STRESS ANALYSIS OF FEMUR AND FEMORAL STEMS FOR HIP ARTHROPLASTY

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To my beloved family

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ABSTRACT

Osteoarthritis is the major reason that causes hip problem. According to Cristofolini (1997), there are more than 800,000 hip replacements being implanted worldwide annually. It is important to know the performance of hip prostheses especially the stability and the longevity. In this project, numerical simulation based on finite element method is used to analyze the mechanical behavior of femur-implant system. Finite element analysis is carried out on three-dimensional model of a human femur on both full and half models. This is to investigate the behavior of an intact femur under loading. Then, the analysis is repeated for an Anatomic Medullary Locking (AML) hip prosthesis, which is of one type of cementless hip prosthesis, implanted inside the femur. This is only done on half femur model. Both the stem and the head are made by Cobalt Chromium Molybdenum (CoCrMo). After that, the analysis is carried out on a cemented hip prosthesis. The cement is made by polymethylmethacrylate (PMMA), which is of flexible polymeric cement. The hip prosthesis model used for analysis is of Charnley type. The study on the stem length effect is then done. Lastly, the analysis is repeated for cancellous with different density. The cortical, cancellous, metal and cement are assumed to be linear, elastic, isotropic and homogeneous. Linear elastic analysis is adapted and maximum principal stress/strain and von Mises stress are the criterions that are of concern. Results show that both full and half femur modeling give similar stress distribution. Besides, the treated femur is always understressed at the upper most region of the femur. Cemented type of total hip replacement (THR) gives a better stress distribution on the femur compared to cementless type. In addition, hip prosthesis with shorter stem induces the stresses more evenly on the femur. Also, different cancellous density does not significantly affect the stresses.

ABSTRAK

Osteoartitis merupakan sebab utama yang mengakibatkan masalah pinggul. Menurut Cristofolini (1997), setiap tahun sekurang-kurangnya 800,000 kes penggantian pinggul dilaporkan. Mengetahui prestasi pinggul palsu terutamanya kestabilan dan panjang hayatnya adalah penting. Dalam projek ini, kaedah unsur terhingga digunakan untuk membuat analisis. Pertama, analisis ke atas model femur penuh dan separuh dalam 3 dimensi dijalankan. Ini bertujuan mengkaji kelakuan femur atas bebanan. Selepas itu, analisis dijalankan ke atas pinggul palsu tanpa simen, iaitu “Anatomic Medullary Locking” (AML), yang ditanam ke dalam pinggul. Analisis ini turut dibuat ke atas model separuh sahaja. Bahan yang digunakan untuk membuat pinggul palsu ialah Kobalt Kromium Molibdenum (CoCrMo). Seterusnya, analisis dijalankan ke atas pinggul palsu jenis bersimen. Simen yang digunakan adalah diperbuat daripada sejenis polimer lentur, iaitu “polymethylmethacrylate” (PMMA). Model pinggul palsu yang digunakan ialah jenis Charnley. Analisis diteruskan untuk mengkaji kesan panjang batang pinggul palsu ke atas pengagihan tegasan pada femur. Akhirnya, kesan ketumpatan kansel yang berlainan juga dikaji. Semua korteks, kansel, logam dan simen dianggap sebagai lelurus, elastik, isotropisme dan seragam. Analisis lelurus elastik dipilih dan kriteria utama ialah tegasan/terikan prinsipal maksimum dan tegasan von Mises. Keputusan menunjukkan bahawa tegasan pada kedua-dua model femur penuh and separuh adalah serupa. Selain itu, tegasan pada bahagian paling atas femur yang dijalankan pembedahan selalu sangat rendah. Total hip replacement (THR) jenis bersimen mengenakan tegasan dengan lebih bagus ke atas femur. Di samping itu, pinggul palsu yang berbatang pendek dapat mengagihkan tegasan ke atas femur dengan lebih seragam. Ketumpatan kansel yang berlainan tidak banyak mempengaruhi tegasan ke atas femur.

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LIST OF SYMBOLS

A	-	Cross sectional area
A_c	-	Cross sectional area of the cortical
A_i	-	Cross sectional area of the implant
d	-	Femoral head diameter
E	-	Elastic modulus
E_c	-	Elastic modulus of the cortical
E_i	-	Elastic modulus of the implant
F	-	The total applied axial load
F_c	-	Load carried by the cortical
F_i	-	Load carried by the implant
I	-	Moment of inertia
M	-	The total applied moment
n	-	Factor of safety
ε	-	Strain
θ	-	Anteversion
ρ	-	Density
ρ_c	-	Density of the cortical
σ	-	Stress carried by a body
σ_{UTS}	-	Ultimate tensile strength
σ_{Y}	-	Yield strength of a body
υ	-	Poisson’s ratio

CHAPTER 1

INTRODUCTION

1.1 Problem Definition

Hip problem is getting more and more common nowadays. According to Cristofolini (1997), there are approximately 800,000 total hip replacements (THR) being performed around the world every year. In Malaysia, for past four years, there are at least 600 THR being reported (Norhan, 2005). The main reason of hip failure is due to osteoarthritis, where the cartilage of a person is broken down. Cartilage is the connective tissue that covers the head of the hip bones. When the cartilage is being worn away, the femoral head and the acetabulum will rub one another. This will cause wear on the bone. Consequently, one will feel pain due to the friction between the ball and socket of the hip. It happens even with small movements. Figure 1.1 and 1.2 show the normal working hip and the degenerated hip respectively.

