

## OPTIMIZATION OF SKELETAL HIP IMPLANT CROSS-SECTIONS

Sudesh Sivarasu, Pearline Beulah, Lazar Mathew  
School of Bio Sciences & Technology,  
VIT University, Vellore  
sudeshsivarasu@gmail.com

**Abstract:** Aseptic loosening is the most important cause of failure in total hip replacement (THR), associated with pain and restriction in the range of the joint motion. Solid stems are found to have a greater rigidity, therefore, transfer fewer loads proximally, which results in high proximal stress shielding of the proximal femur. A stem of low stiffness alone would not suffice in achieving a reduced or optimal stress shielding. A skeletal hip implant with varying cross-sections was designed and analysed. The skeletal hip implant with a hexagonal cross section had a better load bearing capacity. This novel design would ameliorate the implant fixation, minimize stress shielding, maintain appropriate strength, rigidity, enhance the longevity of the implant and relieves patients from discomfort.

**Keywords:** Hip Implant, Skeletal Implant, Hexagon cross- section, Total Hip Arthroplasty

---

### 1. INTRODUCTION

The introduction to the use of Charnley hip prosthesis and the successive designs has provided consistently successful hip replacement procedures since the early 1960s. The total hip replacement procedures have increased in the past decades. Nearly 500,000 hip replacements surgeries take place each year in the US alone, with approximately one fourth which requires revision surgeries. The major causes for the revision surgeries are aseptic loosening, dislocation, improper design, wear, stress- shielding on the bone, mechanical and biological factors. The principal causes of aseptic loosening are; mechanical failure of the implant or cement, presence of wear debris into the interface region, relative motion across the bone- implant interface, and stress shielding in the bone. Each of these phenomena can initiate a biological response in the bone leading to resorption and the eventual loosening of the implant. The performance of an implant is dependent upon the micromotion, patient age, material parameters, geometric parameters, bone-implant interactions and implantation techniques.

According to Wolff's Law, trabecular morphology of the proximal femur adapts to support the complex stresses imposed on the hip joint.

The trabecular microstructure manifests the principal stress magnitudes and directions formed during the stance phase of gait. The primary compressive trabeculae forms a central pillar of densely packed, plate- like trabeculae ideally suited to support axial

compressive loads, while the primary tensile trabeculae forms an arc along the femoral neck to resist bending moments.

Micromotion is seen between the bone-implant interface and results in the loosening of the implant. Increased micromotion is a factor which is responsible for the decrease in the amount of bone that grows into the implant. The bone growth over the implant is hindered by a high degree of micromotion in the interface and the lack of in-growth results in decreased longevity of the implant. It also results in the reduction of the stability of the hip implant, growth of fibrous between the interfaces. Therefore micromotion between the bone-implant interface needs to be minimized in designing a hip implant. The need to concentrate on the longevity of the implants has been increasing. A material with high toughness and wear properties are essential for a good hip implant.

Hip implants fail depending on the design. Stress shielding is found to be the major cause for the failure of the hip implants. This can lead to the implant being replaced, or revised, which is painful for the patient and difficult for the health care industry. Naturally the stress is distributed over the entire cross-section of the femur with bending and compression as major modes of loading. But after Total Hip Arthroplasty (THA), the load is transferred across the bone-cement – prostheses interface. This altered load leads to the loading on the prosthesis away from the bone with an increase in interface stresses. The bending

displacements in the bone which surrounds the stem are reduced due to the relatively high flexural stiffness of the implant. This results in the stress shielding on the femur. An apparent solution to the shielding problem would be a prosthesis which loads the proximal end of the femur in a manner similar to the natural state.

