The Initial Modelling of Hybrid Plating For Internal Fixation Construct by Using 3-D Bone Model

Nafisah Arina Hidayati, Moch. Agus Choiron, Sofyan Arief Setyabudi, Erwin Sulistyo
Department of Mechanical Engineering, Brawijaya University, Malang, Indonesia
E-mail : nafisah@ub.ac.id

Abstract. The development of locking plate design provides benefits especially for more stable plate fixation in bone and allows better fracture joint development. Hybrid locking plate modelling as fixation on femur fracture by using a real bone model were investigated. Internal fixation modelling were successfully perfomed on ANSYS v.14.5 with the geometry of femur as a 3D bone model which was obtained from CT-scan process. The configuration of screw bone mounting with the N-L-N-L N-L-N-L pattern filled 8 holes in the locking plate. The mounting of bone screws in the fixation process induced the contact areas as the origin of stress development. It is worked as the support of the locking plate that has been locked with locking screw and it is expected to maintain a stable position of the femur bone on its position. The low stress on femur bone were obtained which means that the bone was not much suffered due to applied load and may also affect the bone healing process. The use of hybrid plating is expected to guarantee a fixed fixation condition so that the bone healing process by callus formation between broken bones can take place continuously.

Keywords: Hybrid plating, femur fracture, 3D bone, configuration, stress.

1. Introduction
Femur is the tight bone which supports the body weight during activities. Femur as the part of lower limbs has function to connect the upper body on the hips and the lower body on the knees. As the longest tubular bone with anterior bow anatomy, it serves as the strongest bone in human body. Therefore, a femur fracture is a result of a high-energy trauma except in eldery people or diseased bones [1]. In general, the discontinuity on the bones is caused by direct trauma or severe injuries such as in a car accident or a fall from high position. To support the broken bones, fixation plates has been used by implant it inside or outside the body depends on the fracture conditions. The types of fracture are might formed depend on position of limb during impaction and magnitude of applied loads [2].

Femoral shaft fracture is condition with a break anywhere along the length of femur. This type of broken leg almost requires surgery to heal and growth, which is commonly, use locking compression plate (LCP) for long bone fracture treatments [3, 4]. LCP is plating technique that provides a threaded and flat screw holes in adjacent position. This plate gives wide range of options for implant to be used for locking screws and nonlocking screws. In case of conventional plate, it applies some pressure on the bone hence resulted some friction at the contact sites between plate and bone. The increase of axial load cycles has decreased the frictional force, which affected to screw rigidity and loosed the plate. If this happens prematurely, fracture instability will occur and might lead to implant failure [5, 6]. In
consequence, the procedure to obtain and maintain the tightness of screws while maintaining its stability by locking plate fixation are become a main concern during broken bones healing process. The big challenge for a surgeon to manage the bone fracture cases is planning and decision making before and during operative treatment. How to obtain and maintain the stability of the fracture fixation determines the times required for bone healing [7, 8]. Therefore, to attain a satisfactory bone union, the correct selection and application of surgical technique is more important than the type of plate used [4]. Determination of bone screw mounting [3] to control the axis and rotation is mandatory to avoid postoperative malrotation, hence connection stability and torsional rigidity was maintained [9, 10]. The use of hybrid plating on femur fracture shows a more significant effect on bone healing [5, 11, 12]. However, the previous study on variations of bone screw mounting are mostly performed on hollow cylinder models with the screws towards applied axial load, cyclic load and torsion [11, 13].

In order to approach the actual condition in the case of fixation in a broken bone, it is very important to do hybrid locking plate modelling using a real bone model. The configuration of screw mounting with load applied would fit to the bone geometry. Thus, the analysing of the bone model influence on the fixation process is required. Therefore, the objective of present study is how to create modeling for internal fixation on femur fracture by using a real 3D bone model. Performing fixation modelling employs finite element-based software can be one method to gain biomechanical background and guidelines for operative treatment of fractures. Internal fixation modelling by using hybrid plating construct was performed by using software based on finite element analysis [14].

