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MODELING AND ANALYSIS OF FEMUR COMPONENT OF A PROSTHETIC KNEE JOINT

G Krishnateja [*1], K. Mahender [2]
[*] Mechanical Engineering Department, Anurag Group of Institutions, India

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ABSTRACT

Degenerative arthritis is a disease that affects the line cartilage of the knee joint. It causes severe pain in the joint and may require a replacement surgery of the affected knee with artificial components. Geometric complexity and non linearity of the materials of the knee make the analytical solutions of the mechanical behavior of the knee joint difficult. The knee is the most complex joint within the human body. Computational modeling of the knee provides a way for better understanding the interplay between the hard and soft tissue constituents of the knee during normal and pathologic function. Additionally, properly validated models can be used in the design of knee implant systems by understanding the mechanics of the restored knee in order to more closely replicate the healthy knee.The objective of this dissertation was to model a femur part of prosthetic knee joint from the available literature and study the distribution of stresses in the same by assigning it the desired material properties.Commercially available software (ANSYS 11.0) was used for numerical estimation of static stress. The effects of the different materials and flexion angles on stresses in the femur component were investigated.

I. INTRODUCTION

The human lower limb is adapted for weight-bearing, locomotion and maintaining the unique, upright, bipedal posture [1]. The knee joint is the middle joint of the lower limb. It works in conjunction with the hip and ankle joint, for supporting and moving the body during a variety of both routine and difficult activities. The weight of the body, inertia forces and muscle forces are transmitted to the ground through the knee, which has to bear compressive forces up to six times body weight during daily life activities [2,3]. The knee is one of the most often injured joints, since it is the most heavily loaded and one of the most mobile joints in the human body and is regularly subjected to great mechanical demands [4, 5]. Because of that, knee is associated with a high incidence of degenerative and inflammatory diseases. The appropriate method of correction differs from case to case and, usually, surgical intervention is considered once exhausted other medical treatment possibilities.For advanced arthritis, the treatment of choice is, generally, the knee replacement surgery, where the joint surface is replaced by an artificial implant [8], allowing the return to activities of daily living. Although the history of arthroplasty as the creation of an artificial joint with the purpose of restoring motion while relieving pain and maintaining stability had begun early in the nineteenth century, joint replacement took a lot longer to develop [9]. It was not until 1861 that Ferguson [9] reported the first successful knee arthroplasty. This method prevailed for many decades, but there were some problems associated with this attempt at joint reconstruction with the interposition of soft tissues between bone ends. As a result, surgeons began to investigate the use of other materials, including plastic and metal [9].The first attempt for a knee joint prosthesis was actually a hinge fixed by stems into the femur and tibia marrow cavities, in which damaged particular surface of bone was removed and substituted by hinge prosthesis. These early total knee arthroplasty (TKA) systems were highly constrained causing stress concentrations, loosening and infection. As a consequence, they soon failed, and therefore were abandoned. Since the early 60’s, more realistic knee implants have been created and, a new era began in TKA systems, where the incidence of TKA has risen dramatically [10]. Currently, the modern TKA systems contain multiple components made of different materials (metal and polymer) resurfacing femur, tibia and patella that attempt to mimic the natural knee [1]. Therefore, materials and design are important issues in the development biomedical devices. Nowadays, knee arthroplasty has proven to be a very effective surgical treatment, being one of the most common joint replacement procedures [11]. The results of TKA showed that today most patients can expect a ten-year implant survival rate (without the need for another surgery) in the range of 90% to 95% and a fifteen-year survival rate in the range of 85% - 90% [10, 12-15].

II. Theory

- Anotomy

The knee is the largest joint in the human body and among the most important ones to our daily lives. The knee is involved in virtually everything we do from walking to getting up from a chair to driving. The knee joint may look like a simple joint, but in fact, it is one of the most complex joints. Moreover, the knee is more likely to be injured than any other joint in the body.

- Bones of the knee joint

The knee joint is composed of three bones enclosed in a joint capsule:

1. femur,
2. tibia and
3. patella.