Numerous attempts have been made to combat the effect of stress shielding by using cement less, porous, collared, or stemless designs. Flexible stems provoke less stress shielding in the surrounding bone, but higher proximal interface and cement stresses; rigid stems provoke high proximal stress shielding, but lower interface stresses. The more rigid the stem, the less load it transfers proximally to the bone so the greater the stress shielding of the proximal femur. Therefore an implant of low weight would enable to combat the effect of stress shielding on the bone. Changes in the materials and in the design such as the usage of cementless, porous coating placement on the femoral prostheses, less stiff or isoelastic prosthesis were incorporated to more closely match the modulus of the bone.

The medullary vessels are responsible for the cortical bone vascular supply. During Hip Arthroplasty, the main arterial supply to the cortex is cut off and occupies the medullar space. The decreased blood supply will cause the bone to resorb and this would result in the reduction of the bone mineral density in the proximal cortex. To obtain more space for medullary revascularization, the hip stem design can be modified and must be focused to maintain the appropriate strength.

The cross-section of the hip implant can directly impact the distribution of stress around the implant where broad surfaces in the lateral areas transfer load and help reduce implant failure. Small changes in geometry can greatly influence the implant to various load generation while implanted. Therefore there is a need to optimize a skeletal hip implant with the appropriate cross- section, which would not only aid in the best bone- implant interface, but also maintains appropriate strength, rigidity and enhances implant fixation, and offers better motility to the patient. This paper deals with the comparison of masses and analysis of various hip stem designs with varying cross- sections such as the trapezoidal, pentagonal, hexagonal, heptagonal and octagonal. The optimization of the cross –section was performed for the hip implant design which had less weight and a better load bearing capacity.

## 2. MATERIALS AND METHODS

Implants used within the human body must satisfy the requirements of the body environment such as

corrosion resistance, biocompatibility, bio functionality and bioadhesion. Geometry, roughness and other characteristics of the implant surface influence the implant surface-body tissue interaction.

Table 1. Biomaterial for mass determination

Femoral component	- 316L Stainless steel
Acetabular cup	- 316L Stainless steel
Acetabular liner	- UHMWPE ( Ultra High Molecular Weight Polyethylene)

Table 2. Material Composition- 316L Stainless steel

Chemicals	C	Cr	Fe	Mn	Mo	Ni	P	S	Si
Weight in %	0.03	18	65	2	3	14	0.045	0.03	1

Table 3. Mechanical Properties - 316L Stainless Steel

Tensile Strength	- 560 MPa
Yield Strength	- 290 Mpa
Elongation(%)	- 40 %
Rockwell hardness	- 95 HR B
Brinell hardness	- 217 HR B

Table 4. Physical Properties – 316L Stainless steel

Density	- 8000(Kg/m <sup>3</sup> )
Specific heat	- 500(J/Kg.K)

Table 5: Mechanical Properties – UHMWPE

Tensile strength	- 47 Mpa
Yield strength	- 27 Mpa
Elongation (%)	- 525%
Rockwell hardness	-50 R

The skeletal hip implant was designed with various cross sections using SOLIDWORKS.

The material used for the femoral component of the hip implant is 316L Stainless Steel. The material used for the acetabular cup is 316L Stainless Steel and for the acetabular liner is the Ultra High Molecular Weight Polyethylene (UHMWPE).

### 2.1 316L Stainless steel

316L Stainless steel is the most popular alloy used for the orthopaedic medical implants and are normally covered with a thin protective film, which determines the surface properties of an implant.

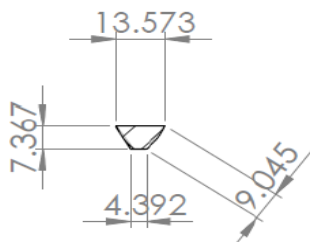
A protective layer of Cr<sub>2</sub>O<sub>3</sub> oxide is formed either during manufacture process or intentionally passivated in various media. This passivation, inhibits further corrosion of the alloy by the formation of the oxide layer instantly, if the surface is damaged. This surface oxide provides better interface with tissue after implantation.

