The Shape Analysis of Hip Prosthesis Inserted in Thai Femoral Bone: Finite Element Analysis

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Abstract

Hip prosthesis was used for the patients who has the hip fracture and unable to recover naturally. This study aims to analyses the six shapes different of hip prosthesis by finite element analysis. All model is cementless hip stem which were used to analyses simulating two of the most common physiological activities – walking and stair-climbing. The design of a hip prosthesis involves parameters which include neck size and lateral shape with the same size of ball diameters. The results showed that the neck size and lateral shape affected the stress distribution on hip prosthesis when inserted in the femoral bone. The maximum von Mises stress at the neck of model 1-3 were 260, 155 and 93 Mpa respectively and maximum von Mises stress at the lateral shape of model 3-6 were 29, 25, 20 and 22.5 MPa respectively. The large neck had less maximum von Mises stress than the small one. The lateral shape with a curved surface had a better stress distribution than the edge shape.

***Keywords**:* Hip prosthesis, Finite element analysis, Shape of hip prosthesis.

1. Introduction

Total hip replacement is a healing process of hip fracture and osteoarthritis in the hip joint. The hip prosthesis is designed and manufactured in various shapes and sizes to fit various body sizes and types. Thus, there are many models of total hip prostheses on the market. New models keep coming with improvements in long term functionality of the prosthesis [1].

In the past, design and analysis of bone-implant hip prosthesis relied on expert's knowledge, experience and ability, trying to avoid any unrecoverable damage on the bones of patients. Due to the difficulty of performing implant tests in vivo, mathematical models have been developed to carry out the structural analysis of implants before applying on a patient. Thus, bone-implant hip prosthesis could be designed and studied with computer simulations. The finite element method (FEM) is an advanced simulation technique that has been used in orthopedic biomechanics since 1972 [2]. It is an important tool used in the design and analysis of total joint replacements and other orthopedic devices. Finite element analysis offers a non-destructive approach for bone-implant hip prosthesis. It allows many scenarios to be studied in computer environment before the prosthesis is actually inserted. This simulation streamlines the design and prevents any permanent damage caused by miss-implementation [3].

This study is aimed to analyze the six different shapes of hip prosthesis by finite element analysis. This analysis is to attempt to analyze the prosthesis by using parameters the fallowing parameters: neck size and lateral shape with the same size of ball diameters when inserted in the femoral bone.

2. Materials and Methods

2.1 Finite element models

A three-dimensional model of the femoral bone was created by computed tomography (CT) scan data based on the average geometry of 108 Thai femoral [4]. All models of hip prosthesis made by using SolidWork 2010 software. Hip prostheses and femoral bone were analyzed by finite element method (MSC Marc 2005 software package). The femur-implant model had a total of 37,168 nodes and 147,299 elements.

2.2 Hip designs

A finite element analysis (FEA) was performed. The six designs were shown in Fig. 1 and were assigned as Titanium Alloy. In this analysis, ball diameter and neck length were fixed. All models were created by varying the area of prosthesis neck and lateral shape.

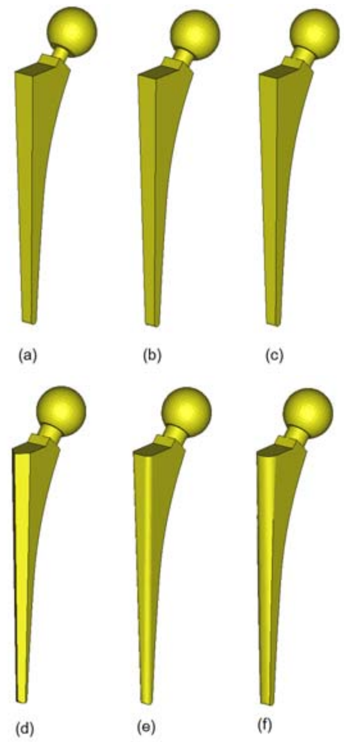

Fig.1 (a) First hip prosthesis design with small neck size, (b) Second hip prosthesis design with medium neck size, (c) Third hip prosthesis design with large neck size and rectangular lateral shape, (d) Fourth hip prosthesis design with triangle lateral shape, (e) Fifth hip prosthesis design with edge fillet lateral shape, (f) Sixth hip prosthesis design with curve lateral shape.

2.3 Material properties

Material properties of the cortical bone, cancellous bone, and hip prosthesis were assumed to be homogeneous, isotropic, and linear elastic as shown in table. 1.

Table. 1 Material properties of bones and prostheses [5]

Material	Elastic modulus (MPa)	Poisson Ratio
Cortical bone	14,000	0.4
Cancellous bone	600	0.2
Titanium	110,000	0.3

2.4 Boundary conditions

Loading and boundary conditions described by Heller *et al.* [6] applied to the proximal femur depended on the activities of walking and stair-climbing as shown in Fig. 2.

