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Finite Element Analysis of Femur Bone

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Abstract: The result of this project research, which relates to the original design for total hip joint replacement, are presented in this project. Project focused on research and development of implant in the human skeleton solution of this project and research was recommended by several prestigious institutions, hospitals and many more orthopaedists. Research methodology of total hip joint replacement has focused on a comprehensive analysis with the help of the suitable design software. To determine the stress state in the femoral component of the total hip joint replacement, which are presented in this project research, the FEM software NX cad and Hyper mesh was used, which are practically implemented into patients around the world. Based on this knowledge and experiences of many years of leading Slovak orthopaedists as well as experts in the field of material engineering such analysis was carried out in this study to and test a new type of femoral component for hip prosthesis replacement. The result of the project and research is the design and implementation of new type of composed alternative hip replacement. This is made by different composite metal and alloys.

Keywords: Hip joint, Hip prosthesis, composite metal and alloys, NX and Hyper mesh software, Modification and Analysis.

I. INTRODUCTION

Bone is the primary structural element of the human body. It serves to protect vital internal organs and it forms a series of levers that multiply the forces generated during skeletal muscle contraction, transforming them into bodily movements. It is a self-repairing and can alter its properties in response to the stresses placed upon it. It also serves as a reservoir of calcium, phosphate, and other ions that can be stored or released in a controlled fashion to maintain homeostasis in body fluids. The process by which bone is shaped or customised is known as modelling while the process by which is bone is repaired and 'fine-tuned' is known as remodelling.

Bone consists of cells embedded in a fibrous organic matrix (osteoid) which is composed of collagen and other proteins. The osteoid matrix makes up approximately half of the bone volume. Bone's characteristic rigidity and strength are derived from the mineral phase which makes up the remaining volume. The principal constituents of bone mineral are hydroxyapatite [Ca10 (PO4)6(OH)2], calcium phosphate and calcium carbonate with lesser quantities of sodium, magnesium, potassium and fluoride. Microscopically, bone is made up of a number of different bone cell types (10% by weight).

There are four types of cells in bone tissue, each of which has a specific role in the formation, resorption and remodelling of bone.

- Osteoprogenitor cells which line the walls of the bones. In response to an appropriate stimulus, these stem cells may differentiate into osteoblasts.
- Osteoblasts are large cells which are arranged in lines along the bone surface. They are responsible for the formation of new bone tissue.
- Osteocytes are osteoblasts trapped by the secretion of the extracellular matrix and are found in lacunae throughout this matrix. They have numerous processes that extend through bony canals

called canaliculi and communicate with each other. These canaliculi are thought to play a role in sensing changes in the bone matrix.

- Osteoclasts are large multinucleated cells which are involved in the resorption of damaged or old bone. On the surface of bone, they are found in small depressions known as Howship's lacunae.

In principle there are two types of bone, as determined by porosity: cortical (compact) bone and trabecular (cancellous, spongy) bone, both are present in the proximal femur.

1. Cortical bone

Fig 1. Cortical (Dense) bone

The hard outer layer of bones is composed of cortical bone tissue. This tissue gives bones their smooth, white, and solid appearance, and accounts for 80% of the total bone mass of an adult skeleton. Its porosity varies from 5% to 10% and its pores consist of space as shown above.

2. Trabecular Bone

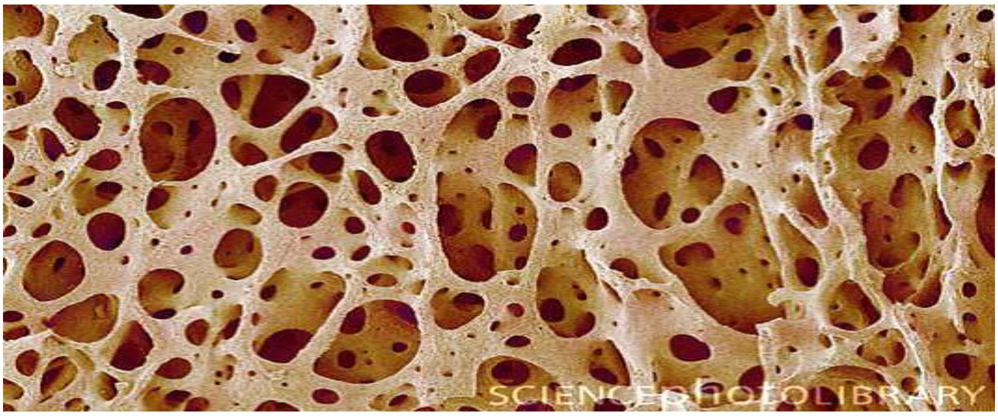


Fig 2. Trabecular (Spongious) bone

Filling the interior of the bone is the trabecular bone tissue, an open cell porous network also called cancellous or spongy bone, which is composed of a network of rod- and plate-like elements that make the overall organ lighter and allowing room for blood vessels and marrow. Trabecular bone accounts for the remaining 20% of total bone mass and its porosity varies from 75% to 95%. Trabecular bone can be described in terms of structural and material properties. Structural properties are extrinsic properties of both the trabeculae and the cavities and are important for the global stress analysis at the macroscopic level. Material properties are defined as intrinsic properties.