### 2.2 Ultra High Molecular Weight Polyethylene (UHMWPE)

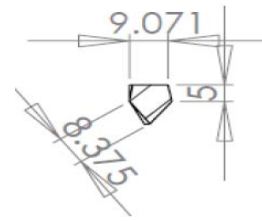
The introduction to UHMWPE articulating against a metallic femoral head, remains the standard surface bearing combination for Total Hip Arthroplasty. UHMWPE is the type of polyolefin, which derives its strength from the length of each individual molecule. It is made up of long molecular chains that serve to transfer load more effectively to the polymer's backbone by strengthening intermolecular interactions. It has high tensile and compressive strength, high operational temperatures and highly resistant to most alkalis and acids.

A skeletal hip implant was designed with various base and the neck cross-sections such as the trapezium, pentagon, hexagon, heptagon and octagon. The weight of all the hip profiles with a complete solid design and skeletal design was calculated and compared. The designs were analysed using COSMOS. The hip implant with the lowest weight and highest weight bearing capacity was optimized.

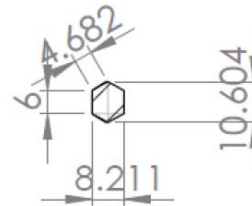
### 2.3 The base cross- sections of the femoral component



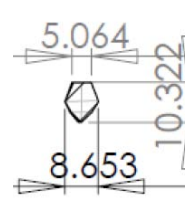
A)Trapezium



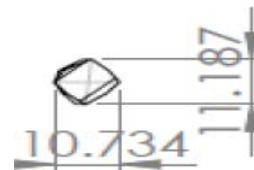
B)Pentagon



C) Hexagon



D) Heptagon



E) Octagon

### 3. WEIGHT EVALUATION OF THE HIP IMPLANT DESIGNS

Solid hip implants were designed with cross sections such as the trapezium, pentagon, hexagon, heptagon and octagon. Skeletal hip implant was designed for all the same five cross –sections. The weight of the solid and the skeletal hip implants were evaluated and a comparative study was performed.

### 4. FINITE ELEMENT ANALYSIS OF THE SKELETAL FEMORAL COMPONENT

#### 4.1 Loading Conditions

The femoral component designs comprising of the five cross – sections were analyzed with forces ranging from 500N to 10 kN. These forces were selected because a typical gait cycle generates forces up to 6–7

times the body weight in the hip joint. But for a single legged stance the force exerted on the leg is considered to be 10 times the weight of the body. But, for analysis the force exerted on the hip was considered nearly 14 times the body weight.

**4.2 FEA of the femoral Component**

The Load was incremented in terms of 500N starting from 500N to 10kN .The load was applied on the femoral head. The restraint was applied to the femoral stem. The results show that the femoral component design with a hexagonal has a maximum load bearing capacity followed by the octagonal, trapezoidal, pentagonal and heptagonal cross –sections.

The results show that the femoral component design with a hexagonal has a maximum load bearing capacity followed by the octagonal, trapezoidal, pentagonal and heptagonal cross –sections.

**4.3 Design of the Skeletal Femoral Component with Hexagonal Cross section**

Table-6 - Comparison of weight of the Hip Profiles

Cross-section	Solid Design Weight in g	Skeletal Design Weight in g
Trapezium	289.5	230.63
Pentagon	303	228
Hexagon	322	208
Heptagon	322.94	211.08
Octagon	285	215.88

