The Notch Effect to Strain Distribution on Thai Femoral Bone after Total Knee Arthroplasty the 4th TSME Conference on Mechanical Engineering (TSME-ICoME)

Korgiattipong J[1], Aroonjarattham P[1,*] and Aroonjarattham K[2]

[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
*Corresponding Author: E-mail: panya.aro@mahidol.ac.th
Tel: 0 2889 2138 ext 6417, Fax: 0 2889 2138 ext6429

Abstract

The strain distribution occurs on femoral bone while the loads transfer from proximal to distal part. The bone may be fracture after received more strain than 25,000 $\mu\varepsilon$. Notching of the anterior femoral cortex after total knee arthroplasty can occur when making an anterior femoral bone cut. The notch of bone makes the stress concentration and transform to strain that should make the bone fracture. This study aims to vary the notch size with 3 depths as 1.5, 2.5 and 3.5 mm. and evaluate the strain distribution on the notch with finite element method under daily activities load to find the notch effect to strain distribution on Thai femoral bone. The result showed that the maximum strain occur 1,530 and 1,830 $\mu\varepsilon$ under walking and stair-climbing respectively. The rise of depth notch tend to increase the maximum strain on the femoral bone, which the surgeon will be avoid this condition for a good clinical result.

***Keywords**:* Notch effect, Strain distribution, Thai femoral bone, Total knee arthoplasty.

1. Introduction

Total joint arthroplasty had greatly improved the treatment of disabling arthritis of the knee. Notching of the anterior femoral cortex during total knee arthroplasty had been complicated as one factor contributing to these periprosthetic femoral fractures. A biomechanical study had shown that notching of the anterior cortex significantly lessens the load to failure by decreasing the bending strength by 18% and torsional strength by 40% [1]. Both clinical and biomechanical strongly suggest that anterior notching of the distal femoral cortex increase the risk of a supracondylar femoral fracture after total knee arthroplasty [2-3]. The stress concentrations created by anterior femoral cortex notching are of considerable importance because of their possible association with supracondylar femur fractures when a notch is recognized at the time of surgery.

The purpose of this study aims to evaluate the effect of the anterior notching size to strain distribution on Thai femoral bone by finite element method.

2. Materials and Methods

The finite element model in this study was divided to 2 main parts as Three-dimensional Thai femoral bone model and total knee prosthesis model.

2.1 Three-dimensional Thai Femoral Bone Model

The Thai femoral bone was scanned by computerized tomography (CT) scanner. The CT images was analyzed and reconstructed with ITK-SNAP program as shown in Fig. 1.

Fig.1 Show the three-dimensional Thai femoral bone.

The bone was divided to 4 part as proximal cortex, distal cortex, proximal cancellous and distal cancellous.

2.2 Total Knee Prosthesis Model

The total knee prosthesis had reflected the x-ray in scanning process. We created the resin model of total knee prosthesis as shown in Fig. 2 and constructed the model with CT data as shown in Fig. 3.

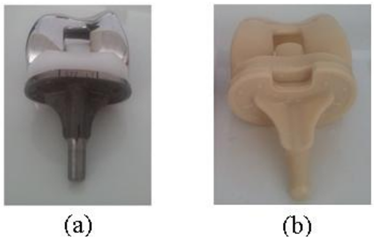

Fig. 2 Show the model of: (a) The Total knee prosthesis and (b) The Total knee prosthesis of resin model.

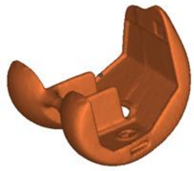

Fig. 3 Show the three-dimensional model of femoral component.

The model of bone-implant was created with anterior femoral cut as shown in Fig. 4 and varied to produce varying notch depth (h) with notch length (l) 5 mm as shown in Table. 1.

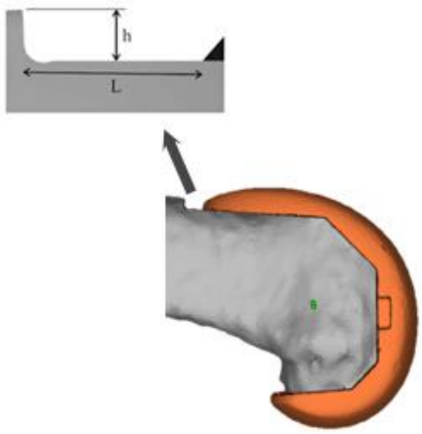

Fig. 4 Show the femoral notch geometry

Table. 1 Show the parameters of notch depth and notch length.

