Finite Element Analysis of Dynamic Hip Screw for Intertrochanteric Fracture

Supakit Rooppakhun and Kasem Siamnuai

Abstract—**The aim of the present study was to evaluate the intertrochanteric fracture fixation by a Dynamic Hip Screw (DHS) with the various plate length. The analysis domains consist of the intact femur with two millimeters of the fracture gap stabilized by 2-hole, 4-hole, 6-hole and 8-hole of DHS. All simulations were performed under one-legged stance walking activity condition. In this study, the stress distribution, elastic strain, and strain energy density were the main parameters used to evaluate the risk of implant failure, the stability of fracture site including the energy absorption or load sharing, respectively. According to the results, there are no significant differences in the increasing plate length to the level of stress distribution as well as the stability of fracture. In early state, the patient should be avoided the full bearing weight for the risk of implant failure. In addition, the removal implant should operate after complete healing bone.**

Index Terms—**Dynamic hip screw, plate length, stability of fracture, intertrochanteric fracture**

I. Introduction

Hip fracture is one of the most orthopedic injuries found in elderly [1]. The fractures can be classified in three groups according to the bone portions which are the femoral neck fracture, intertrochanteric fracture, and sub-trochanteric fracture [2]. In general, post-traumatic treatment is done by stabilizing the fracture with fixation devices to allow early weight bearing. The fixation devices for hip fracture can be intramedullary based devices such as Trochanteric Gamma Nail (TGN). However, the extramedullary devices are also utilized. One of the common extramedullary devices, dynamic Hip Screw (DHS) is the standard internal fixation device for the treatment of the hip fracture [3-5]. The system consists of a sliding lag screw assembled to a dynamic plate including the fixation screw. Biomechanically, DHS are subjected to the bending moment generated by the hip contact force and the distance from femoral head center to lateral femoral shaft. The material of DHS may be titanium or stainless steel [1], [6]. The plate length range from 2-hole until 8-hole. Normally, the surgeon selects the length of plate to cover the fracture site. Currently, there are various researches presenting the results of biomechanical performance of DHS [6]-[8]. However, no previous research has interested in the influence of DHS plate length on the mechanical performance.

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Therefore, this study is aimed to investigate the mechanical performance of the DHS by using finite element method. The finite element model of the intertrochanteric femoral fracture stabilized by means of DHS was created in order to evaluate the stress/strain distributions as well as the strain energy density. The effects of the different DHS plate length to the stresses/strain distributions were calculated in the early and complete fracture healing states. In addition, the analyses were also performed in the healed proximal femur with retained DHS and after DHS removal.

II. Materials and Methods

The analyses were performed using MSC PATRAN and MSC MARC MENTAT 2005 commercial finite element software package. The domains under consideration were an intact femur with IA intertrochanteric fracture type [9] stabilized by stainless steel 316 LVM - DHS 135°. In order to investigate the influence of plate length, the 2-hole DHS, 4-hole DHS, 6-hole DHS, and 8-hole DHS were used. The fracture site had two millimeters thickness which was located in the intertrochanteric region.

A. Three-Dimensional Finite Element (3D FE) Models

In this study, the proximal femur was based on the standard femur model of the International Society of Biomechanics Finite Element Repository [10]. The three-dimensional (3D) model of DHSs were created by using SolidWork 2010 CAD commercial software. Ten-node tetrahedral element (Tet-10) was used in the simulation. The 3D FE models were constructed by the means of an automatic mesh generation technique (MSC PATRAN). The numbers of element were range following 49,545 to 78,338 as shown in Fig. 1.

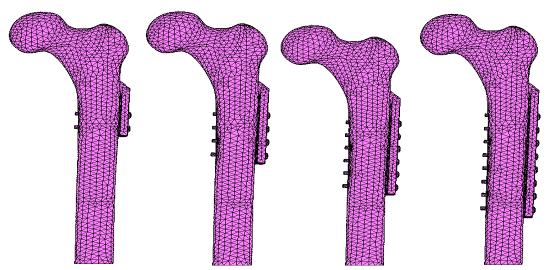

Fig. 1. The 3D FE models of the intertrochanteric fracture stabilized by various DHS; (a) 2-hole DHS, (b) 4-hole DHS, (c) 6-holeDHS, (d) 8-holeDHS