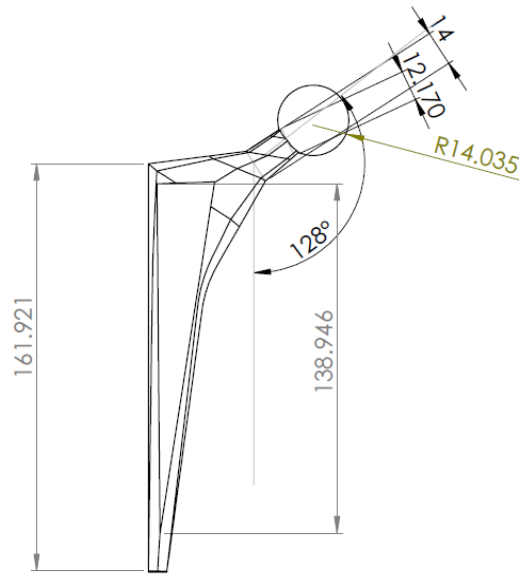


Fig1- Skeletal Femoral Component

Table -7 Comparison of the FEA of the Skeletal Components

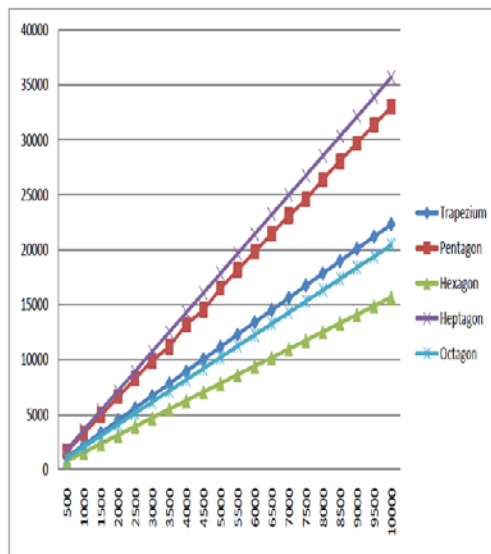


Fig 2- 3D Model of Skeletal Femoral Component

Table 8- FEA of the Femoral Component with Hexagonal cross-section

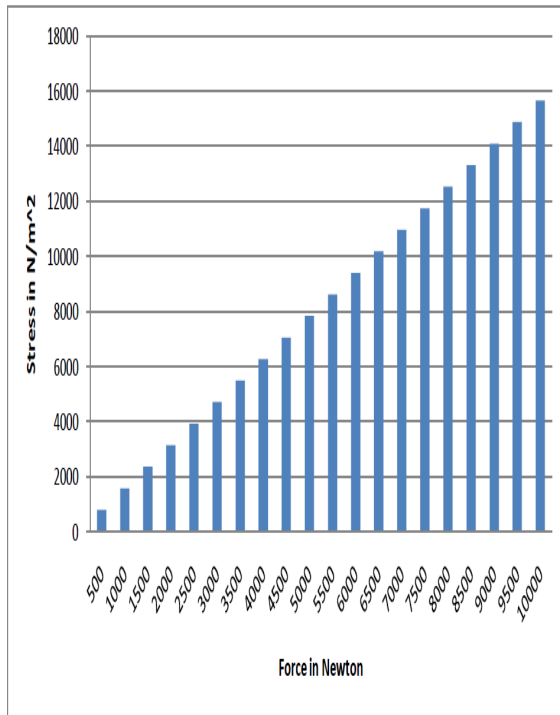


Fig4-3Dmodel of the Acetabular Cup

**5.1 Finite Element Analysis of the Acetabular Cup**

The Acetabular component comprising of the Acetabular cup and the Acetabular liner were analysed.

**5.1. a Loading Conditions**

The Acetabular cup was analyzed with forces ranging from 1000N to 10 kN. These forces were selected because a typical gait cycle generates forces up to 6–7 times the body weight in the hip joint. But for a single legged stance the force exerted on the leg is considered to be 10 times the weight of the body. But, for analysis the force exerted on the hip was considered nearly 14 times the body weight.