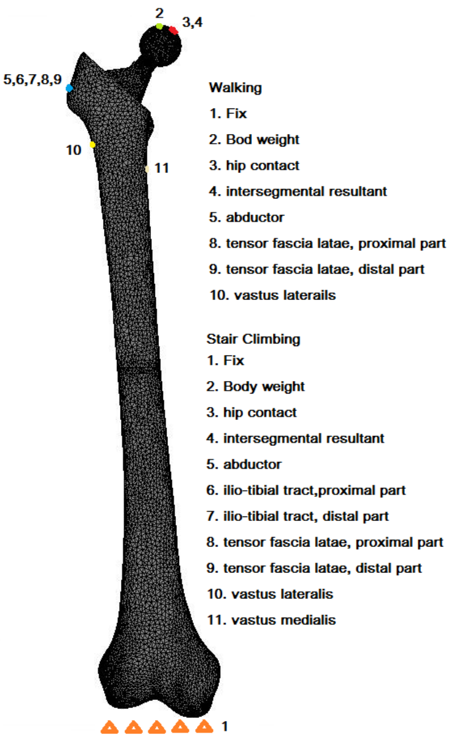

Fig.2 Show loading condition which applies to the femoral bone.

3. Results

Finite element analysis showed that the maximum von Mises stress occurred at the neck region of the hip prosthesis. By comparing the values of the entire three different models with two different activities like walking and stair-climbing, the maximum von Mises stress and maximum total strain of these models in walking and stair-climbing were shown in the table. 2. And 3 respectively. It appeared that the model 3 had the minimum von Mises stress.

Table. 2 Maximum von Mises stresses developed in the neck hip prosthesis and maximum total strain in femoral bone for three different models with activities like walking.

Model	Maximum von Mises stress in neck hip (MPa)	Maximum total strain in femoral bone (Micro-strain)
1	260	1074
2	155	1113
3	93	1162

Table. 3 Maximum von Mises stresses developed in the neck hip prosthesis and maximum total strain in femoral bone for three different models with activities like stair-climbing.

Model	Maximum von Mises stress in neck hip (MPa)	Maximum total strain in femoral bone (Micro-strain)
1	253	1251
2	146	1301
3	90	1384

The neck size of model 3 was fixed and varied in terms of the lateral shape of hip prosthesis showing in model 4, 5 and 6. All models were analyzed in walking and stair-climbing condition. The result is shown in table 4.

Table. 4 Maximum von Mises stresses developed in the lateral side of hip prosthesis for four different models with two different activities like walking and stair-climbing

model	Maximum von Mises stress (MPa)	
	(walking)	(stair-climbing)
3	29	28
4	25	25
5	20	19
6	22.5	21.5

4. Discussion

The maximum von Mises stress and total strain on the hip prosthesis and femoral bone when inserted in Thai femur under the daily activity were shown in Fig. 2 to 7. It showed that the prosthesis neck size and lateral shape affected to the stress distribution. The large neck size had less maximum von Mises stress than the small size and the lateral shape with a curve surface or fillet the edge had better stress distribution than the edge shape.

To compare the hip model with the varied neck sizes, model 3 had less maximum von Mises stress at the neck of hip prosthesis than model 1 by 180 percent, model 2 by 67 percent under walking condition as shown in Fig. 2 and by 181 and 62 percent respectively under stair-climbing condition as show in Fig. 3. Model 3 had the lowest stress because the stress was inversely proportional to the area.

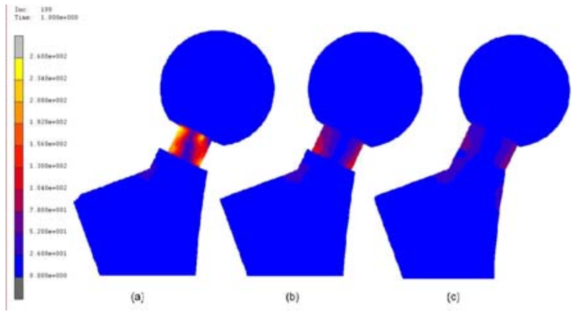

Fig.2 Equivalent von Mises stress at neck region under walking condition (a) Model 1, (b) Model 2, (c) Model 3.

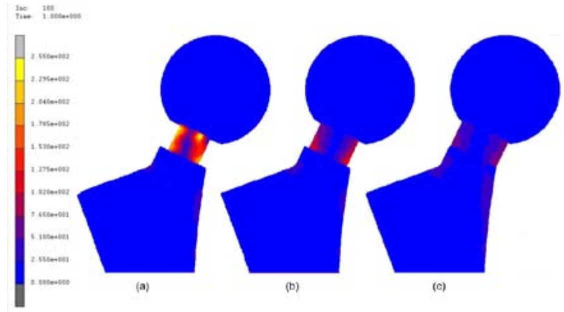

Fig.3 Equivalent von Mises stress at neck region under stair-climbing condition (a) Model 1, (b) Model 2, (c) Model 3.

