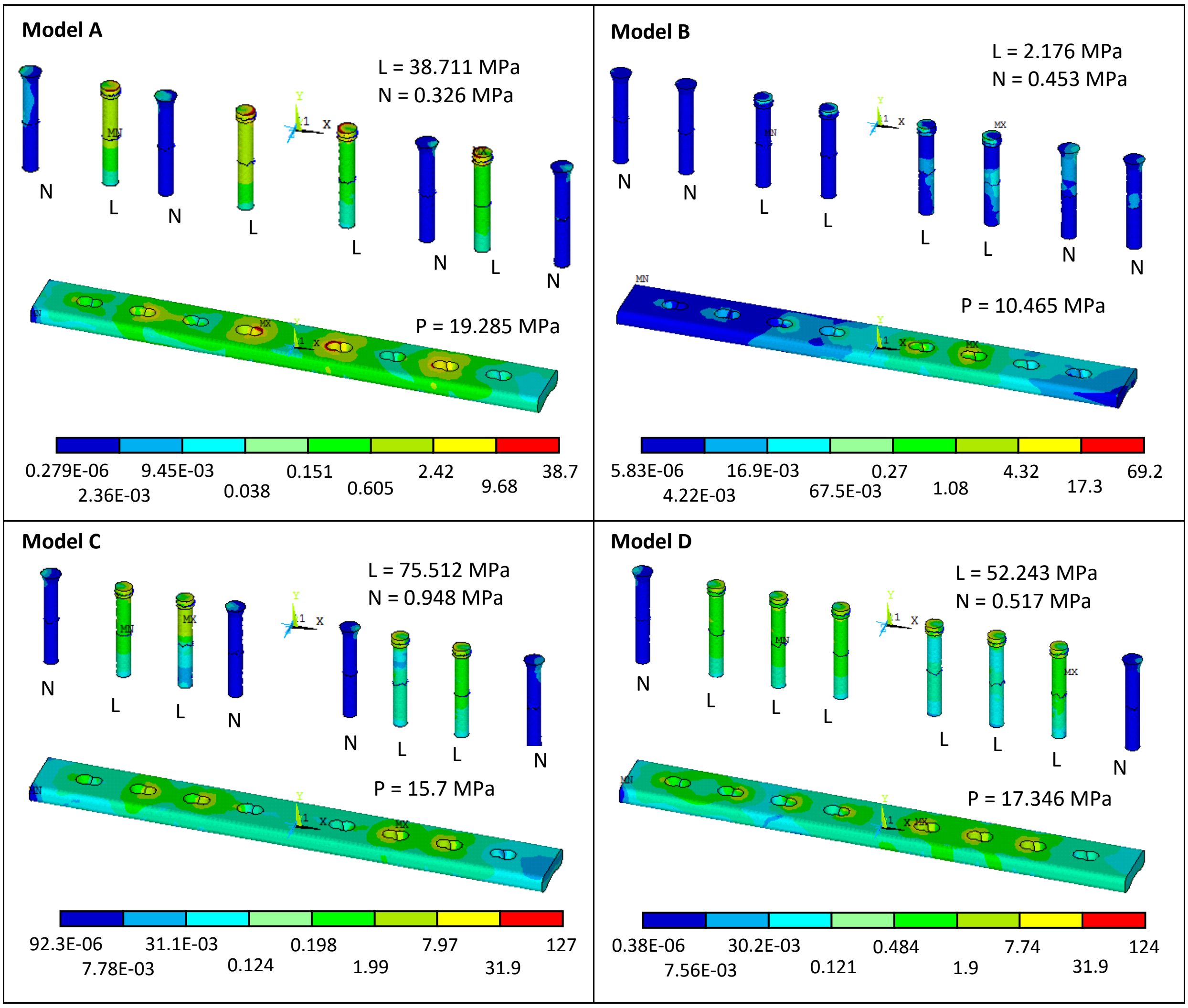


Figure 9. Contour plot of stress on hybrid models plating; L denotes for locking screw, N is nonlocking screw, and P is locking plate (von Mises stress in MPa)

The sequences of constructions with the highest to the lowest stress were Model C, Model D, Model E, Model B and Model A as it is presented in Tab. 3. The stress shown in the table were the equivalent stress values obtained due to axial loading with the failure theory of von Mises. The dark blue color indicates a lower (tensile) tension, while contours degradation with lighter colors denotes the higher stress until reached the maximum value depicted in red as shown in Fig. 8.

