UNIVERSITI PUTRA MALAYSIA

FINITE ELEMENT SIMULATION AND ANALYSIS OF FEMORAL HEAD REPLACEMENT

SEYED ALIREZA ASGARI

FINITE ELEMENT SIMULATION AND ANALYSIS OF FEMORAL HEAD REPLACEMENT

By

SEYED ALIREZA ASGARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

March 2003

DEDICATION

To my family

who always back me between the rock and the hard place…

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FINITE ELEMENT SIMULATION AND ANALYSIS OF FEMORAL HEAD REPLACEMENT

By

SEYED ALIREZA ASGARI

March 2003

Chairman: Associate Professor Dr. Shattri Bin Mansor
Institute: Advanced Technology

Although several years of research and experiment are dedicated to Total Hip Replacement (THR) of the conventional implant, there is yet no reliable answer for those patients who are very active and young. In this study, a modelling of the bone around two different types of implant has been carried out. Currently proposed design studied here, is the generic concept of stemless implant. The stemless implant reconstruction was compared to the conventional implant and also to the intact bone as control solution. A modelling approach with Finite Element (FE) method was adopted. A model of femur was developed and element optimisation was carried out to find the best mesh refinement.

The models were divided into two regions from proximal head to 40 mm distance toward distal end (R1) and 40 mm distance from proximal head toward the distal end (R2). For two different loading conditions of bending and torsion, the models were solved by ANSYS software. The results were compared with those of the experimental literature for validation.

The results of this study showed that the stemless implant had less deviation from the control solution of the bone in all regions and in both loading conditions, comparing to the large deviation of the stemmed implant from the intact bone.

The stemless implant showed perfect fit to the control solution in R2 region except for the 14 mm highest part of this region where the stemless implant showed strain reduction in the interface of the bone and the implant. This region was sub-trochanter and was concluded to practically be the weak point of this type of implant. Meanwhile, the stemless implant type had significant changes in stress and strain distribution in R1 region. This region was the implant region itself and it was concluded that a great amount of care must be taken for this region when designing such an implant.

The results of this study indicated that the stemless type of implant could become a suitable alternative for conventional type of implant in hemi-arthroplasties. However, the fixation of this type of implant and its effect on sub-trochanter region must be considered for designing the final product. More comprehensive numerical investigations on specific designs, with more loading conditions and contact algorithms inclusion, could be of major benefit to improve the final outcome of the design process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIMULASI DAN ANALISIS UNSUR TERHINGGA TERHADAP PENGGANTIAN KEPALA FEMORAL

Oleh

SEYED ALIREZA ASGARI

Mac 2003

Pengerusi: **Prof. Madya Dr. Shattri Bin Mansor**
Institut: **Teknologi Maju**

Walaupun bertahun-tahun penyelidikan dan ujikaji telah dijalankan terhadap Total Hip Replacement (THR) secara konvensional implan, tetapi masih belum ada penyelesaian untuk pesakit yang muda dan sangat aktif. Di dalam kajian ini, permodelan dua jenis tulang sekitar telah dijalankan. Cadangan kajian rekabentuk yang dibentangkan adalah konsep generik terhadap "stemless implant" serta pembinaan semula "stemless implant" dibandingkan dengan implan konvensional dan juga dengan tulang keadaan sempurna sebagai penyelesaian kawalan. Satu pendekatan permodelan secara unsur terhinggi (FE) telah diterima. Satu model femur dan optimasasi elemen telah dijalankan untuk mencari jaringan perbaikan (mesh refinement) yang terbaik.

Model tersebut dibahagikan kepada dua bahagian; dari "proximal head" 40 mm ke "distal end" (R1) dan bahagian kedua ialah 40mm dari "proximal head" ke "distal end" (R2). Untuk dua jenis keadaan bebanan iaitu lenturan (bending) dan putaran (torsion), model tersebut di selesaikan dengan perisian ANSYS. Keputusan telah dibandingkan dengan ujikaji maklumat sebagai pengesahan.

Keputusan kajian ini menunjukkan “stemless implant” mempunyai sisihan yang lebih kurang dari penyelesaian kawalan terhadap tulang dalam semua bahagian daripada kedua-dua keadaan beban berbanding dengan sisihan yang lebih besar pada “stemmed implant” dari tulang sempurna.