B. Material Properties

For the material assignment, different material properties were attributed to the different regions of the proximal femur. In the early state of bone healing (state-1), the material property of fracture site was represented to the initial connective tissue defined as low elastic modulus. On the other hand, the complete fracture healing state (state-2), the material property was increased proportionally to the time of rehabilitation [6]. The material definition of implant was assigned as stainless steel. The material properties were assumed to be linear elastic, homogenous, and isotropic as shown in Table I

TABLE I: MATERIAL PROPERTIES [6]

Part	Elastic modulus (MPa) / Poisson's ratio	
	Cortical bone	*Trabecular bone*
Femoral head	17,000/0.3	900/0.29
Femoral neck	17,000/0.3	620/0.29
Intertrochanterics region	17,000/0.3	260/0.29
Fracture site (state-1)	3/0.4	3/0.4
Fracture site (state-2)	17000/0.3	260/0.29
Femoral shaft	17,000/0.3	
Stainless steel	200,000/0.3	

C. Boundary Conditions

A body weight and related muscle forces in walking activity condition were applied (Table II). The magnitude of applied loads were considered at the state of maximum load occurrence in gait cycle described by Bern-arno et al. [11]. Beside, the distal end of the proximal femur was fully constrained the degree of freedom as shown in Fig. 2

D. Contact Conditions

Regard to the contact condition, all contact body which related to the proximal femur were assumed with no relative displacement to each other. The components of implant attached to the femur were considered as allow the relative displacement, except the screw components simplified to be cylindrical shape. In addition, the dynamic sliding plate was allowed the relative displacement to the lag screw and screw components.

TABLE II: LOADING CONDITIONS UNDER WALKING ACTIVITY [11]

Force	Magnitudes (N)			Point
	X	*Y*	*Z*	
Hip contact	452.38	261.90	-1,833.33	P1
Abductor	-475.00	20.00	700.00	P2
Tensor Fascia Latae	82.40	127	-59.45	P2
Vastus Lateralis	5.63	-135	-673.13	P3
Vastus Medialis	3.80	-12.93	-70.76	P4

III. RESULTS

According to the results, the main parameters related to the maximum von Mises stress, elastic strain , and strain energy density (SED) were invested as following:

A. Maximum Von Mises Stress

As shown in Fig. 3 and Fig. 4, the maximum von Mises stress displayed in the lag screw component with adjacent to the region of DHS hole. The results revealed that the different plate length is not effect to the magnitude of stress on the implants both state-1 and state-2. However, the level of maximum stress on the implant in the state-1 produced higher stress than state-2.

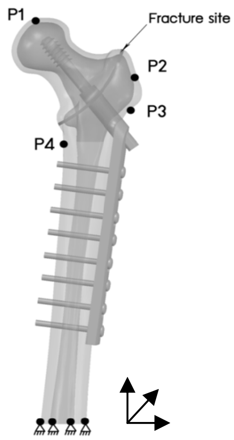

Fig. 2. Domain under consideration and boundary conditions

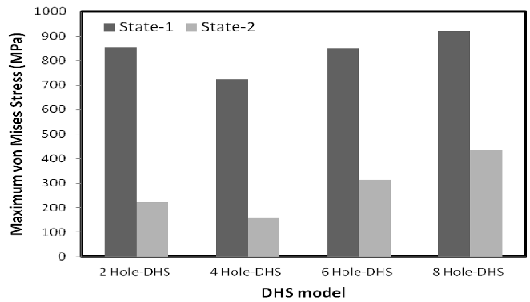

Fig. 3. The maximum von mises stress on the implants

B. Elastic Strain

Table III shows the elastic strain at the fracture site. It can be noticed that there are no the effect of the DHS plate length to the elastic strain values both states-1 and state-2. But the elastic strain in the state-1 produced higher than state-2 with significantly.

TABLE III: THE ELASTIC STRAIN OF FRACTURE SITE

Model	% Elastic Strain	
	State 1	State 2
2-Hole DHS	60.216	0.148
4-Hole DHS	57.906	0.124
6-Hole DHS	60.192	0.339
8-Hole DHS	57.282	0.383

C. Strain Energy Density (SED)

As shown in Fig. 3 and Fig. 4, the high magnitude of the strain energy density exhibited on the surrounding bone closed to the lag screw hole including DHS hole as shown in Fig. 5 and Fig. 6, respectively. It can be noted that, these two region are critical component which adsorbed high SED or load sharing under hip joint load condition. In addition, the magnitude of SED after DHS removal displayed lower values than retaining DHS as represented in Table IV.