Almost all these constructions except models B and E have a maximum stress in the locking screw that was higher than on the plate. Among models with two locking screws and two nonlocking screws configurations, model C produced the highest maximum stress of approx. 75.51 MPa with two locking screws arrangement adjacent to the fracture site. While the addition of a single locking screw with a sequential position on the model D has decreased the maximum stress becomes approx. 52.24 MPa. Insertion of two locking screws and two nonlocking screws in alternating configuration produced a higher stress in the model A with the maximum stress of approx. 38.71 MPa. A lower stress occurred in the model B where the locking screw and nonlocking screw which are mounted in sequence (locking screws were closer to the fracture gap position), it was approx. 21.76 MPa.

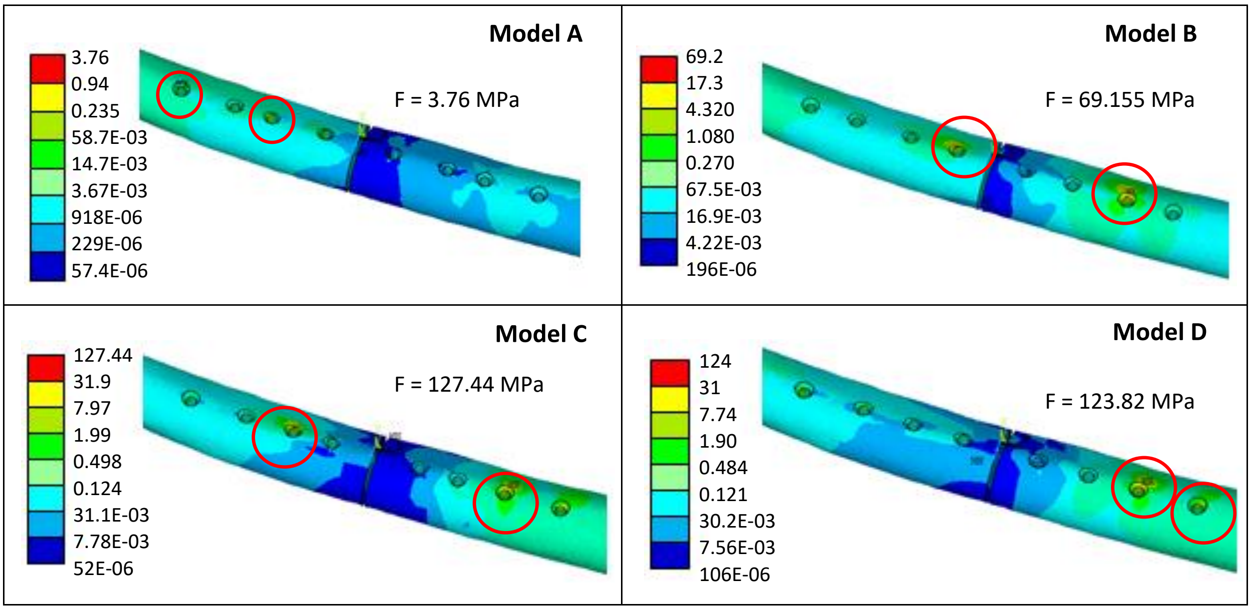


Figure 10. The contour plot of stress distribution on the femur bone (von Mises stress in MPa). Red circles indicate the maximum stress sites.

In locking screws the stress was uniformly distributed mainly on the upper half of the screw length. The maximum stress occurred on one side of the screw shaft or the screw head. The stress that was much lower in the nonlocking screw has occurred in almost models, as shown in Fig. 9 with dark blue contours. In the locking plate, the stress was relatively higher than nonlocking screws. Some stress concentration areas were revealed at higher stress in the hole filled by the locking screws. This phenomenon also occurred in the femur bone models with the maximum stress at the screw holes as it is presented in Fig. 10. The femur model was used in this study have no inner trabecular core, which means only consists of cortical bone. The implant of bone screws was considered would adapt to the threaded holes in the femur bone. These constructions are still can give an idea that the stress concentration would occur at the interface between the screw and the bone.