“Stemless implant” menunjukkan penyesuaian yang sempurna terhadap penyelesaian kawalan dalam bahagian R2 kecuali pada 14mm bahagian tertinggi dimana stemless implant menunjukkan pengurangan terikan pada persemukaan terhadap tulang dan implan. Sementara itu, “stemless implant” mempunyai perubahan ynag ketara dalam taburan tegasan dan terikan dalam bahagian R1. Kawasan ini adalah bahagian implan tersendiri yang dimasukkan, maka telitian yang lebih perlu diadakan pada bahagian tersebut ketika merekabentuk implan tersebut.

Keputusan kajian ini menunjukan “stemless implant” adalah sesuai sebagai alternatif untuk jenis konvensional implan dalam “hemi-arthroplasties”. Walau bagaimanapun, penyesuaian dan keberkesanan implan jenis ini terhadap bahagian “sub-trochanter” mesti dipertimbangkan untuk mereka bentul produk akhir. Penyiasatan perangkaan yang lebih komprehensif dengan rekabentuk spesifik pada keadaan bebanan yang lebih dan algorithma sentuhan boleh menjadi kebaikan utama untuk memajukan keputusan akhir dalam proses merekabentuk.

ACKNOWLEDGEMENTS

One page to acknowledge all those who encouraged, inspired, and hung out with me during my stay at UPM, ITMA... my supervisor, Assoc. Prof. Dr. Shattri B. Mansor for his guidance and generous support, which indeed I couldn't finish this work without him, my committee member Dr. Rahmita Wirza for her advices, as well as the faculty and staff at the Institute of Advanced Technology for being so cool. I extend my gratitude to my co-supervisors, to Assoc. Prof. Dr. Abdel Magid Hamouda for his solid, logical suggestions for conquering obstacles and his unlimited support in my presentation in Japan, and also to Assoc. Prof. Dr. Harwant Singh for his casual, nurturing relationship that allowed some of my rather abstract and often harebrained ideas to mature into interesting scientific questions, he also provided me a chance to see a wonderful THA surgical operation from close up. This was once-in-a-life time chance for me and I am thankful to the surgeon of this operation and my co-author, Dr. Bernard Prakash for his critical discussions. I am also deeply indebted to Dr. Elsadig Mahdi for his help in so many aspects of my work and life. Indeed his moral and kind guidance was one in a kind. I thank my friends and lab mates, past and present, for their collaboration as colleagues and support as friends. Finally, and most importantly I would like to thank my family particularly my parents, Jalal and Parvin, for the obvious reasons (i.e., my birth) and for their enthusiastic support. My sisters Yasmin and Ladan get credits for they lifted me up when I couldn't reach. They are the ones who held me up and never let me fall. And last but not least, my dear friends, Kambiz and Samad for their invariable help and support. They have been and will be my inspiration...

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

SHATTRI BIN MANSOR, Ph.D.
Associate Professor,
Institute of Advanced Technology,
Universiti Putra Malaysia.
(Chairman)

ABDEL MAGID HAMOUDA, Ph.D.
Associate Professor,
Institute of Advanced Technology,
Universiti Putra Malaysia.
(Member)

HARWANT SINGH, Ph.D.
Associate Professor,
Orthopaedic and Traumatology Department,
Hospital Seremban.
(Member)

RAHMITA WIRZA, Ph.D.
Institute of Advanced Technology,
Universiti Putra Malaysia.
(Member)

AINI IDERIS, Ph.D.
Professor / Dean,
School of Graduate Studies,
Universiti Putra Malaysia.

Date:

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF ABBREVIATIONS

BW	Body Weight
CAD	Computer Aided Design
CPU	Central Processor Unite
CT	Computed Tomography
ERi	Element Refinement number, i =1,2,3,4,5 indicates the mesh numbers where ER1 is the coarsest mesh and ER5 is the finest mesh
FEA	Finite Element Analysis
FEM	Finite Element Modelling
IGES	International Graphic Exchange System
ISB	International Society of Biomechanics
NDOF	Numbers of Degrees Of Freedom
NURBS	Non Uniform Rational B-Splines
S1	Maximum principal stress error in case of only one axial load with Unit BW
PL1 to PL3	Three positions in lateral aspect of the femur starting from 50mm proximal distance with 10 mm intervals
PM1 to PM3	Three positions in medial aspect of the femur starting from 50mm proximal distance with 10 mm intervals
PMMA	Poly Methyl Methyl Acrylate
Pz	Axial load distribution in case of bending loading condition
R1	Region that stemless implant had direct interface with the bone
R2	Region where the intramedullary part of the stemmed model had direct interface with the bone.
SF	Standardised Femur
T10	Tetrahedral 10-nodes element
T20	Brick shaped 20-node element
T4	Linear tetrahedral 4-nodes element
THA	Total Hip Arthroplasty
THR	Total Hip Replacement

CHAPTER ONE

INTRODUCTION

The human body is probably the most incredible piece of engineering ever devised. Therefore, it takes a pretty well engineered product to go into the human body and work side-by-side with the highly complex systems of the body. Orthopaedic implants are one of the most important products of this kind and amongst them hip and articulation implants, are the most widely used ones.