2. Method
Femur fracture modelling was performed using finite element analysis based software, ANSYS Multiphysics v. 14.5. The femur bone model was obtained from the CT-scan process of the adult human femur bone, which is then processed into 3-D CAD for further study [15-18]. The type of locking plate used was a hybrid plating with a combination of locking screw and non-locking screw of eight holes. The material for locking plate and bone screw was made from SS 316 L. The locking plate design with the femur bone model is shown in Figure 1 while the locking plate and bone screw dimensions used are shown in Figures 2 and 3. The plate is situated on the lateral side of the bone with some adjusted space over the bone [19]. The distance between the plate and the bone gives effects on the fixation stability and the bone healing process [20]. Thus, the position of the bone over the plate was set at a distance of 2 mm to allow blood supply so as to support the bone healing process [5, 13]. Fracture gap was 2 mm in the middle of femur shaft (diaphysis) which [21-24]. To simplify the screws geometry, it was modeled as a solid cylindrical shape without threads. Table 1 presents the properties for the hybrid plating construct. In this study, to model hybrid plating, the installation of bone screw was varied with the combination of N-L-N-L N-L-N-L where N is non-locking screw and L is the locking crew. The use of non-locking screw on the outer end of the plate because it can reduce the risk of broken parts [25].

Figure 1. Femur fracture modelling with hybrid plating constructs
Figure 2. Dimensions of bone screw; (a) locking screw (b) non-locking screw [26]

Table 1 Mechanical properties of hybrid plating materials for internal fixation modeling

|                        | Femur [27] | Locking plate -Bone screw [28] |
|------------------------|------------|-------------------------------|
| Modulus elasticity (GPa) | 17.4       | 193                           |
| Yield strength (N/m²)   | 115        | 290                           |
| Tensile strength (MPa)  | 133        | 485                           |
| Compressive strength (MPa) | 195    | 570                           |
| Poisson ratio           | 0.39       | 0.30                          |
| Density (kg/m³)         | 1950       | 8000                          |

Figure 3 Geometry of LCP plate with 8 screw holes configuration (in mm) [18]

Internal fixation modeling using hybrid plating is performed by importing the geometry of the real femur bone obtained from CT-scan images [18]. Locking plates with screw bone combinations were created according to specifications and it arranged to obtain a femur fracture model. Meshing or discretization process of all existing geometries is done by input the material properties and the use of SOLID element type 187. SOLID Element 187 as shown in Figure 4 is a high-order 3-D element with 10-node, SOLID187 element has a quadratic displacement behavior that is very suitable to model irregular meshing [14]. The result of the geometry meshing is shown in Figure 6 with finer element sizes on the parts that are in contact with each other or on uneven surfaces. This carried out to get a better element form approach function. The element size globally is smart 6, while for the screw hole section a smaller element size is used which is a contact area with a size of 0.6 which can be seen in Figure 5.

Figure 4. Geometry of SOLID187 elements [14]
Pretension bolt is a loading condition or giving the initial tightening force when a screw or bolt is mounted. Pretension was subjected to elements along the threaded surface. For locking screw, the pretension was applied to the shaft and head. Whereas in non-locking screw, the pretension was only applied to threaded shaft. The pretension force used was 1000 N and its position as shown in Figure 6 with a blue arrow which is the tangential direction of force [29].

When bone screw mounted in femur bone through locking plate, it involves several conditions where each geometry were in contact. These prevail when internal fixation is implanted or when loading occurs, that is, when a patient with a broken bone is in standing position or doing activities. The contact conditions that occur in the case of internal fixation are described as model in Figure 7. The contact area is defined as the area that touch each other between fixation components with the friction coefficient between 0.15 - 0.2.
Femoral bone is considered as a fixed structure because it is articulates with joint on the knee which is immovable. Therefore, the type of constraint given is all dof on the right femur. In this condition, surface pressure was applied to the femur bone head and constraints in the direction of UY and UZ. Locking plate is considered an immovable object, therefore all dof constraints are also applied on the right side. Whereas for locking screw is given UX, UZ constraints which allows Y direction movement (when plate is lifted) and on non-locking screw is given UY, UZ constraint which allows X direction movement (when shifting together with the bone) as show in the Figure 8. The load was subjected on the head of femur in the form of surface load which is the body weight of 75 kg.

![Figure 8. Load and boundary condition settings](image)

3. Results and Discussion

Internal fixation modeling in femur fracture case has been carried out through ANSYS Multiphysics/LS Dyna using nonlinear static analysis. P load, which is a normal adult body mass, was set statically to the head of the femur. Figure 9 shows the distribution of stresses arising in each component of a hybrid plating construction. With the load on the femur head, a tensile stress distribution is generated on the femur, locking plate, and bone screws. The stress distribution contour appears to be concentrated in the locking screw mounting area as shown in Figure 9.