**5. DESIGN OF THE ACETABULAR CUP**

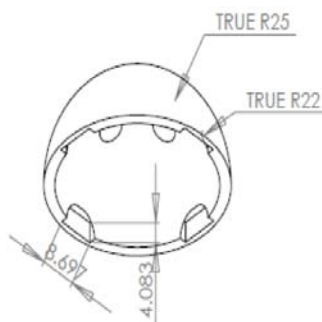
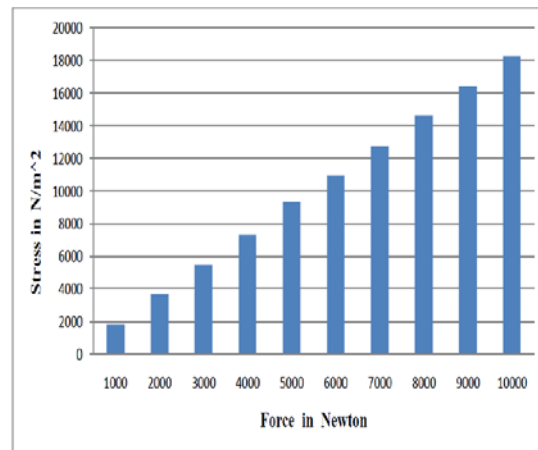


Fig3 – Acetabular Cup

Table 9- FEA of the Acetabular Cup



**5.1. b FEA of the Acetabular Cup**

The Load was incremented in terms of 1000N starting from 1000N to 10kN .The load was applied on the top of the Acetabular Cup surface. The restraint was applied to the inner Acetabular Cup surface.

## 6. DESIGN OF THE ACETABULAR LINER

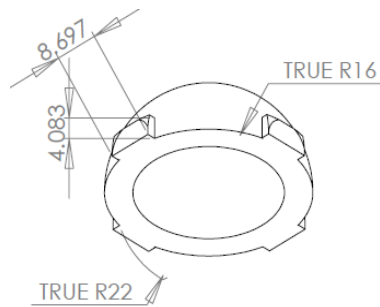


Fig5- Acetabular Liner

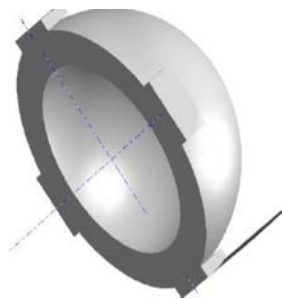


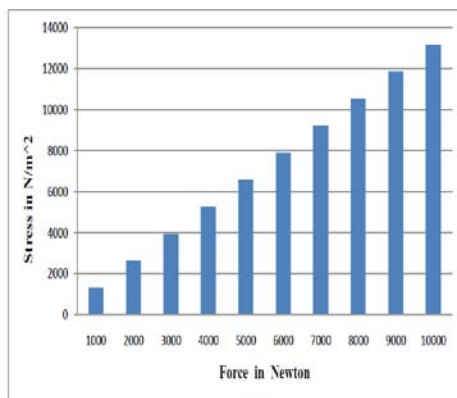
Fig6- 3D model of the Acetabular Liner

### 6.1 Finite Element Analysis of the Acetabular Liner

#### 6.1.a Acetabular Liner - Loading Conditions

The Acetabular cup was analyzed with forces ranging from 1000N to 10 kN. These forces were selected because a typical gait cycle generates forces up to 6–7 times the body weight in the hip joint. But for a single legged stance the force exerted on the leg is considered to be 10 times the weight of the body. But, for analysis the force exerted on the hip was considered nearly 14 times the body weight.

Table 10- FEA of the Acetabular Liner



#### 6.1.b FEA of the Acetabular Liner

The Load was incremented in terms of 1000N starting from 1000N to 10kN .The load was applied on the top of the Acetabular liner surface. The restraint was applied to the inner Acetabular liner surface.

## 7. RESULTS AND DISCUSSION

The solid femoral component and the skeletal femoral component were designed with varying cross-sections and the weights of the designs were evaluated. The weights of both the solid and the skeletal designs were compared. Weight reduction of about 35 % was observed in the skeletal component with hexagonal cross-section than the solid femoral component with the same cross-section. Therefore the skeletal component with the hexagonal cross-section was chosen to be the optimal design based on the weight of the design.