Total Hip Arthroplasty (THA) and Total Hip Replacement (THR) are surgical processes in which the femoral head is resected and after reaming and preparation of the femoral canal, a femoral stem with a ball head is inserted.

The most common indication for hip surgery is degenerative arthritis. In healthy joints, the articulating surfaces are covered with cartilage to provide smooth articulation. Various diseases may initiate degenerative changes in the cartilage, leading to joint wear and incongruity. The severe pain and reduced function of the hip are results for the patient.

Total hip replacement surgery creates a new artificial joint that ultimately can be pain free. The implant is designed to replicate the human anatomy - the relatively simple ball-and-socket structure of the hip joint.

The goals of total hip replacement are to relieve the pain, restore normal leg length and normal movement and range of motion while ensuring the stability of the implant and its long-term fixation and durability.

1.1. Problem Statement

THA is a story of success in relieving the pain. Nevertheless, there is still no end for this story since the life span of orthopaedic devices in patient's body remains as of a challenging problem. Cooper et al. (1992) estimated the number of hip fractures worldwide at 1.66 million in 1992 and expected that this number would increase to 6.26 million in 2050. Currently the most successful hip implants reside inside the patient's body for not more than 20 years. This encourages the research to find new and novel means of enhancing the performance of the hip implants. The common point of view is that the implant alters the natural loading mechanism of the bone and therefore leads to bone resorption (e.g. Lewis et al. 1984, Huiskes et al. 1992, Huiskes 1993, Van Reitbergen et al. 1993, Weinans et al. 2000, Simõe et al. 2000). With the exception of the use of new materials, however, biomechanical engineers have not significantly improved the longevity of the original Charnley concept (Huiskes, 1993). The challenge is to introduce new and novel designs with respect to new geometry and/or new material properties for the implant.

1.2. Importance of the Study

It is crucial to investigate ways that might help to reduce the failure rate of total hip replacement and the need of revision surgeries which are of great cost to both patient and health service. This kind of operation (revision surgeries) is commonly required after 10 to 15 years of initial hip replacement. It is usually due to bone-implant bond loosening and other issues such as biocompatibility, stress shielding, initial instabilities, fatigue, wear, dislocation and inadequate bone ingrowth. These complications are based on the implant design and its material as well as environmental factors such as surgical procedure and patient factors. Herberts and Malchau (1997) studied nearly 100,000 total hip replacements and suggested that surgical and patient factors have the most significant effect on the success of hip replacement. Although these environmental effects are not directly related to the implant, many of them can be considered for when designing the new implants. It means that, the appropriate design of the hip implant even can reduce the effects of environmental factors. Chang (1999) included these factors in an optimisation study for design and analysis of femoral components for total hip replacement with respect to variation in loading, bone properties and interface conditions. Nonetheless, several problems may follow even when a very skilful surgical operation is performed due to the complications that the hip implant induces to the patient.

1.3. Aims and Objectives

It is the ultimate aim of this investigation to make a reduction in complications facing patients. This cannot be achieved unless every single idea that might benefit the health service is studied thoroughly. This research is an effort to develop an approach and investigate new and currently proposed designs that may significantly improve the longevity of a hip implant inside the body of the patient. Hence, the implant might last a reasonable length of time that ideally would exceed the expected life span of the individual patient without the need for revision surgery.

The main objective of this project is to develop an approach to investigate the improvement of stress shielding in femoral part with regard to design of the hip implant in total hip replacement. The objectives can be summarised as follows:

- Developing an approach for modelling of the bone with or without the implant.
- Simulation of the bone around orthopaedic implants with different designs.

Two types of implants have been considered for this investigation namely, stemmed and stemless implant. For simulating the mechanical behaviour of the bone in presence of these types of implants, a modelling approach has been developed and implemented to compare fundamental mechanics of stemmed, stemless and intact bone under bending loading condition. Furthermore, the developed model is used to evaluate the hip implant design effect on torsion loading condition.