In human anatomy, the femur, or thighbone, is the longest, largest, strongest and heaviest bone [4, 5, 29]. As can be seen in Figure 1.2, the distal extremity of the femur – proximal articular surface of the knee joint –, is composed of two convex protrusions, the medial and the lateral femoral condyles. The condyles are separated posteriorly by an intercondylar fossa and are joined anteriorly by the femoral trochlear groove or surface. At its distal end, its major weight-bearing articulation is with the tibia, at the inferior and posterior surfaces of the femur's condyles (which constitute the surface for articulation with the corresponding condyles of the tibia and menisci). It also articulates anteriorly with the patella, at the trochlear groove.

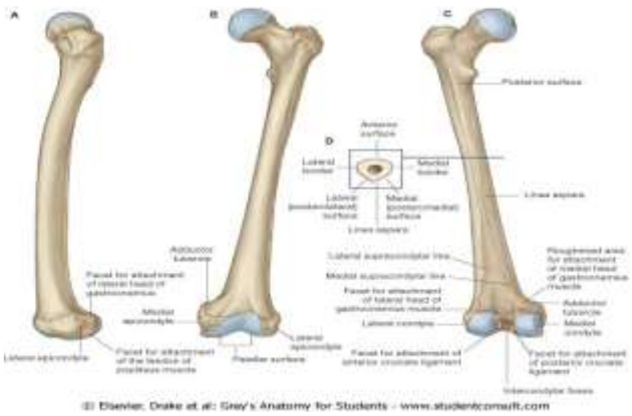

Figure:
Shaft and distal end of femur.

A. Lateral view. B. Anterior view. C. Posterior view. D. Cross-section through shaft of femur

Figure:

III. Problem Statement

The objective of the dissertation is to model a Femur component of a Prosthetic Knee Joint and obtaining the stress induced and the deformation produced during the gait cycle at different flexion angles. Based on deformation produced, a better material for the manufacturing of Femur component is suggested.

Analysis is carried out for various loads, different flexion angles and for different materials

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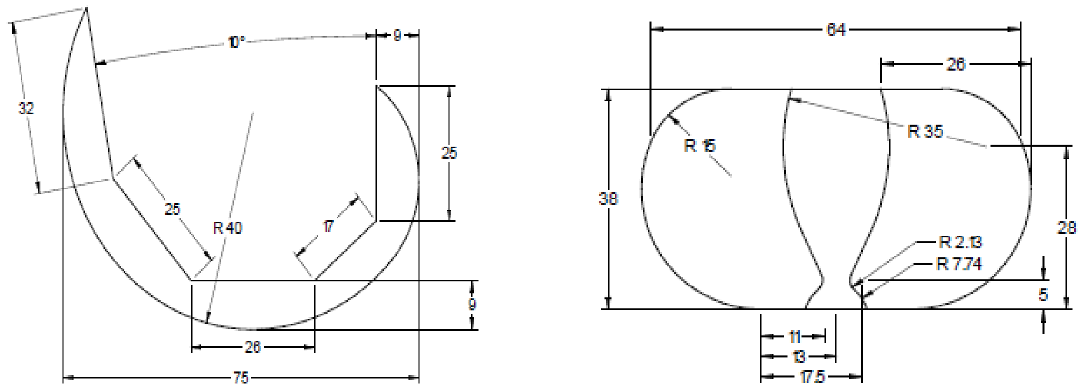
IV. Methodology

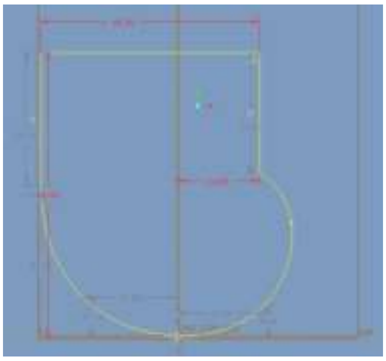
Overview of steps involved in solving the problem

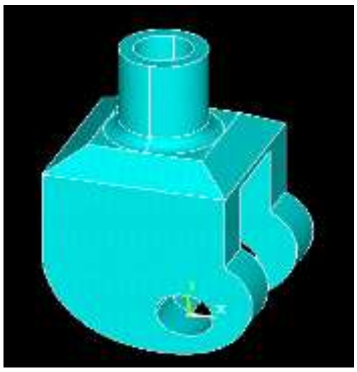
Step-1:-Dimensions of a knee joint is taken from the available literature.