Therefore, it is important to design an implant, which is called hip prosthesis, to replace the failed femur part. In this project, the analyses will be mainly concerning about how does the stress distributed when the hip prosthesis is implanted compared to the intact femur. Besides, the ability of the hip prostheses to withstand the loading will be determined, too. For cemented total hip replacements (THR), the sustainability of bone cement under loading will also be determined.

The main purpose in this project is to study the stresses carried by the femur before and after total hip replacement. Similarity in the stress is important to ensure the femur is still being properly stressed under loading and thus also enhance the bone growth. If the femur is overstressed, there will be bone thickening, whereas if it is understressed, bone resoprtion will occur. Consequently, there is a high possibility for the implant to loose (Frost, 1964; Cowin and Hart, 1985; Harrigan et al., 1996; van Rietbergen et al., 1997).

Besides, the stresses carried by the hip prosthesis and bone cement are also studied. This is to make sure that stresses experienced by those two components do not exceed the yield strength of the materials.

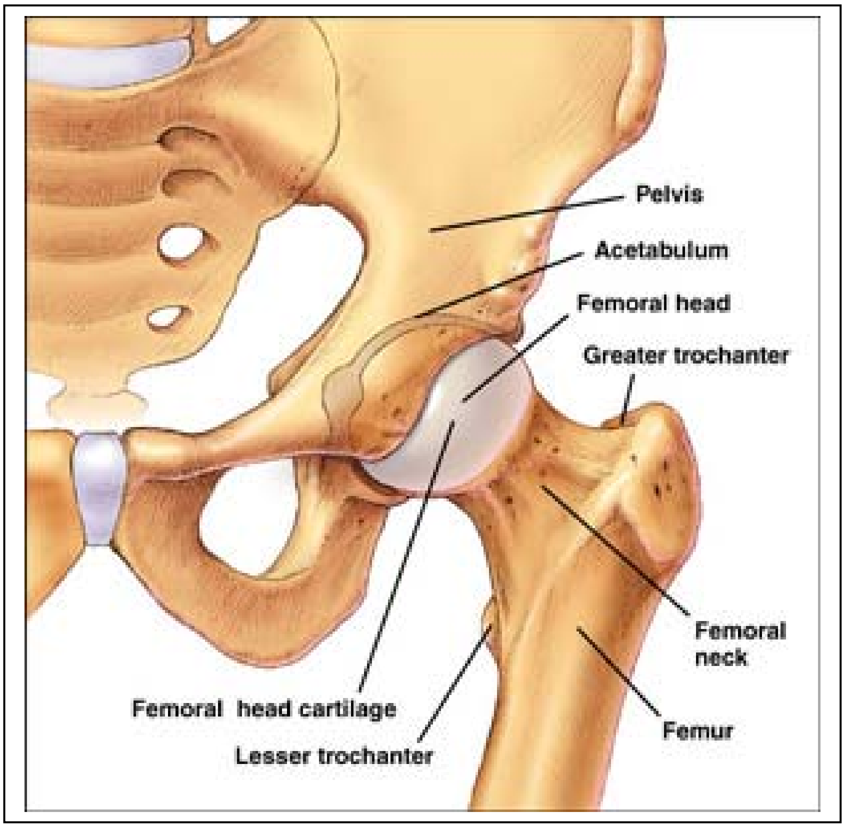

Figure 1.1 Normal working hip (Coordinated health, 2004)

Figure 1.2 Degenerated hip (Coordinated health, 2004)

1.2 Objectives

The objectives of this project are to

i. Develop finite element modeling procedure of current available hip prostheses, bone cement and femur.

ii. Perform static analysis to estimate the stress distribution within the hip prostheses, bone cement and femur.

iii. Study the difference between the stress distribution on the femur with cemented and cementless type of total hip replacement.

iv. Study the effects of different stem length on the stress distribution in the femur.

1.3 Scopes

The scopes of this project include

i. Intact femur.

ii. Charnley and Anatomic Medullary Locking (AML) hip prostheses.

iii. Linear elastic static analysis, where the major outputs of concern are maximum principal strains and von-Mises stresses.