To achieve the above set objectives, a numerical method Finite Element Modelling and Analyses (FEM, FEA) was adopted. Generally, a FEA includes three phases, preprocessing, processing and postprocessing. In case of complex structure such as bone, the most difficult phase of FEA is laid in pre-processing. In this thesis, the most efficient and validated way was identified and implemented to do further analyses.

1.4. Layout of Thesis

This thesis is divided into six chapters. Following this preliminary chapter, which is introduction to this research, chapter two is the literature review of showing that the current design of stemless hip implants was historically proposed long time ago. The conventional type of implant is also presented and debated in this chapter showing its progress during five decades of its application in THR. Chapter three discusses the methodology of this research and is followed by FEM, which is presented in chapter four. Thus, chapter four presents details of preprocessing, processing and postprocessing of FEA of this research. Following that, the results of the analyses are presented and these results are discussed in chapter five which is chapter of results and discussion. Finally, the conclusion and recommendations are presented in chapter six followed by list of publications of this research.

CHAPTER TWO

LITERATURE REVIEW

THR is enabling hundreds of thousands of people who suffer from problems in joint femur, to live fuller and more active lives. Using metal alloys, high-grade plastics and polymeric materials, orthopaedic surgeons can replace a painful, dysfunctional joint with a highly functional, long-lasting prosthesis. Over the past half-century, there have been many advances in the design, construction and implantation of artificial hip joints, resulting in a high percentage of successful long-term outcomes.

2.1. History of THA

The earliest practise of THA can be traced back to 18^{th} century (Cameron, 1991). In 1926, Hey Groves used ivory hip arthroplasty for fracture of bones and in 1940 Harboush implanted prosthesis for the femoral head. This prosthesis, which is shown in Figure 2.1 was similar to a hemi-arthroplasty and eroded the acetabulum. For that reason, Harboush concluded that both head and acetabulum should be replaced as well. That was followed by Judet implants in 1946, which were stemless implants. Before them, Austin Moore and Harold Bohlman implemented a femoral head replacement; their original design had side plates but later they introduced the idea of intramedullary stem (Cameron, 1991).

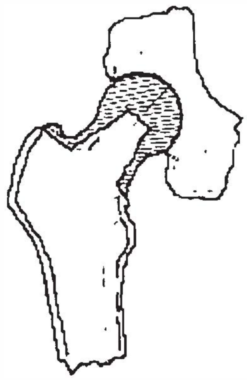

Figure 2.1: Harboush implant in 1940 (reproduced from Cameron, 1991).

The first THR was designed and implemented by Phillip Wiles from the Middlesex Hospital, in London in 1930's. Prior to this date, prosthetic replacement surgery was carried out with one arthritic surface being replaced and the results were unsatisfactory (Coombs et al., 1990).

G. K. McKee began development of THR designs after Wiles. The results of his various uncemented prototypes were initial relief of pain followed by loosening and mechanical failure (August et al., 1986).

One of the first widely used and successful THR was McKee-Farrar THR, which had chrome cobalt metal on metal articulation, and both acetabular and femoral components were fixed with cement (Sven-Arne et al., 1996 and August et al., 1986)

However, the first modern total hip was designed and carried out by Sir John Charnley, a British orthopaedist, who proposed a low friction arthroplasty by using high density polyethylene for the acetabular portion and the stem with cobalt chromium alloy.

Before 1958, Charnley found out that the metal on metal articulation of McKee joints was unsatisfactory because of its high frictional torque. In his opinion, this frictional torque is the reason for eventual loosening of the fixation of the McKee components in their bony bed. His experiments showed that the natural elasto-hydrodynamic lubrication with synovial fluid could not be used to reduce the frictional torque of the metal on metal articulation and this led him into the field of polymers. In his first attempt, Teflon on Teflon bearings -as a resurfacing for the arthritic femoral head and acetabulum-wore out within two years (Charnley, 1961 and Charnley, 1965)

Charnley's next attempt at hip arthroplasty followed the McKee idea of resecting the femoral head and inserting a stemmed component cemented into the upper femur in years 1958-1962. The metal head of this component articulated against a Teflon socket inserted into the acetabulum. Consequently, high wear of the Teflon occurred in several hundred patients who were treated by this method, and it caused severe osteolysis and loosening in the surrounding bone and a large number of revision operations had to be performed (Charnley, 1965).

Charnley found out that there was a direct relationship between femoral head size and volumetric polymer wear. Therefore he became determined to use small (22.25 mm) head in his future designs in order to minimize the plastic wear volume. This had two undesirable side effects. Linear penetration into