Dimensional view of Prosthetic knee joint

Step-2:- Modeling the femur part in CAD software (PRO-E)





Modeled view of Prosthetic knee joint 3D Final Model

Step-3:- Converting it to .iges file format

Step-4:- Importing model to Ansys 11.0

Step-5:- Defining Materials

Materials Used

Titanium-Aluminium alloy, Stainless steel, Cobalt-Chromium are the most important material used in medical applications and is used for manufacturing Femur component of the knee joint.

Material properties

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Stainless steel	Values
Tensile Strength, Ultimate	864 MPa
Tensile Strength, Yield	602 MPa
Poisson's Ratio	0.286
Modulus of Elasticity	196 GPa
Compressive yield strength	1080 MPa

Titanium- Aluminum	Values
Tensile Strength, Ultimate	220 MPa
Tensile Strength, Yield	140 MPa
Poisson's Ratio	116 Gpa
Modulus of Elasticity	0.34
Compressive yield strength	1080 MPa

Chromium-Cobalt	Values
Tensile Strength, Ultimate	1300 MPa
Tensile Strength, Yield	980 Mpa
Modulus of Elasticity	220 Gpa
Poisson's Ratio	0.34
Compressive yield strength	1714 MPa

Step-6:- Generating Mesh

Step-7:- Applying Loads

Step-8:- Obtaining Solution

Step-9:- Review Results

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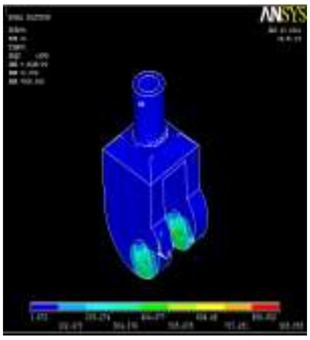
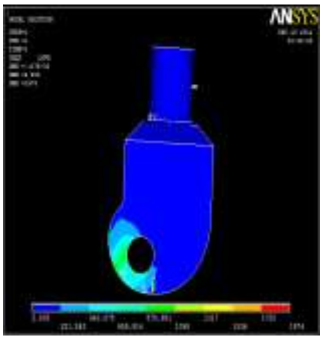
Max stress and Max displacement plot for stainless steel for Load of 2100N

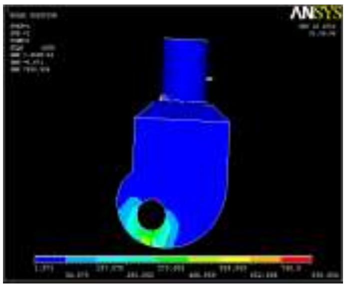


30^0 flexion angle



60^0 flexion angle

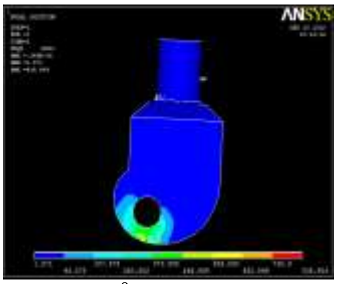
Max stress and Max displacement plot for Ti-Al for Load of 2100N



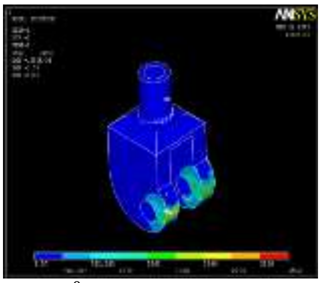
30^0 flexion angle

60^0 flexion angle

Max stress and Max displacement plot for Co-Cr for Load of 2100N



30^0 flexion angle



60^0 flexion angle

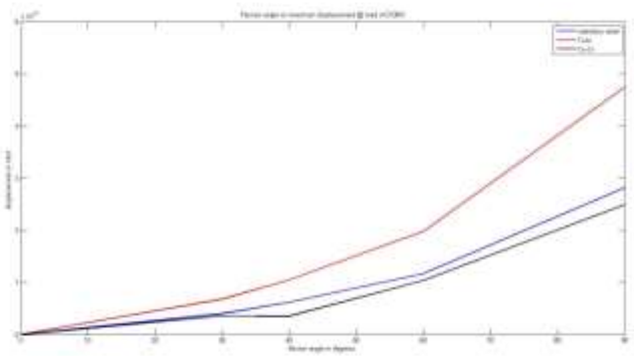
V. RESULTS AND DISCUSSIONS

For 2100 N load taking the FOS as 3

Flexion Angle		Stainless steel	Ti-Al alloy	Co-Cr alloy
30^0	Displacement (mtrs)	$0.403 e^{-4}$	$0.682 e^{-4}$	$0.359 e^{-4}$
	Max.von Mises stress (Pa)	908.88	838.904	828.904
60^0	Displacement (mtrs)	$0.117 e^{-3}$	$0.198 e^{-3}$	$0.104 e^{-3}$
	Max.Von misses stress (Pa)	1974	1876	1876

