Biomechanical Effect of Fin on Hip Prosthesis to Thai Femoral Bone

Boonyapat Pradabkaew[1], Panya Aroonjarattham[*1], Nawapol Saktaveekulkit[1], Kitti Aroonjarattham[2], Kriskrai Sitthiseripratip[3], and Banchong Mahaisavariya[4]

[1] Department of Mechanical Engineering, Faculty of Engineering, Mahidol University, Nakhonpathom, Thailand 73170
[2] Department of Orthopaedic, Faculty of Medicine, Burapha University, Chonburi, Thailand 20131
[3] National Metal and Materials Technology Center, Pathumthani, Thailand 12120
[4] Department of Orthopaedic Surgery, Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand 10700
* Corresponding Author: Tel: 0 2889 2138 ext 6401-3, Fax: 0 2889 2138 ext 6429
E-mail: egpaj@mahidol.ac.th

Abstract

Cementless hip stem prosthesis was used to restore the femoral head. It can be divided into 2 model types: the hip stem with fin and without fin. The femoral bone model was reconstructed from a computed tomography and the hip modal was carefully created from CAD software by comparing with real shape. Hip prosthesis was inserted by virtual simulation into the femoral bone for the characteristics of actual surgery. Finite element analysis was used to determine the stress distribution on hip prosthesis and strain distribution on femoral bone under walking and stair-climbing condition. The results showed that the model with fin had less stress distribution than one without fin.

***Keywords**:* Hip stem with fin, Hip prosthesis, Finite element analysis, Stress distribution.

1. Introduction

Total hip replacement is the most successful operations in orthopedic surgery, It helps patients to return to their usual lifestyle. It is an orthopedic procedure that involves a surgical excision of the head; a proximal neck of the femur and; a removal of the acetabular cartilage and subchonral bone. Normally, there are 2 types of total hip prosthesis that are commonly used. The choice depends on the type of banding with the host bone the prosthesis, which could either bd cemented or cementless one [1].

The cementless hip stem has been studied. It was designed, aiming to avoid bone cement and conserving bone; to eliminate thigh pain and; to avoid proximal stress-shielding. The cementless hip was straight stem design available in three different neck angles 125, 135, and 145 degrees accordingly [2]. This study considered 2 model types: cementless hip stem and neck angle 135 degree due to the appropriate features neck shaft angle of morphological Thai proximal femur [3]. There were hip stem with fin and without fin. Finite element analyses was employed to study the stress distribution on hip prosthesis and strain distribution on femoral bone [4-5].

2. Materials and Methods

The finite element model used in this study represented a femur-implant with anatomical position. The hip model was carefully created from SolidWork program, comparing to the real shape and three dimensional femoral bone model reconstructed from computed tomography (CT) scan data based on the average geometry of 108 Thai femoral [3,6]. Hip prosthesis was inserted by virtual simulation into femoral bone for the characteristic of actual surgery.

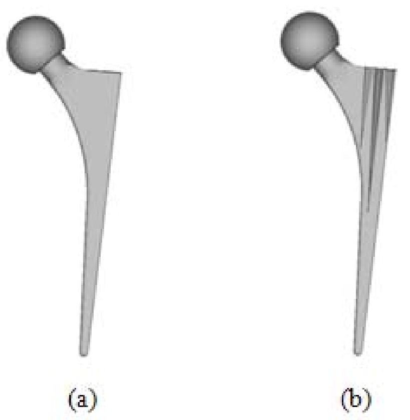

Fig.1 The model of hip prosthesis (a) without fin and (b) with fin

The structured mesh was generated from MARC2005. The femur-implant model had a total of 20,377 nodes and 79,833 elements. The mechanical properties were assumed to be linear elastic and isotropic material. Material properties of all models were shown in Table 1.

Table. 1 Material properties were assigned for the Finite element model [7].

Model	Modulus (MPa)	Poisson's Ratio
Titanium alloy	110,000	0.3
Cortical Bone	14,000	0.4
Cancellous Bone	600	0.2

In general loading conditions, the force distributed on the hip prosthesis depends on the joint reactions as well as on the muscle forces. Thus, to investigate the implant biomechanics, it is necessary to know the force exerted in each muscle. Two of the most common physiology activities: walking and stair-climbing were used in this analysis [8]. The femoral model was fully fixed at the distal end as shown in Fig 2 and Table 2

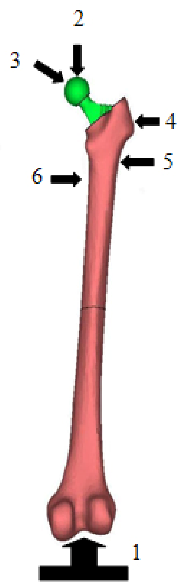

Fig.2 The position of bone-implant and muscular force by the proximal part.