3. Anatomy of Hip or Pelvic Joint

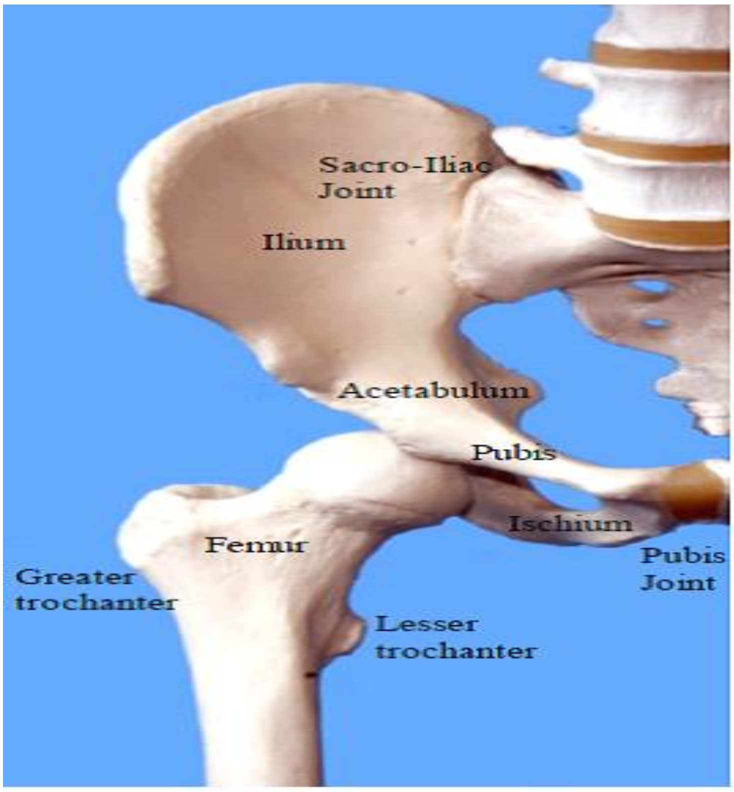


Fig 3. Hip joint

The hip joint is a ball and socket joint formed by the articulation of the spherical head of the femur and the concave acetabulum of the pelvis. It forms the primary connection between the lower limbs and the skeleton of the upper body and its primary function is to support the weight of the body in both static and dynamic postures. Both the femur and acetabulum are covered with a layer of cartilage to provide smooth articulation and to absorb load. The entire hip joint is surrounded by a fibrous, flexible capsule to permit large ranges of motion but to prevent the proximal femur from dislocation.

4. Location &Anatomy of the Femur (Hip) Bone

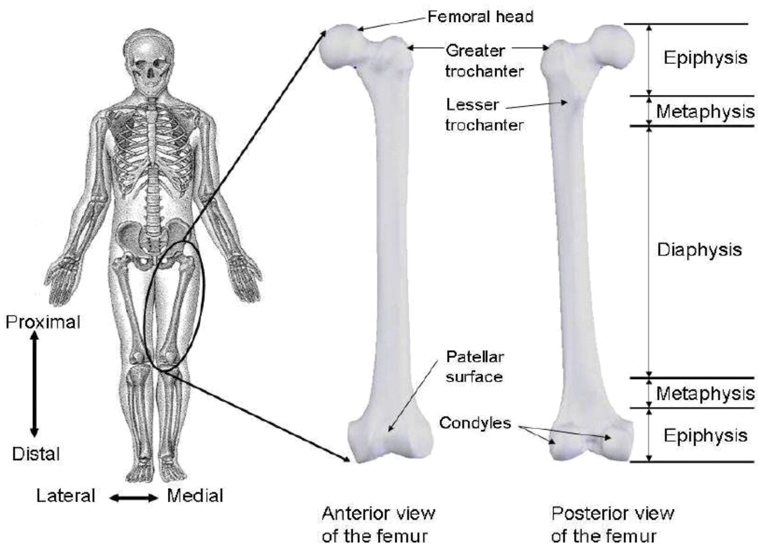


Fig 4. Anatomy of Femur bone

The femur is the longest and strongest bone in the human body. It consists of a head and a neck proximally, a diaphysis (or shaft) and two condyles (medial and lateral) distally. The diaphysis of femur is a simplistic, cylindrical structure, while the proximal femur is irregular in shape, consisting of a spherical head, neck and lateral bony protrusions termed the greater and lesser trochanters. The trochanters serve as the site of major muscle attachment. The lateral location of these structures offers a mechanical advantage to assist with abducting the hip.