3.2 Discussion

Femur bone under axial load due to the weight of the body results in developed stress which distributed throughout the internal fixation construction, it worked as resistance to deformation (Fig. 8 and 9) [Beer 2012, Gere 2004]. The fracture gap as a site for callus formation showed dark blue color indicates the stress distribution occurred was low. The load received on the proximal (femoral head) will be forwarded to the left side of diaphyseal (femoral shaft), then it was transmitted through the bone screws and locking plate. This condition resulting stress at the right side of diaphyseal (femoral shaft). On the proximal area especially at the femoral neck exhibited a high-stress distribution as a reaction force since this part was attached to the body. At distal part has a lower stress value as it is presented in Fig. 11. This was due to the femoral shaft was cut. The distal femur will only receive a reaction force when the foot set down and party from the hybrid plating load.

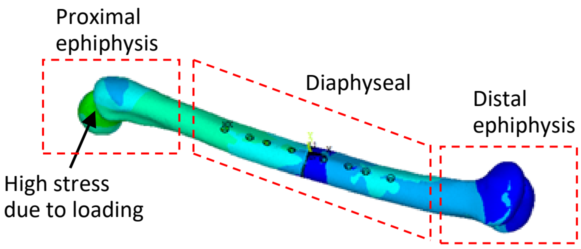


Figure 11. Plot of stress contour on internal fixation of Model A

As a result of the axial compression load on the femur head, the left side of the bone attached to the pelvis would seem to be moved. This displacement gave a boost to the part of the femur that was attached to the knee. In this condition, a locking screw with a threaded head and locked at locking plate will be able to maintain axial and angular stability against developed bending forces. Thus, the locking screw shaft will be shifted in accordance with the direction of both fixed screw head position as it is illustrated in Fig. 12 [Szypryt 2009, Doornink 2010]. This results in stress concentration areas on the top screw shaft and screw head. In nonlocking screws, there will be relaxation (loosen) occurred. Loosening in vertical axis direction might have occurred since the screw head has no angular stability which means the resistance to bending forces was less [Bottlang 2009, Egol 2004].

Model C with N-L-N N-L-N bone screw configurations resulted in the highest stress distribution most on the segments: locking screws, nonlocking screws and femoral bones. This might happen since the locking screw that lies between the nonlocking screws in one segment of the femoral bone. In Model D with more locking screw composition N-L-L L-L-L-N has caused a slight decrease in stress distribution. With the sum of the number of locking screw around the fracture site, it tends to cause the hybrid plating construction became more rigid. Therefore, a high-stress distribution on the segments was exhibited.

Model A with the alternating configuration of locking screws and nonlocking screws yielded lower stress. According to Tab. 3, the stress in the locking screw was almost half of the stress on the C and D models. While the stress in the femoral bone has significantly decreased of approx. 127.44 MPa and approx. 123.82 MPa on the C and D models to 3.76 MPa on model A.

The combination of the bone screw with adjacent position in model A has decreased the enduring stress on femur. The locking screws typically produced high stress distribution due to the bending load, where the head and the screw shaft were attached on the plate and femur [Szypryt 2009]. The high stress concentrations due to the mounting of locking screws was countered by the nonlocking screws. Therefore the femur in Model A enduring the lowest stress. This means the femur bone with the alternating sequence of bone screw was not much affected due to loading. Since the bone is capable of regenerating itself completely by callus formation, the mechanical stress may also affect the bone healing process [Ghiasi 2017] . For this reason, it could be pointed out that model A would be able to assist a stable bone healing process.

On model B, successive locking screws were inserted near to the fracture gap with the configuration of N-N-L-L L-L-N-N. This configuration provided the stress on plate and screws were the lowest among all the models, particularly on the locking screw. But on the femoral bone was relatively lower than the model C and D were to be approx. 69.155 MPa. This value was higher than the stress in model A. This represented that the hybrid plating construction on model B was relatively more stable because each segment of plating construct did not experience too high stress. As the result, the lateral displacement which occurred at locking screws has raised the stress concentration, while the loosening on the nonlocking screws can be further minimized, as it is illustrated in Fig. 9,10, and 12 model B. The plate fixation rigidity affects the fixation stability. But the lower stress on the femur bone biologically would also become one aspect to accelerate the bone healing process. Model A underwent lowest stress distributions in all segments, means it was the safe condition for fixation constructs and the bone health.