Table 2 presents the maximum stress which is occurred at components of a hybrid plating construction. It can be seen generally that the sequence of stress distribution from the highest to the lowest stress was at the locking screw, locking plate area, non-locking screw, and femur bone. The locking screws experienced the highest stress since it suffered the bending force while load applied. The screws tend to resist their positions on hybrid construct, therefore high stress concentration were developed on the head ans shaft of the screw [5]. The attachment of nonlocking screws at the end of fixation produced low stress at the screws or femur [25]. These screws also provided space to the bone to move or growing, hence give influence to the bone healing process [5,11-12].

![Figure 9. Stress distribution on hybrid plating construction](image)
Figure 10. Stress distribution is concentrated in the locking screw mounting area

Table 2. Maximum stress which are occurred at hybrid plating components

| Components         | Stress (MPa) |
|--------------------|--------------|
| Locking screw      | 38.711       |
| Nonlocking screw   | 0.326        |
| Locking plate      | 19.285       |
| Femur              | 3.76         |

Tensile stress distributions were developed throughout the internal fixation construction when the femur bone was under axial load due to the weight of the body, it worked as resistance to deformation (Fig. 8 and 9) [30, 31]. In the middle of femur where the fracture gap was existed showed dark blue color indicates the stress distribution occurred was low. This gap has function as the site for callus formation. When the load received on the femoral head (proximal), it will be forwarded to the femoral shaft (left side of diaphyseal), then it transmitted through the bone screws, locking plate and the right side of femoral shaft (diaphyseal). The femoral neck on the proximal area represented a high-stress distribution which is work as a reaction force since this part was attached to the body. At distal part has a lower stress value as shown in Fig. 11. Since the femoral shaft was cut, the distal femur will only receive a reaction force when the foot is in contact with the floor.

Figure 11. Plot of stress contour on femur with hybrid plating

The combination of the bone screw with adjacent position N-L-N-L L-N-L-N resulting with a low enduring stress on femur. High stress distribution was typically produced at the locking screws due to the bending load, where the screw’s head and shaft were attached on the plate and femur [5]. The mounting of nonlocking screws would countered the high stress distributions due to locking screws. Therefore the femur in this hybrid plating construct enduring the lowest stress. This means the femur bone with the alternating sequence of bone screw was not much affected due to applied load on the femur. Since the bone is capable of regenerating itself completely by callus formation, the mechanical stress which occurred at the internal fixation construct may also affect the bone healing process [32]. Accordingly, it could be pointed out that modelling of hybrid plating with configuration of N-L-N-L L-N-L-N would be able to assist a stable bone healing process since the enduring stress on femur was small (Table 2).
As matter of fact that the femur model was used in this study only consists of cortical bone, the developed stress due to screw mounting would adapt to the geometry of 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. Therefore, for the further study, it is necessary to perform femur bone modelling with combination of cortical bone and cancellous tissue [15]. The load types and load cycle numbers might also affect the hybrid plating construct towards the femur stability or rigidity [29]. Hence, the internal stress distribution in the fixation constructs and femur segments could be observed which one of the model would give approach procedure to achieve a stabil bone fixation. The variation on screw configuration were also reported affected the behaviour of hybrid plating constructs due to applied axial load [19].

4. Conclusion
Internal fixation modeling on femur fracture by using hybrid plating constructs were investigated with screw configurations of N-L-N-L, L-N-L-N. The mounting of bone screw in the fixation process induced the contact areas as the origin of stress development. It is worked as the support of the locking plate that has been locked to the bone, thus it is expected to maintain a stable position of the femur bone on its position during the healing process. 3D real bone modelling has given a real approachment of stress distribution due to applied axial load. The alternating configuration of bone screws result in low stress distributions on femur were observed. The use of hybrid plating is expected to guarantee a fixed fixation condition so that the bone healing process with the formation of callus between broken bones can take place continuously.

