Finite Element Analysis of Equivalent Stress and Deformation of Cement less Hip Prosthesis

[1]D..Bubesh Kumar, [2]Dr. K.G.Muthurajan

[1]Associate Professor,Mechanical Engineering Department ,
Aarupadai Veedu Institute of Technology, Vinayaka Mission University, Chennai
[2]Sr. Professor, Mechanical Engineering Department, VMKEC, Salem.

Abstract - **The finite element method, one of the most advanced simulation techniques in solid mechanics, is used for orthopedic biomechanics. It is used as a tool for the design and analysis of total joint replacement and other orthopedic devices. The design of hip joint prostheses is a complex process that requires close co-operation between engineers and surgeons. To design highly durable prostheses one has to take into account the natural processes occurring in the bone. Hip prosthesis was used for the patients who has the hip fracture and unable to recover naturally. This study aims to analyses the hip prosthesis by finite element analysis. The model is cementless hip stem which were used to analyses simulating common physiological activity standing. The design of a hip prosthesis involves parameters which include femoral neck and femoral head. The results showed that the neck size and femoral head affected by stress distribution on hip prosthesis when inserted in the femoral bone. The maximum von Mises stress at the neck of model and maximum von Mises stress at the head of the model, Total deformation and directional deformation were also analyzed. The von mises stresses were analyzed to find the relationship between the ranges of applied loads. These parameters were taken to rectify old design with the new design in terms of material, shape of the implants without compromising the functionality of the implant and appropriate shape for the titanium implant is proposed. These findings can form a base for further research such as the optimum design of bone-implant hip prosthesis. This study is aimed to analyze the stress and deformation of hip prosthesis by finite element analysis , when inserted in the femoral bone.**

Keywords - **Hip prosthesis, Finite element analysis, Shape of hip prosthesis Finite element method**

I. INTRODUCTION

Millions of patients all over the world undergo total hip replacement, the strength of the hip joint prostheses is very important for the life of the implants 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 keeps 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 stress and deformation of hip prosthesis by finite element analysis, when inserted in the femoral bone.

II. MATERIAL MODELS

Titanium materials for implant [6] were used in the finite element simulation. Behaviors of these materials are represented with linear isotropic material models [11-16]. The maximum von Mises stress at the neck of model and maximum von Mises stress at the head of the model are were analyzed .Total deformation and directional deformation [17-21] was also analyzed. The young's modulus, Poisson ratio of titanium are 110Gpa , 0.3 respectively. The material properties [22-28] of bone is given in the table 1.

TABLE I Bone Material Properties

S.No	Material	Elastic modulus	Poisson Ratio
1	Cortical bone	14,000	0.4
2	Cancellous bone	600	0.2

Loading conditions

For static analysis, a load of 50N to 1800 N (Fstatic) with is applied on the surface of the implant bearing as shown in Fig1. Static load represents a person of 60 kg [23]. An abductor muscle load is not applied .An ilio tibial-tract load (Filio tibial-tract) is not applied to the bottom of the femur . Distal end of the femur is constrained not to move in horizontal direction.

Three Dimensional Modeling

Three dimensional modeling of the hip implant was carried out using Ansys Workbench 12. Computer Aided model Stem shapes have significant influence on the performance of prostheses. Stem shapes with smooth surfaces generally reduce stress concentrations and lead to high fatigue life of the prosthesis less stress [7-10]. For the femur geometry the model of indian femur was used. The femur model was created using Ansys WorkBench 12, CAD model of the complete prosthesis was imported into ANSYS WorkBench 12 Analysis Module . Preprocessing environment to create the finite element model required in the analyses. Stem shapes have diameters of 15 mm. Stem lengths are 85 mm. Curved stem has radius of 50 mm. Finite element model required in FE analysis is created by discretizing the geometric models shown in Fig1in to smaller and simpler elements. The discretization was performed in ANSYS environment. The three-dimensional solid model assembly of femur, and implant was transferred to ANSYS Workbench by direct interface.To build the finite element model, of femur, and implant were meshed using a higher order three dimensional solid element; SOLID187 which has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions [19].

Analysis of HIP joint

Finite element models: A three-dimensional model of the femoral bone was created by ANSYS WorkBench 12. Hip prostheses and femoral bone were analyzed by finite element method, ANSYS WORKBENCH12 Software. The implant model had a total of 37,168 nodes and 147,299 elements. Hip designs: A finite element analysis (FEA) was performed. The femur prosthesis [29-34] was assigned a Titanium Alloy. In this analysis, ball diameter and neck length were fixed. Finite element analysis and results: Static analyses of the prosthesis should be conducted to ensure about the safety of the design. In the literature, prostheses are often designed according to the results of static analysis. Static finite element (FE) analyses are mostly conducted under body weight loads. The stresses developed on the prosthesis are responsible for the fracture or fatigue failure of the prosthesis. To investigate how static analysis prosthesis is analyzed under static body weight load. Finite element analyses of the prosthesis are carried out using ANSYS on a P4 2.0 GHz Intel processor PC. Analyses take about 1 h of CPU time. Von Mises stresses in the stem shapes resulted from static finite element analyses as shown in the figure 5. It is important that the maximum equivalent stress on the prostheses should be lower than the endurance limit of the prosthesis materials for safety. The calculated VonMises stresses as shown in Table 3 are much lower than the yield stresses of Titanium given in Table 1. This means, prosthesis with stems is safe for stress condition without considering the muscle forces. Total Deformation and Directional Deformation analysis are shown in the Figure 3 and Figure 4.