5. Failure of Femur (Hip) Bone

The failure of the femur bone is common now days. The failure of this bone occurs due to following reasons.

- Accidents: Due to the growth of high speed automobiles, the road accidents are also becoming common in the human life. Due to high forces generated with the metal impacts, the femur bone will fracture.
- Diseases: Most hip fractures occur as a result of low-energy falls in elderly patients. Humans suffer from the various hip joint problems due to diseases like osteolysis, osteoarthritis, a vascular necrosis, rheumatoid arthritis, fracture neck of femur, other inflammatory arthritis, developmental dysplasia, Paget’s disease, arthrodesis (fusion) takedown, tumour, etc. some of them are discussed below.
- Osteolysis: It is local loss of bone tissue and appears because of wear. Destruction of bone takes place especially by bone resorption through removal or loss of calcium. Osteolysis may be evident in neoplastic, infectious, metabolic, traumatic, vascular, congenital and articular disorders.
- Osteoarthritis (OA): It is degenerative arthritis disease because, a “wearing out” involving the breakdown of cartilage in the joints and is one of the oldest and most common types of arthritis. It is characterized by breakdown of the joint’s cartilage. Cartilage is part of joint and cushions ends of the mating bones. The bones get deformed, and even small movements will cause friction between the ball and the socket of the hip, causing severe pain.
- Avascular Necrosis: This is caused by lack of blood supply into bone. This condition may ultimately lead to bone death. Pain usually develops gradually and may be mild initially. If avascular necrosis progresses, bone and the surrounding joint surface may collapse causing increase in pain.
- Developmental Dysplasia: Developmental Dysplasia of the hip is a condition in which the femoral head has an abnormal relationship to the acetabulum. It includes frank dislocation (luxation), partial dislocation (subluxation), or instability of the hip, wherein the femoral head comes in and out of the socket. Radiographic abnormalities reflect inadequate formation of the acetabulum.
- Paget’s disease: It is a metabolic bone disorder of unknown origin. This normally affects older people. Bone is a living tissue and is constantly being renewed. Paget’s disease of bone causes increased and irregular formation of bone. The bone cells, which are responsible for dissolving body’s old bones and replacing them with new ones, become out of control.

6. Types of Failure of Hip Bone

The failure or fracture occurs in different locations of hip bone, depending upon this criteria fracture of hip bone is classified into following types.

- Femoral head fracture: It denotes a fracture involving the femoral head. This is usually the result of high energy trauma and a dislocation of the hip joint often accompanies this fracture.
- Femoral neck fracture: It denotes a fracture adjacent to the femoral head in the neck between the head and the greater trochanter. These fractures have a propensity to damage the blood supply to the femoral head, potentially causing avascular necrosis.
- Inter trochanteric fracture: It denotes a break in which the fracture line is between the greater and lesser trochanter on the intertrochanteric line. It is the most common type of hip fracture.
- Sub trochanteric fracture: It involves the shaft of the femur immediately below the lesser trochanter and may extend down the shaft of the femur.

7. Total Hip Prosthesis (THP)

Due to the failure of hip bone due to accidents and diseases discussed above, we need to think of replacement mechanisms with the objective of same or improved life. Hip replacement surgery is the second most common joint replacement procedure, closely following knee replacements. The surgery is performed when the hip joint has reached a point when, due to different diseases and injuries, painful symptoms can no longer be controlled with non-operative treatments. In a hip replacement procedure, surgeons remove the damaged joint surface and replace it with an artificial implant called Prosthesis.

The prosthesis for total hip replacement consists of a femoral component and an acetabular component. The femoral stem is divided into head, neck and shaft. The femoral shaft is made of Ti alloy or Co Cr alloy or 316L stainless steel and is fixed into a reamed medullary canal by cementation or press fitting. The femoral head is made of Co Cr alloy, alumina or zirconia. The acetabular component is generally made of ultra-high molecular weight polyethylene (UHMWPE).