Variation of stresses with varying load and flexion angles

Material	Angles	Von misses stresses	Load
Stainless Steel	0^0 to 90^0	137.264 to 3704	2100
	0^0 to 90^0	313.779 to 8468	4800
Ti-Al	0^0 to 90^0	123.527 to 3508	2100
	0^0 to 90^0	282.37 to 8019	4800
Co-Cr	0^0 to 90^0	123.527 to 3508	2100
	0^0 to 90^0	282.375 to 8019	4800



VI. CONCLUSION

As the flexion angle increased from 0^0 to 90^0 the von misses stress increased under loads of 2100N and 4800N the stress induced in stainless steel is more when compared to other materials. But the induced stress (3704Pa) is less than the ultimate tensile strength of the stainless steel (1000 Mpa) as shown in table 6.3. therefore component is safe

As the flexion angles are increasing from 0^0 to 90^0 the deformation increased as shown in table 6.4

From the graphs it is evident that Co-Cr is suggested as the best material for the manufacturing of Femur component as it shows less displacement for different flexion angles

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VII. REFERENCES

[1] Palastanga, N. and Field D., *Anatomy and human movement structure and function.* 4th ed. 2002: Butterworth-Heinemann.

[2] Kutzner, I., Heinlein, B., F. Graichen, A. Bender, A. Rohlmann, A.M. Halder, A. Beier, and G. Bergmann, *Loading of the knee joint during activities of daily living measured in vivo in five subjects*. J Biomech. 2010 Aug 10;43(11):2164-73.

[3] Taylor, R., Heller, O., Bergmann, G., Duda, N., *Tibio-femoral loading during human gait and stair climbing*. Journal of Orthopaedic Research 22 (2004) 625-632.

[4] Tortora, G. and Derrickson, B., *Principles of anatomy and physiology*. 12th ed. 2009: John Wiley & Sons, Inc.

[5] Darrow, M., *The Knee Sourcebook*. 1st ed. 2002: McGraw-Hill.

[6] Bei, Y., *Dynamic simulation of knee joint contact during human movement.* Dissertation for the doctor degree, University of Florida, 2003.

[7] Carvalho, F., *Tratamento da gonartrose numa abordagem cirúrgica*, Dissertation for the master degree, Universidade da Beira Interior, 2010.

[8] NIH Consensus Statement on total knee replacement. NIH Consens State Sci Statements 2003 Dec 8-10;20(1):1-34.

[9] Shetty, A.A., A. Tindall, P. Ting, and F.W. Heatley, *The evolution of total knee arthroplasty. Part I: introduction and first steps*. Current Orthopaedics, 2003. 17: p. 322-325.

[10] Wylde, V., Dieppe, P., Hewlett, S., Learmonth, I.D., *Total knee replacement: Is it really an effective procedure for all?*. The Knee 14 (2007) 417–423.

[11] Pryde, A., *Physical Rehabilitation*, 2007, Pages 219-250.

[12] Lonner, H., Frank, Pedlow, Siliski, *Total Knee Arthroplasty for Post-Traumatic Arthrosis*. The Journal of Arthroplasty Vol.14 No. 8 1999.

[13] Yercan, H., Selmi, T., Sugun, T., Neyret, P., *Tibiofemoral instability in primary total knee replacement: A review, Part 1: Basic principles and classification*. The Knee 12 (2005) 257–266.

[14] Lombardi, A., Berasi, C., Keith, Berend, R., *Evolution of Tibial Fixation in Total Knee Arthroplasty*. The Journal of Arthroplasty Vol.22 No.4 Suppl.1 2007.

[15] Peters, L., Erickson, J., Kloepper, G., Mohr, A., *Revision Total Knee Arthroplasty With Modular Components Inserted With Metaphyseal Cement and Stems Without Cement*. The Journal of Arthroplasty Vol. 20 No. 3 2005.

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