Table.2 Show loading condition which applied to proximal femur

Point condition	Walking	Stair-climbing
1	fix	fix
2	body weight	body weight
3	hip contact	hip contact
	intersegmental resultant	intersegmental resultant
4	aboductor	aboductor
	tensor fascia,Proximal	ilio-tibial tract, Proximal
	tensor fascia,Distal	Ilio-tibial tract,Distal
		tensor fascia Proximal
		tensor fascia Distal
5	vastus lateralis	vastus lateralis
6		vastus medialis

3. Results

The stress distribution on the hip implant with fin under walking and stair-climbing load was less than the one without fin. The results are shown in Table 3

Table. 3 Maximun von Mises stress on hip stem models.

Condition	Hip models	Von Mises Stress [MPa]
Walk	Fin	131
	Without Fin	176
Stair-climbing	Fin	132
	Without fin	178

The magnitudes of stress and contour distribution of two hip implant models in both physiological walking and stair-climbing are shown in Fig 3 and Fig 4

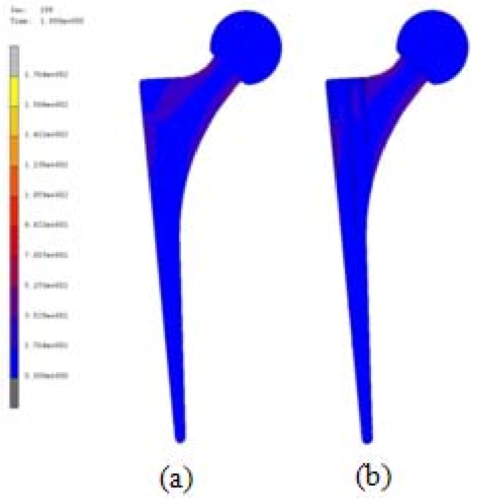

Fig.3 The stress distribution on two hip implant models under walking condition (a) hip without fin and (b) hip with fin.

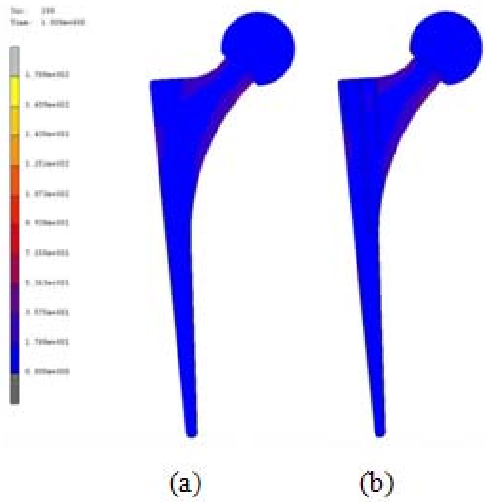

Fig.4 The stress distribution on two hip implant models under stair-climbing condition (a) hip without fin and (b) hip with fin.

The strain distribution similar in femoral bone models in both physiological walking and stair-climbing are shown in Fig 5 and Fig 6

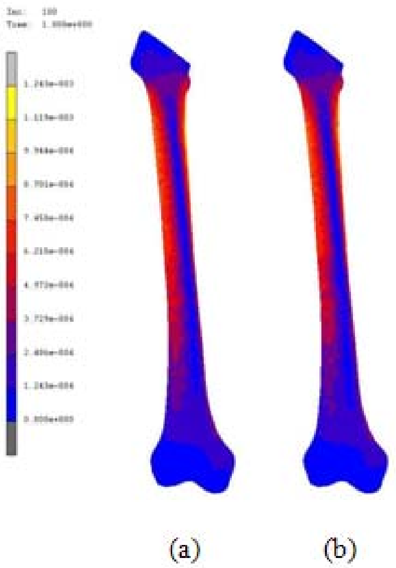

Fig.5 Equivalent total strain on femoral bone under walking condition. (a) Bone was inserted hip without fin. (b) Bone was inserted hip with fin.

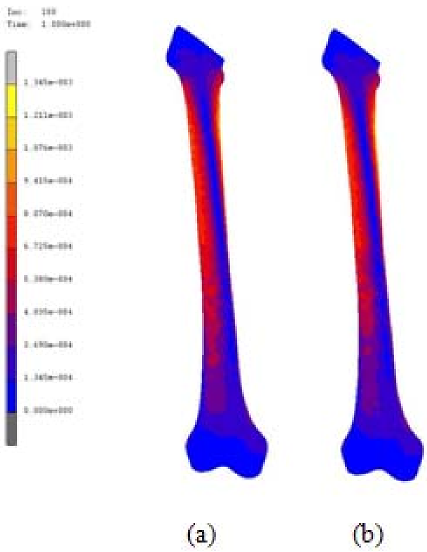

Fig.6 Equivalent total strain on femoral bone under stair-climbing condition. (a) Bone was inserted hip without fin. (b) Bone was inserted hip with fin.