Model	Notch length (mm)	Notch depth (mm)
1	5	1.5
2	5	2.5
3	5	3.5

2.3 Material Properties

Material properties of cortical bone, cancellous bone and total knee prosthesis, which were constructed from Cobalt-Chrome alloy, were assumed to be homogeneous, isotropic and linear elastic as shown in Table. 2.

Table. 2 Show the material properties of bone and prosthesis [4].

Model	Elastic modulus (MPa)	Poisson's ratio
Cortical bone	14,000	0.3
Cancellous bone	600	0.2
Cobalt-Chrome alloy	230,000	0.3

2.4 Boundary Conditions

The femoral bone was fully fixed at the distal end (zero displacement). The force of body weight was transmitted to the head of the femoral bone and the muscle force was distributed on the proximal part as shown in Fig. 5. The most common physiology depended on the daily activities of walking and stair-climbing [5].

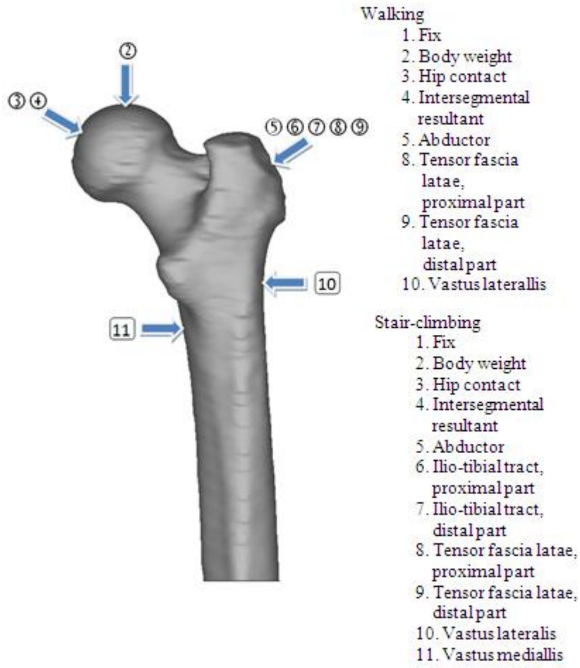

Fig. 5 Show loading conditions which applies to the bone.

2.5 Finite Element Model

The bone model had validated by applied load to analyze the strain distribution and had compared the result from Duda *et al* [6]. The model of bone-implant was built up with four-node tetrahedral elements. It had a total of 43,967 nodes and 181,340 elements.

3. Results

The maximum equivalent of total strain, occurred at the notch, under walking and stair-climbing condition were shown in Table. 3 and 4 respectively.

Table. 3 Show the maximum equivalent of total strain at the anterior femoral notch on Thai femoral bone under walking condition.

Model	Maximum equivalent of total strain (microstrain)
1	753
2	1,040
3	1,530

Table. 4 Show the maximum equivalent of total strain at the anterior femoral notch on Thai femoral bone under stair-climbing condition.

Model	Maximum equivalent of total strain (microstrain)
1	785
2	1,110
3	1,830

The maximum strain distribution, occurred on the anterior femoral notch had increased with notch depth in both conditions. Under stair-climbing condition, femoral bone was received maximum strain than walking condition as shown in Fig.6.

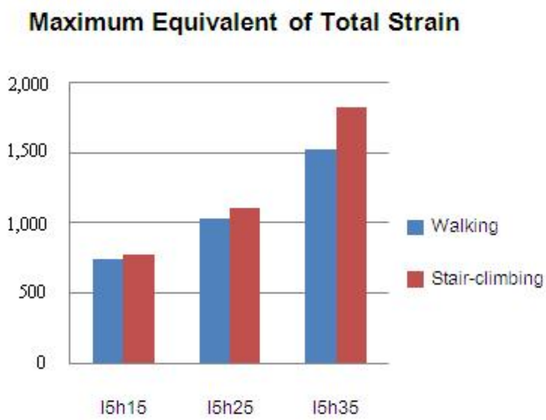

Fig. 6 Show the maximum equivalent of total strain at the anterior notch on distal cortex under walking and stair-climbing condition.

4. Discussion

Periprosthetic supracondylar femoral fracture was an uncommon complication following total knee arthroplasty, with a reported prevalence of 0.30% to 4.8% [7-8]. Notching of the anterior femoral cortex during total knee arthroplasty had been complicated as one factor contributing to these periprosthetic femoral fractures. The strain distribution on the femoral bone increased with increasing notch depth, which was shown in Fig. 7 for notch depth 3.5 mm.