The applied axial loading on the femur can produce bending forces on the screws and a bending moment on the locking plate. The far cortex of the femur bone has the greatest micromotion at the fracture gap compared to the near cortex. With the rigidity of locking plate, this behaviour is stimulated to the screw head loosening [Egol 2004, Hak 2010]. The screw loosening or the screw motion on hybrid plating construction might happen due to another reason. The femoral shaft with the distal part attached to the knee, in standing or walking position is enduring the body weight or another force which are acting directly to the femur shaft axis. Therefore, this condition could be simplified as a column structure under compression vertical load. The axially applied load tends to make the femoral shaft deflects laterally and endure lateral bending. This phenomenon is called buckling that is could lead to the failure of the shaft or any structure which has less rigidity [Beer 2012, Gere 2004]. As an example, the fractured femoral bone with the buckling behaviour has made the screws to be loosened or shifted from its position, since the plate has more rigidity.

In this study, the applied load was one cycle static load. The screw displacement was very small in the case of less than 1 micrometer for all hybrid plating constructions. It can be said that there was no prominent displacement where micromotion have occurred. Fig. 12 shows the extreme visualization of screw displacements on hybrid plating construction under axial load. The loosening process on the nonlocking screw is not visible because there are no effects of loading in the vertical direction. The bending force on the screws tends to push the screw shaft inward which resulted in bend motion towards the fracture gap. This condition almost occured on locking screws since the head were attached on the plate. On the distal parts, the bending force effects on mounted screws is diminished which resulted in lesser screws displacement.

Over a long period of time, there may be an increase in axial loading cycles that cause the screw to be shifted, resulted in screw loosening. This condition may contribute to implant failure due to unstable bone fixation [Szypryt 2009]. This study has modelled the effect of internal fixation by using hybrid plating with the configuration of bone screws on the fracture femur. The simulation results as presented in Fig. 12 have shown agreement with the condition of femur under axial loading with fixation constructs [Hak 2010].