IV. DISCUSSIONS

Currently, the implant failure complication was interested mostly because it affect to the patient, especially in secondary operative such as expensive charges and high risk of infection. In the analyses, von Mises stress is an important parameter to evaluate the implant failure. According to the results, the maximum von Mises stress occurred in state-1 (early state of bone healing) closed to the yield strength of implant material which approximately 600-800 MPa [12]. Consequently, there was a risk of implant failure in state-1. Therefore, in order to avoid implant failure in early state of bone healing, the patients should not bear full weight and use clutch for helping during walking. The results also revealed that the critical region was found at lag screw which has corresponding to Heynes et al. [13]. In addition, after complete healing bone, the maximum von Mises stress was reduced to lower value of yield strength that cause were forces transferred to the bone.

The goal of treatment of intertrochanteric fracture using internal fixation for stabilization is to allow early load bearing. Therefore, mechanical performance evaluation of implant can be observed from the elastic strain at the fracture site. The elastic strain is a parameter to evaluate displacement of the fracture site. The good treatment needs to induce the elastic strain of fracture about 2-10 percent for support to form of new bone formation [14]. However, the elastic strain in state-1 produced high value that was obviously not proper for bone formation. Therefore, this is strongly confirmed that the patient should avoid full weight bearing in this state.

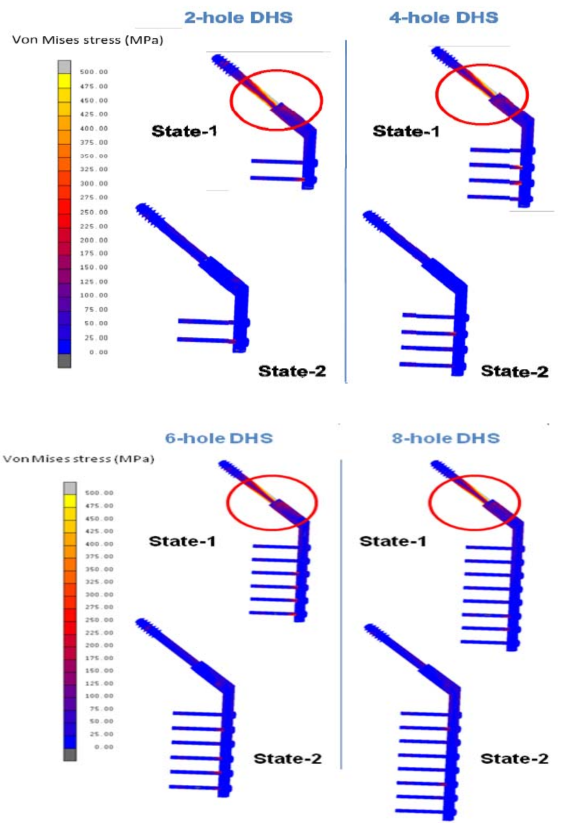

Fig. 4. The maximum von MISES stress on 2-hole DHS, 4-hole DHS, 6-hole DHS and 8-hole DH

The strain energy density (SED) is an indicator to energy absorption or load sharing in any materials that was different mechanical property data [15], [16]. Therefore, the SED is a suitable parameter to evaluate risk of bone fracture because the bone composed different material properties. In the analysis, the state-1 is the critical state, because it may be incurred the biomechanical failure to bone easily. The results of SED show that the critical component occurred high SED is the femoral head cancellous region inside lag screw hole. These are the effect of bending moment produced from the hip contact force and distance from the femoral head center to the femoral shaft cortex. In addition, the removal DHS is a better choice after bone healing complete. Due to the retaining DHS produced high SED that occurred inside the holes insertion of lag screw and screw fixation. This may be the effect of stress concentration between DHS implant and surrounding bone.

V. Conclusion

The study presented the biomechanical analysis of DHS implant by means of finite element method. Plate length has no influences on stress occurred on implant as well as stability of fracture. In early state of bone healing, however, the patient should not bear full weight because there is a risk of implant failure. In addition, the DHS should remove after bone healing process. This study analyzes only one type of intertrochanteric fracture. Further investigation based on other hip fracture type and also clinical experiment should be performed.