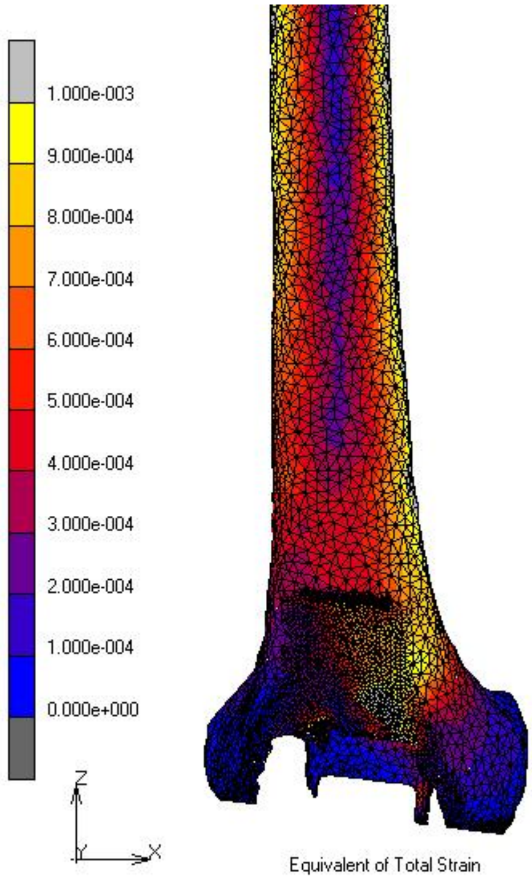

Fig. 7 Show the strain distribution on distal cortex under stair-climbing condition.

The rising stress occur at the notch was caused by the stress concentration. The increasing of notch depth had effect to the bending stress at the notch and been changed to the strain on the bone. The strain distribution on the bone was the main factor affecting to the bone fracture, which did not greater than 25,000 microstrain. In this study, the strain on the distal cortex was in the physiological loading zone of Frost's mechanostat theory [9] as shown in Fig. 8 but it likely to increase with more notch depth.

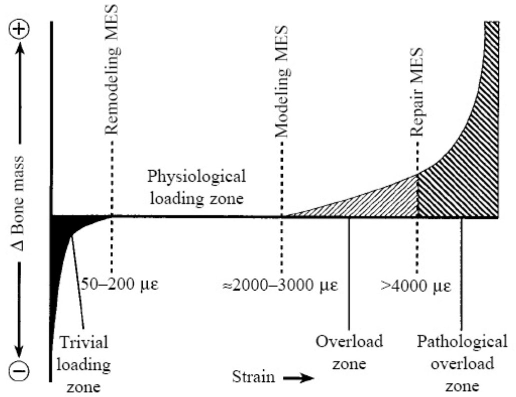

Fig. 8 Show graph of Frost's mechanostat theory [7].

5. Conclusion

Weaken of the bone by notching the anterior femoral cortex after total knee arthroplasty be realize for the surgeon. The patient of osteoporosis condition may have periprosthetic supracondylar femoral fracture after total knee replacement with anterior notch.

6. Acknowledgement

The author wish to thank the Faculty of Medicine, Burapha University for their kind support of the facilities.

7. References

[1] Lesh, M.L., Schneider, D.J., Deol, G., Davis, B., Jacobs, C.R. and Pellegrini, V.D. (2000). The consequences of anterior femoral notching in total knee arthroplasty, *Journal Bone and Joint Surgery*, vol. 82-A, pp. 1096-1101.

[2] Madsen, F., Kjaersgaard-Amderson, P., Juhl, M. And Sneppen, O. (1989). A custom-made prosthesis for the treatment of supracondylar femoral fractures after knee arthroplasty: report of four cases, *J. Orthop Trauma*, vol. 3, pp. 332-337.

[3] Dennis, D.A. (2001). Periprosthetic fractures following total knee arthroplasty, *Journal Bone & Joint Surgery*, vol. 83-A, pp. 120-130.

[4] Peraz, 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 fracture, *J Med Eng&Phys*, vol. 30, pp. 755-760.

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

[6] Duda, G.N., Heller, M., Albinger, J., Schulz, O., Schneider, E. and Claes, L. (1998). Influence of muscle forces on femoral strain distribution, *Biomechanics*, vol. 31, pp. 841-846.

[7] Aaron, R.K. and Scott, R. (1987). Supracondylar fracture of the femur after total knee arthroplasty, *Clin Orthop*, vol. 219, pp. 136-139.

[8] Lesh, M.L., Schneider, D.J., Deol, G., Davis, B., Jacobs, C.R. and Pellegrini, V.D. (2000). The consequences of anterior femoral notching in total knee arthroplasty, *J. Bone & Joint Surgery*, vol. 82-A, pp. 1096-1101.

BME-1004

[9] Frost, H.M. (1997). Defining osteopenias and osteoporoses: another view (with insights from a new paradigm), *Bone*, vol. 20, pp. 385-391.