4. Discussion

The cementless hip prothesis is widely used because of its good clinical outcomes after hip arthroplasty. The least maximum von mises stress can help minimize the long-term problems [9-12]. This study was aimed to investigate the stress distribution on a cementless hip prothesis when inserted in Thai femoral bone. The finite element analysis was an acceptable tool in terms of evaluating the mechanical performance of many orthopedic implants. The stress distribution on the implant was not over the range of yield strength. [Yield strength of Titanium alloy is 870 MPa]

The maximum von Mises stress on hip with fin and without fin under walking condition were 131 MPa and 176 MPa respectively and under stair-climbing condition were 132 MPa and without fin 178 MPa respectively. The result showed that the hip prosthesis with fin, had less maximum stress than one without fin because it had larger surface contacting the inter medullary surface which transfers more stress than the other.

5. Conclusion

The new design of hip prosthesis should have fin at the anterior and posterior side to produce less maximum von Mises stress on the implant. The result must be validated with the mechanical testing device.

6. Acknowledgement

The authors would like to thank for the acknowledgement of Mahidol University and the national Metal and Materials Technology Center (MTEC), for their kind support of the facilities

7. References

[1] Kim, KJ. M.D., Rubash, HE. M.D., Wilson, SC. M.D., D'antonio, JA. M.D. and Mcclain, EJ. M.D. (1993). A Histologic and Biochemical Comparison of the Interface Tissues in Cementless and Cemented Hip Prostheses, *Clin Orthop Relat Res*, vol. 287, Feb 1993, pp. 142-52.

[2] Surgical Technique CLS Spotorno Stem of Zimmer,URL:http://www.sinaxmedica.com.ar/bo/pdfs/40.pdf, access on 15/04/2011

[3] Mahaisavariya, B., Sitthiseripratip, K., Tongdee, T., Bohez, E. and Vander Sloten, J. (2002). Morphological study of the proximal femur: a new method of geometrical assessment using 3-dimensional reverse engineering, *Medical Engineering & Physics*, vol. 24, November 2002, pp. 617-622.

[4] Pancanti, A., Bernakiewicz, M. and Viceconti, M. (2003). The primary stability of a cementless stem varies between subjects as much as between activities, *Journal of Biomechanics*, vol. 36, June 2003, pp. 777-785.

[5] Rafiq, M., Kadir, A. and Kamsah, N. (2009). Interface Micromotion of Cementless Hip Stems in Simulated Hip Arthroplasty, *American Journal of Applied Sciences*, vol. 6, 2009, pp. 1682-1689.

[6] Aroonjarattham, P., JiamwatthanachaiM, P., Mahaisavariya, B., Kiatiwat, T., Aroonjarattham, K. and Sitthiseripratip, K. (2009). Three-dimensional morphometric study of the Thai proximal humerus, *J. Med Assoc Thai*, vol. 92, 2009,pp. 1191-7.

[7] Perez A., Mahar A., Negus C., Newton P. and Impelluso T. (2008). A computational evaluation of the effect of intramedullary nail material properties on the stabilization of simulated femoral shaft fractures. *Medical Engineering & Physics*, vol. 30.issue 6, July 2008, pp. 755-760

[8] Heller, M.O., Bergmann, G., Kassi, J.-P., Claes, L., Haas, N.P. and Duda G.N. (2005). Determination of muscle loading at the hip joint for use in pre-clinical testing, *Journal of Biomechanics*, vol. 38, 2005, pp.1155-1163.

[9] Chess, D.G., Grainger, R.W., Phillips, T., Zarzour, Z.D. and Sheppard, B.R. (1996). The cementless anatomic medullary locking femoral component: an independent clinical and radiographic assessment, *Can J Surg*, vol. 39, Oct 1996, pp. 389-92.

[10] Effenberger, H., Ramsauer, T., Böhm, G., Hilzensauer, G., Dorn, U. and Lintner, F. (2002). Successful hip arthroplasty using cementless titanium implants in rheumatoid arthritis, *Arch Orthop Trauma Surg*, vol. 122, Mar 2002, pp. 80-7

[11] Schreiner, U., Scheller, G., Herbig, J. and Jani, L. (2001). Mid-term results of the cementless CLS stem A 7- to 11-year follow-up study, *Arch Orthop Trauma Surg*, vol. 121, Jun 2201, pp. 321-4.

[12] Bhalodiya, HP. M.S.(Ortho) and Singh, SP. M.S.(Ortho). (2009). Results With the Cementless Spotorno Stem in Total Hip Arthroplasty, *The Journal of Arthroplasty*, vol. 24, December 2009, pp. 1188-1192.