Finite Element Analysis was carried out for all the Skeletal Femoral components. Linear behaviour was observed for all the designs. The results show that, the skeletal femoral component with hexagonal cross-section had a better load bearing capacity than the rest of the designs, followed by the octagon, trapezium, pentagon and the heptagon cross-sections. So the skeletal component with the hexagonal cross-section was optimized based on the FEA of the design.

Thus the Skeletal Hip implant was optimized based on the Weight and the cross-section of the design.

## 8. CONCLUSION

This novel skeletal hip implant has a better load bearing capacity and has less weight compared with the rest of the designs. This design would be prototyped after the completion of the Range of Motion analysis.

## 9. REFERENCES

1. Blake Latham a, T. Goswami, Effect of geometric parameters in the design of hip implants paper IV, Materials and Design 25 (2004) 715–722.
2. Anthony L. Sabatini a, Tarun Goswami, Hip implants VII: Finite element analysis and Optimization of cross-sections, Materials and Design 29 (2008) 1438–1446.
3. M.J. Fagan and A.J.C. Lee\*, Role of the collar on the femoral stem of cemented total hip replacements J. Biomed. Eng. 1986, Vol. 8, 295-304.
4. Sudesh Sivarasu and Lazar Mathew, Finite Element Based Design Optimization of a Novel High Flexion Knee used in Total Knee Arthroplasty, Applied Bionics & biomechanics, 2008 5(2): 77-87.
5. Daniel Kluess , Heiner Martin , Wolfram Mittelmeier , Klaus-Peter Schmitz , Rainer Bader, Influence of femoral head size on impingement,

**NCCI 2010 -National Conference on Computational Instrumentation  
CSIO Chandigarh, INDIA, 19-20 March 2010**

dislocation and stress distribution in total hip replacement, *Medical Engineering & Physics* 29 (2007) 465–47, 1

6. Sudesh Sivarasu, Lazar Mathew, Finite Element Analysis of a Novel High Flexion Knee(Ti-UHMWPE) used in Total Knee Arthroplasty; *Biomedical Engineering: Applications, Basis and Communications*, World Scientific Publishing 2009 (Accepted in Press)

7. E. Pyburn a, T. Goswami, Materials and Finite element analysis of femoral components paper III – hip joints *Materials and Design* 25 (2004) 705–713.

8. Eiichi Genda, Norimasa Iwasaki, Guoan Li, Bruce A. MacWilliams, Peter J. Barrance, Edmund Y.S. Chao\*, Normal hip joint contact pressure distribution in single-leg standing-effect of gender and anatomic parameters, *Journal of Biomechanics* 34 (2001) 895–905

9. A.Rohlmann, U. Mb'ssner, G. Bergmann and R. Kolbel\* , Finite Element Analysis and Experimental

Investigation of stresses in Femur, *J. Biomed. Eng.* 1982, Vol. 4, July 241-246

10. Chan-Tsung Yanga (Article in press), Design and test of hip stem for medullary Revascularization, *Medical Engineering & Physics*.

11. Sudesh Sivarasu, Lazar Mathew, Structural Responses of a Novel High Flexion Knee(SS316-UHMWPE) used in Total Knee Arthroplasty using Finite Element Analysis ; *Biophysical Reviews and Letters*, World Scientific Publishing 2009 (Accepted in Press)

12. S. Gross<sup>1</sup>, E.W. Abel\*, A finite element analysis of hollow stemmed hip prostheses as a means of reducing stress shielding of the femur, *Journal of Biomechanics* 34 (2001) 995–1003

13. R. D. Crowninshield, D. R. Pedersen, R. A. Brand, A Measurement of Proximal Femur Strain with Total Hip Arthroplasty<sup>1</sup>, *Journal of Biomechanical Engineering*, August 1980, Vol. 102 (230-23)