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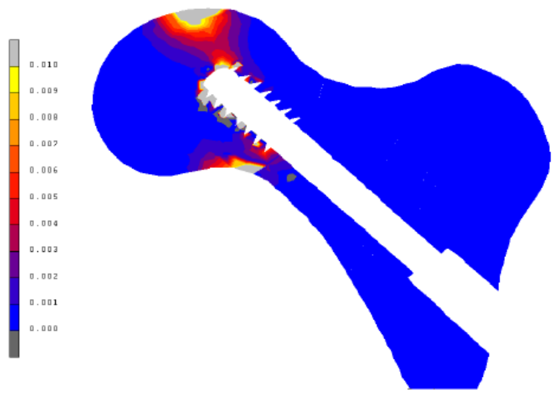
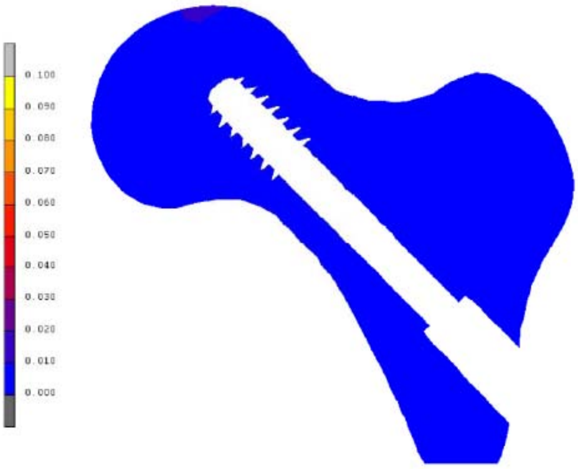
TABLE IV: The SED in each regions with retaining and removal DHS

Regions	Retaining DHS (MPa/1000)				Removal DHS (MPa/1000)			
	2-hole	4-hole	6-hole	8-hole	2-hole	4-hole	6-hole	8-hole
Femoral neck cortex	19.03	20.40	21.39	18.94	25.79	34.08	26.32	24.90
Femoral neck cancellous	109.97	107.60	108.32	89.63	66.33	149.99	94.03	68.20
Head cancellous inside lag screw hole	2,421.54	5,570.47	5,360.00	36,063.64	191.65	191.00	227.34	215.88
Shaft cortex inside DHS hole	1,897.95	1,855.95	1,229.25	4,460.47	35.05	35.37	39.50	39.66
Shaft cortex inside screw hole	221.10	324.90	284.77	255.15	14.10	11.95	35.92	17.27

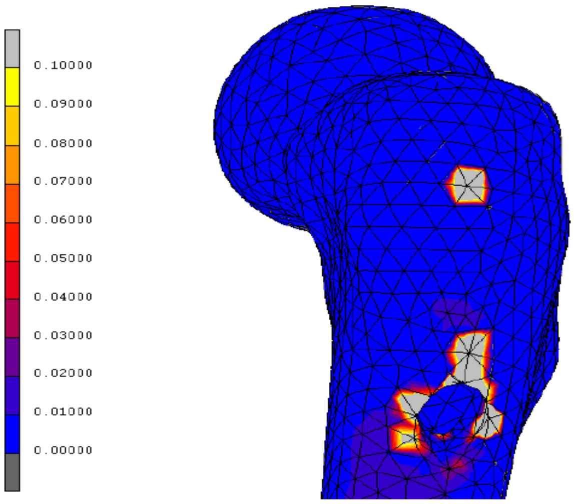


(a)

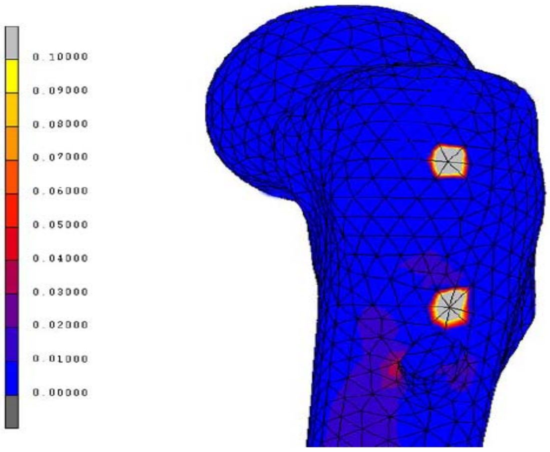


(b)

Fig. 5. The maximum SED at proximal neck cancellous region inside lag screw hole with: (a) retain of 2-hole DHS and (b) removal of 2-hole DHS



(a)



(b)

Fig. 6. The maximum SED at proximal shaft region inside DHS plate hole with: (a) retain of 2-hole DHS and (b) removal of 2- hole DHS

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