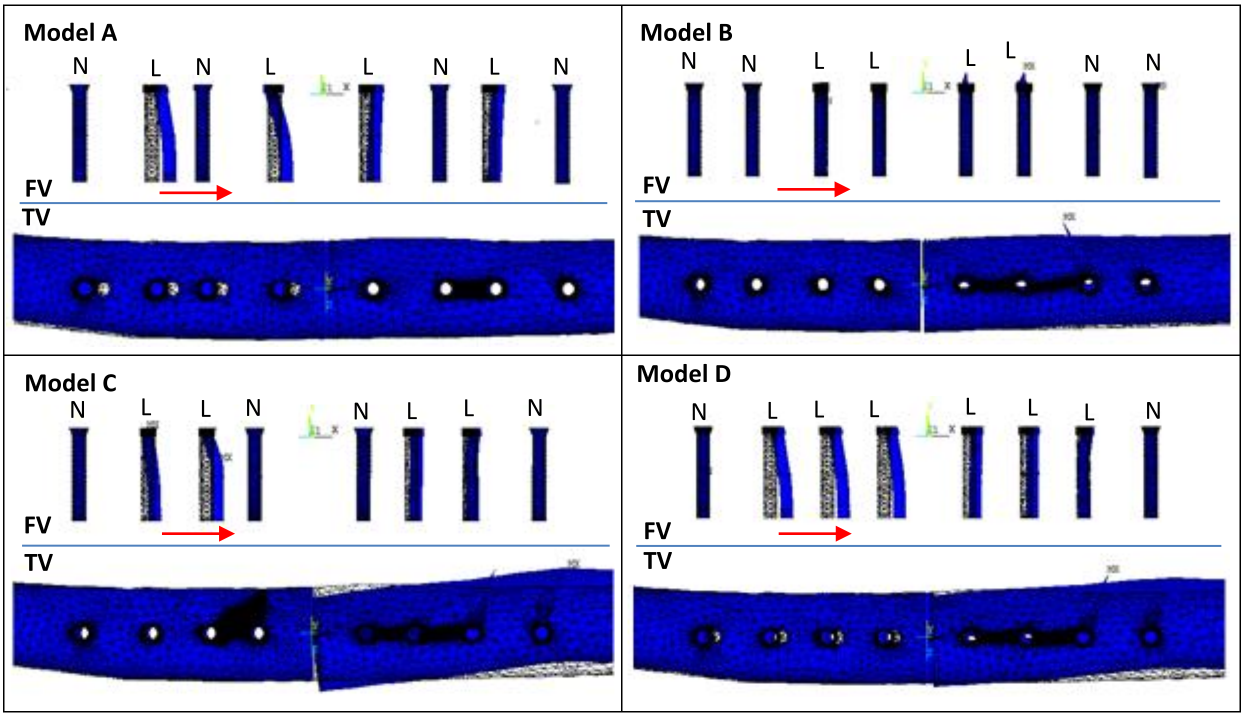


Figure 12. Simulation of the approximation displacements that occur when hybrid plating subjected to axial loading. The meshed volume is the actual shape and the blue color is the displaced volume. The red arrow indicates bending forces direction. FV: front view, TV: top view, correspond to the modelling coordinate system on Fig.7.

In order to better understanding the behaviour of bone-plate fixation under loading, it is better to put the other load fashion such as bending load and bending moment and load cycle numbers [Gervais 2016]. For further study, the 3D femur bone ought to be modelled as trabecular bone, cortical bone with cancellous tissue and marrow on different densities [Isaza 2013]. Hence, the interaction of stress distribution in the femur segments and the fixation construct could be observed. The parts of the bone tissue which is affected during fixation could be fully considered. Many aspects may contribute to the bone healing process such as biological factors and mechanical environment which must be considered for better study [Ghiasi 2017] .

4. CONCLUSIONS

In this study, the effects of screw configurations in fractured femur model by using hybrid plating constructs were investigated. It was shown that the insertion of screw types near to the fracture gap lead to the developing of stress distributions at femur and fixation constructs. While placing two locking screws on the right and left side of the gap, with the alternating configuration of bone screws has generated lowest stress distributions at all segments. The stability and rigidity of bone fixation are important, but the enduring stress at each segment, especially femur bone, will promote the bone healing process.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Design and Engineering System Laboratory of Mechanical Engineering Department, Brawijaya University and also thankful to the Histology Anatomy Laboratory of Medical Faculty, Brawijaya University, Indonesia.

REFERENCES

[Ahmad 2007] Ahmad, M. et al. Biomechanical Testing of The Locking Compression Plate: When Does The Distance Between Bone and Implant Significantly Reduce Construct Stability. Injury, Vol. 38, No. 3, March 2007, pp 358-364. ISSN 0020-1383

[Amalraju 2012] Amalraju, D. and Dawood, A.K.S. Mechanical strength evaluation analysis of stainless steel and titanium locking plate for femur bone fracture. Engineering Science and Technology: An International Journal (ESTIJ), June 2012, Vol.2, No. 3, pp 381-388. ISSN 2250-3498

[ANSYS 2017] ANSYS ACADEMIC Version 18.1, 2017.

[AO Foundation 2017] AO Foundation. Plates-AO Surgery Reference. Online Reference in Clinical Life. https://www2.aofoundation.org, 2017.

[Beer 2012] Beer, F.P. et al. Mechanics of Materials. Six Edition, New York: Mc GrawHill, 2012. ISBN 978-0-07-338028-5

[Bottlang 2009] Bottlang, M. et al. A Nonlocking End Screw Can Decrease Fracture Risk Caused by Locked Plating in The Osteoporotic Diaphysis. The Journal of Bone and Joint Surgery, Vol. 91, 2009, pp 620-627. ISSN 0021-9355

[Claes 2002] Claes L. et al. The Effect of Mechanical Stability on Local Vascularization and Tissue Differentiation in Callus Healing. Journal of Orthopaedic Research, 2002, Vol. 20, pp 1099-1105. ISSN 0736-0266