Boundary conditions

Loading and boundary conditions described by Bubesh [39] applied to the proximal femur depended on the activities of normal load at 300N to very high load at 1800N .Load is applied on the head of the femur implant and on the distal end of the femur is fixed .The figure1 shows the loading condition applied to the cementless femoral Implant [35-38].

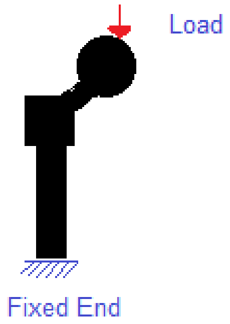

Fig.1 Show loading condition which applies to the femoral Implant

Biological considerations

Stress and Deformation occur on the femur when the femur bone is implanted with hip prosthesis .The stress on the femur and the deformation on the femur is different. Stresses on the implant and deformation on the implant usually different .The mismatch of the stress and deformation between the implant and bone will have biological effect on the bone .The stress should not be abruptly changed from the bone to implant , If there is change in stress levels ,as the case of bone plate, the change in the young's modulus leads to stress shielding and weakening of the bone .The same phenomenon may occur in the case of hip implants .The deformation of the bone is usually in micro strains .If there is mismatch of strain between bone and implants due to deformation of the implants it may result in less of the tissue growth surrounding the implants.

III. RESULTS

Finite element analysis showed that the maximum von Mises stress occurred at the head region of the hip prosthesis. By analyzing the maximum von Mises stress and directional and unidirectional deformation of the model are shown in the table 2. It appeared that the neck had the minimum von Mises stress. Maximum von Mises stresses are developed in the head of the hip prosthesis. Table: 3 and figure: 5 shows the Equivalent von-mises developed in the femur due to range of loads .

TABLE 2 Load vs. Directional Deformation, Total Deformation of femoral head and femoral Neck

Load	Directional Deformation Head	Total Deformation Head	Directional Deformation Neck	Total Deformation Neck
300	0.0001121	0.190009	0.00003643	0.14785
600	0.00022421	0.44366	-0.000078486	0.34498
900	0.00033631	0.57027	-0.00011773	0.44355
1200	0.00044841	0.7603	-0.00015697	0.5914
1500	0.00048518	0.95040	-0.00019622	0.73924
1800	0.00067262	1.1405	-0.00023546	0.88709

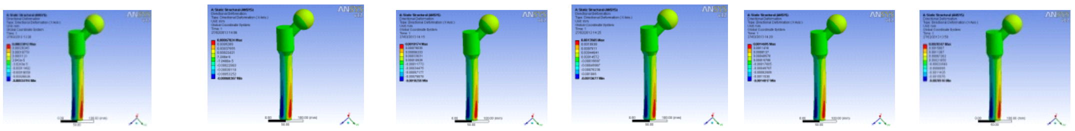
300N 600N 900N 1200N 1500N 1800N

Fig 3: Directional Deformation of femoral head

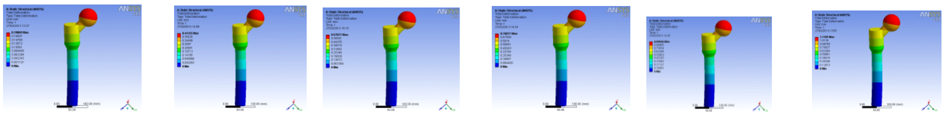
300N 600N 900N 1200N 1500N 1800N

Fig 4: Total Deformation of femoral head

Table 3: Load vs. Equivalent (von-mises) Stress for femoral head and neck

Load	Head	Neck
300	0.0043484	1.1872
600	0.0086968	2.3744
900	0.013045	3.5615
1200	0.017394	4.7487
1500	0.021742	5.9359
1800	0.02609	7.1231

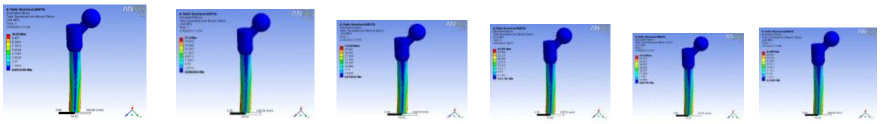
300 600 900 1200 1500 1800

Fig 5 Equivalent VON-MISES Stress

IV. DISCUSSION

The maximum Equivalent (von Mises) stress, total deformation and unidirectional deformation on the hip prosthesis and femoral bone when inserted in Indian femur under the standing load condition . It showed that the prosthesis neck size and femoral head affected to the stress distribution. The neck of the femoral had less maximum von Mises stress than the head of the femoral , As a result, the femoral had more load distribution .The result showed that hip prosthesis with less stress in the neck area must be chosen for good clinical result .The strains in the implants should match with the bone , this analysis helps to find better material for implants.

V. CONCLUSION

To conclude, hip prosthesis should have less stress in the neck area. Therefore, the new design of hip prosthesis must take these conditions in consideration for good clinical result and the decrease in the implant damage. Maximum Equivalent von Mises stresses developed in the neck of the hip prosthesis and maximum total deformation in the implant for static condition were analyzed. The design of the implants should have stress distribution similar to the bone of the patient.

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