5. References
[1] Kutz M 2003 Standard handbook of biomedical engineering and design. McGraw-Hill. New York.
[2] Fleps I 2018 On the internal reaction forces, energy absorption and fracture in the hip during simulated sideways fall impact PloS ONE 13 8: e0200952 1-18.
[3] Niemeyer P and Südkamp NP 2006 Principles and clinical application of the locking compression plate (LCP) Actachirurgiae Orthopaedicae Et Traumatologiae Čechosl. 73 221-28.
[4] Azboy I et al. 2013 Effectiveness of locking versus dynamic compression plates for diaphyseal forearm fractures Orthopedics 36 (7) 917-22.
[5] Szypryt P and Forward D 2009 The use and abuse of locking plates Orthopaedics and Trauma Elsevier Ltd. 23 4 281-290.
[6] Cronier P et al. 2010 The Concept of locking plates Orthopaedics & Traumatology: Surgery & Research 96S S17-S36.
[7] Waner M 2016 Fracture fixation using the locking compression plate (LCP). AO Trauma Principles Course- Basic Principles of Fracture Management.
[8] Neumann M V et al. 2015 Management of femoral shaft fractures Acta Chirurgiae Orthopaedicae Et Traumatologiae Čechosl. 82 22-32.
[9] Stoffel K et al. 2003 Biomechanical testing of the LCP-how can stability in locked internal fixators be controlled? Injury 34 11-19.
[10] Nourisa J et al. 2015 The Effects of bone screw configurations on the interfragmentary movement in a long bone fixed by a limited contact locking compression plate J. Biomedical Science and Engineering 8 590-600.
[11] Egol KA et al. 2004 Biomechanics of locked plates and screws Journal Orthopaedic Trauma 18 8 488-93.
[12] Smith WR et al. 2007 Locking plates: tips and tricks The Journal of Bone & Joint Surgery 89a (10) 2298-307.
[13] Guthrie KMR et al. 2015 Mechanical evaluation of locking, nonlocking, and hybrid plating constructs using a locking compression plate in a canine synthetic bone model Veterinary Surgery 44 (7) 838-42.
[14] ANSYS ACADEMIC Version 18.1 2017.
[15] Isaza E et al. 2013 Determination of mechanic resistance of osseous element through finite element modeling Proceedings of the 2013 COMSOL Conference in Boston.
[16] Francis A and Kumar V 2012 Computational modeling of human femur using ct data for finite element analysis International Journal of Engineering Research & Technology (IJERT) 1 6.
[17] Masood MS et al. 2013 Unconventional modeling and stress analysis of femur bone under different boundary condition International Journal of Scientific & Engineering Research 4 (12) 293-96.
[18] Hidayati NA et al. 2018 Configuration on hybrid plating to improve internal fixation on femur bone model MM Science Journal 2018 2 2406-14.
[19] AO Foundation 2017 Plates-AO Surgery Reference. Online Reference in Clinical Life. https://www2.aofoundation.org.
[20] Ahmad M et al. 2007 Biomechanical testing of the locking compression plate: when does the distance between bone and implant significantly reduce construct stability Injury 38 (3) 358-64.
[21] Steiner M 2014 Numerical simulation of callus healing for optimization of fracture fixation stiffness PLoS One 9(7): e101370 1-11.
[22] Smith WR et al. 2007 Locking plates: tips and tricks The Journal of Bone & Joint Surgery 89 (10) 2298-307.
[23] Claes L et al. 1997 Influence of Size and stability of the osteotomy gap on the success of fracture healing Journal of Orthopaedic Research 15 (4) 577-84.
[24] Claes L et al. 2002 The effect of mechanical stability on local vascularization and tissue differentiation in callus healing Journal of Orthopaedic Research 20 1099-105.
[25] Bottlang M et al. 2009 A nonlocking end screw can decrease fracture risk caused by locked plating in the osteoporotic diaphysis The Journal of Bone and Joint Surgery 91 620-27.
[26] Synthes Instruments and Implants 2002 Small fragment locking compression plate (LCP) system. West Chester: Synthes Inc., USA.
[27] Dhanopia A and Bhargava M 2017 Finite element analysis of human fractured femur bone implantation with PMMA thermoplastic prosthetic plate Procedia Engineering 173 1648-65.
[28] Amalraju D. and Dawood AKS 2012 Mechanical strength evaluation analysis of stainless steel and titanium locking plate for femur bone fracture Engineering Science and Technology: An International Journal (ESTIJ) 2 (3) 381-88.
[29] Gervais B et al. 2016 Failure analysis of A 316l stainless steel femoral orthopedic implant, case studies in engineering failure analysis 5-6 30-38.
[30] Beer FP et al. 2012 Mechanics of Materials. Six Edition, New York: Mc GrawHill.
[31] Gere JM 2004 Mechanics of Materials. Belmont: Brooks/Cole-Thomson Learning.
[32] Ghiasi MS et al. 2017 Bone fracture healing in mechanobiological modeling: A review of principles and methods Bone Reports 6 87-100.