[Cronier 2010] Cronier, P. et al. The Concept of Locking Plates. Orthopaedics & Traumatology: Surgery & Research, 2010, 96S, pp 17-36. ISSN 1877-0568

[Dhanopia 2017] Dhanopia, A. and Bhargava, M. Finite Element Analysis of Human Fractured Femur Bone Implantation with PMMA Thermoplastic Prosthetic Plate. Procedia Engineering, 2017, Vol. 173, pp 1648-1665. ISSN 1877-7058

[Doornink 2010] Doornink, J. et al. Effects of Hybrid Plating With Locked And Nonlocked Screws on The Strength of Locked Plating Constructs in The Osteoporotic Diaphysis. The Journal of Trauma: Injury, Infection, and Critical Care, August 2010, Vol.69, No. 2, pp 411-417. ISSN 1079-6061

[Egol 2004] Egol, K.A. et al. Biomechanics of Locked Plates and Screws, Journal Orthopaedic Trauma. September 2004, Vol. 18, No. 8, pp 488-493. ISSN 0890-5339

[Freeman 2010] Freeman, A.L. et al. How Much Do Locked Screws Add To The Fixation Of “Hybrid” Plate Constructs in Osteoporotic Bone? Journal of Orthopaedic Trauma, 2010, Vol. 24, pp 163-169. ISSN 0890-5339

[Gere 2004] Gere, J.M. Mechanics of Materials. Belmont: Brooks/Cole-Thomson Learning, 2004. ISBN 0-534-41793-0

[Ghiasi 2017] Ghiasi, M.S. et al. Bone fracture healing in mechanobiological modeling: A review of principles and methods. Bone Reports, Elsevier Ltd., 2017, Vol. 6, pp 87-100

[Masood 2013] Masood, M.S. et al. Unconventional Modeling and Stress Analysis of Femur Bone Under Different Boundary Condition. International Journal of Scientific & Engineering Research, December 2013, Vol. 4, No. 12, pp 293-296. ISSN 2229-5518

[Niemeyer 2006] Niemeyer, P. and Südkamp, N.P. Principles and Clinical Application of The Locking Compression Plate (LCP) Actachirurgiae Orthopaedicae Et Traumatologiae Čechosl., 2006, Vol. 73, pp 221-228. ISSN 0001-5415

[Nourisa 2015] Nourisa, J. et al. The Effects of Bone Screw Configurations on The Interfragmentary Movement in A Long Bone Fixed by A Limited Contact. Journal Biomedical Science and Engineering, 2015, Vol. 8, pp 590-600. ISSN 1937-6871

[Saidpour 2006] Saidpour, H. Finite Element Stress Analysis of A Hybrid Fracture Fixation Plate. Proceedings of Advances in Computing and Technology (AC&T), The School of Computing and Technology 1st Annual Conference, 2006. London: University of East London, pp 173-183.

[SW 2014] SW (Solid Work) Student Version, 2014.

[Smith 2007] Smith, W.R. et al. Locking Plates: Tips and Tricks. The Journal of Bone & Joint Surgery, October 2007, Vol. 89-a, No. 10, pp 2298-2307.

[Stoffel 2003] Stoffel, K. et al. Biomechanical Testing of The LCP - How Can Stability in Locked Internal Fixators Be Controlled. Injury, 2003, Vol. 34, pp 11-19.

[Synthes 2002] Synthes Instruments and Implats. Small Fragment Locking Compression Plate (LCP) System. West Chester: Synthes Inc., USA, 2002.

[Szypryt 2009] Szypryt, P. and Forward, D. The Use and Abuse of Locking Plates. Orthopaedics and Trauma, Elsevier Ltd., 2009, Vol. 23, No. 4, pp 281-290. ISSN 1877-1327

CONTACTS:

Nafisah Arina Hidayati, M.Eng.
Dr.Eng. Moch. Agus Choiron
Dr.Eng. Sofyan Arief Setyabudi
Brawijaya University, Mechanical Engineering Department
Jl. M.T. Haryono 167, Malang, 65145, Indonesia
Tel.: 62-0341-587710
e-mail: nafisah@ub.ac.id
http://mesin.ub.ac.id/