The femoral bone inserted with model 3 had more maximum total strain than model 1 and 2 by 7 and 4 percent respectively under walking condition as shown in Fig. 4 and by 10 and 6 percent respectively under stair-climbing condition as show in Fig. 5. The bone inserted model 3 had the highest total strain because the hip prosthesis had the lowest stress. As a result, the femoral had better load distribution

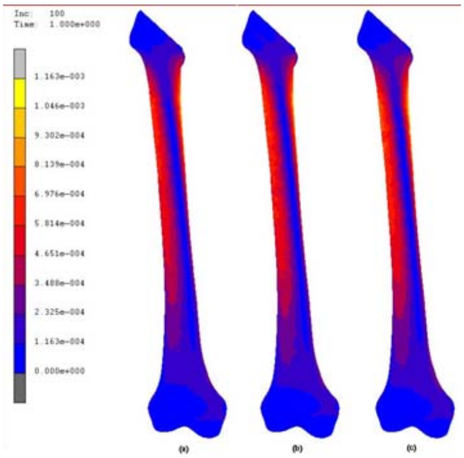

Fig.4 Equivalent total strain on femoral bone under walking condition (a) bone inserted model 1, (b) bone inserted model 2, (c) bone inserted model 3.

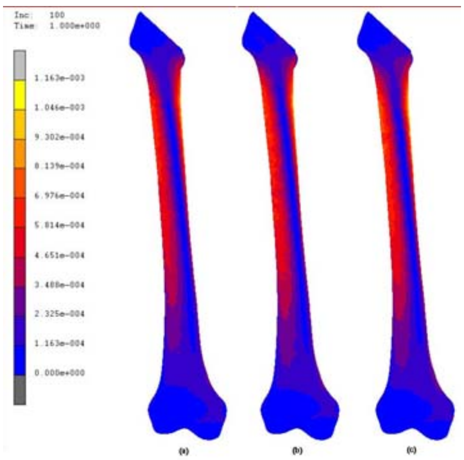

Fig.5 Equivalent total strain on femoral bone under stair-climbing condition (a) bone inserted model 1, (b) bone inserted model 2, (c) bone inserted model 3.

The result showed that hip prosthesis with large neck area must be chosen for good clinical result since the percentage of the decrease in maximum von Mises stress exceeded the percentage of the increase in maximum total strain.

In case of varied lateral shape with fixed neck size, the model 5 with fillet the edge of lateral shape had the lowest maximum stress compared to the others in both activity as shown Fig. 6 and 7. Thus, model 5 appeared to be the best because the stress can distribute thru the lateral side better than the model 4 and has a bigger area than the model 6.

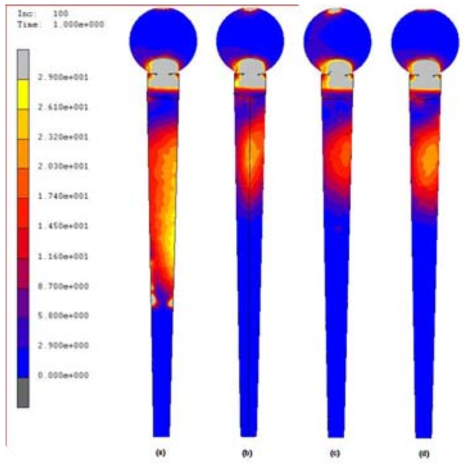

Fig.6 Equivalent von Mises stress on hip prosthesis under walking condition (a) Model 3, (b) Model 4, (c) Model 5, (d) Model 6.

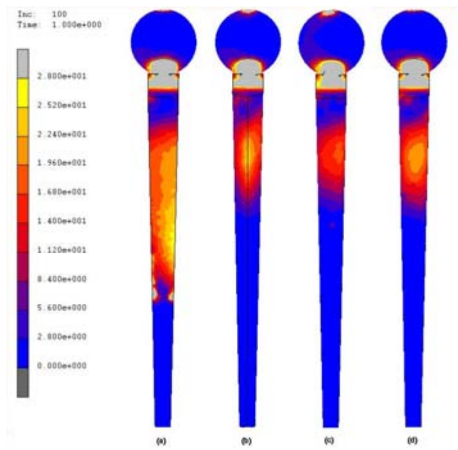

Fig.7 Equivalent von Mises stress on hip prosthesis under stair-climbing condition (a) Model 3, (b) Model 4, (c) Model 5, (d) Model 6.

5. Conclusion

To conclude, hip prosthesis should have a large neck area with fillet at the lateral edge for the appropriate stress distribution. Therefore, the new design of hip prosthesis must take these conditions in consideration for good clinical result and the decrease in the implant damage.

6. Acknowledgement

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