8. Commonly Used Implant Biomaterials

Metals, ceramics and polymers are used to replace bone in the human body. Metals have strength and stiffness that make them suitable for many load-bearing applications. Metallic biomaterials are indicated for use in areas of high static or cyclic stress. Such activities include lifting, running, bending or chewing. All of these actions will transfer stresses to the implant, and metallic materials are best suited to these applications. Ceramic materials are designated where resistance to wear is of primary importance, and polymeric materials are used where stability, flexibility and controlled porosity are required In general, an implant alters the mechanical and chemical environment in its immediate neighbourhood (locally) and throughout the body (systemically). The below table shows the different implant materials used in the replacement surgery.

Table 1. Classification of Implant Material

Metals	Ceramics	Polymers
316L stainless steel	Alumina(Al_2O_3)	Ultra high molecular weight polyethylene
Co-Cr Alloys	Zirconia	Polyurethane
Titanium	Carbon	
Ti6Al4V	Hydroxyapatite	

The implant for total hip replacement consists of a femoral component and an acetabular component. The femoral stem is divided into head, neck and shaft. The hip implant is shown in below Fig.

Fig.5. Typical hip implants of varying size

II. LITERATURE SURVEY

P. Colombi [1] had worked on fatigue analysis of cemented total hip arthroplasty. The author considered a quasi-three-dimensional finite element model for fatigue analysis of the hip implant and two different damage rules, linear and non-linear were proposed to produce two different damage evolution algorithms. One of the disadvantage of his work was he assumed bone as an isotropic material for evaluating the fatigue life time. But bone is an anisotropic material.

H. Yoshida et.al., [2] predicted the joint degeneration mechanism and prosthetic implant wear by estimating the hip joint contact area and pressure distribution during activities of daily living. The authors take the help of generic hip model, Discrete Element Analysis technique and the in vivo hip joint contact force data for estimating the above biomechanical data. The authors calculated the pressure distribution in eight different daily living activities. They found that during fast, normal & slow walking peak pressure of moderate magnitude was located at the lateral roof of the acetabulum and in standing up and sitting down, during knee bending the peak pressures were located at the edge of the posterior horn. They used these results data in prosthetic component wear and fatigue test set up.

A. Zafer Senalp etal.,[3] had studied the fatigue failure of implant material due to Forces applied to the implant during human activities. The authors used Finite element method as a tool in the design and analysis of total joint replacements. In their study, four stem shapes of varying curvatures for hip prosthesis were modelled and then Static, dynamic & fatigue behaviour of these designed stem shapes were analyzed using commercial finite element analysis code ANSYS. They have performed Static analyses under body load and Dynamic analyses under walking load. The authors have used Pro/Engineer for CAD modelling of the stem shapes and ANSYS Workbench software for evaluating the Fatigue behaviour of stem shapes. They investigated the Performance of the stem shapes for Ti–6Al–4V and cobalt–chromium metal materials and then compared with that of a commonly used stem shape developed by Charnley. One of the main limitation of their analysis is they built the 3D model as per the geometries of the original hip bone and then they compared the result with Charnely's design, but the geometries of Charnely's model and the hip implants using in THR are entirely different.

Oguz Kayabasi etal., [4] designed four different stem shapes for hip prosthesis to investigate an optimum stem shape. The authors have selected different stem shapes of varying geometries. They first selected standard straight geometry and then two notched geometries and the last one of curved geometry. They conducted the static and dynamic FE analyses of the stems using implicit commercial finite element code. The load considered for static analysis in their study was an average body weight of the human and for dynamic analysis walking condition of the human. Using the above load conditions, the authors performed the static & fatigue analysis in Ansys Workbench & they calculated fatigue safety factor for two different material models; Ti-6Al-4V and cobalt chromium alloy using infinite fatigue life approach.

Anthony L. Sabatini etal.,[5] re-evaluated several hip stems of various cross sections using finite element analysis. The authors compared the von Mises stress of the stems at the designated locations as well as the displacements were recorded. They have taken three materials for the analysis they were; Cr–Co–Mo, Stainless Steel SS316L, and titanium alloy. The authors found that Ti–6Al–4V exhibits lower stress than the other two materials and also, they have noticed that the circular and elliptical cross-sections of the hip implant's stem design produces even distribution of stress throughout the length of the stem than the other cross-sections namely; trapezoid and oval. The authors used COSMOS WORKS software for modelling and analysis of the stem shapes.

David Bennett etal., [6] performed finite element analysis (FEA) on six hip stem designs by considering the forces ranging from 2.5 to 7 KN. They have selected these force range by considering the gait cycle which generates forces up to 6–7 times the body weight in the hip joint. They performed the analysis by assuming rectangular cross section of the stem for various designs and optimized the one which has highest stress and displacement to a lower stress and displacement combination. In their analysis they found that the cross-section which has a circle in the medial end and a square at the lateral end provide suitable design characteristics.

S. Griza etal., [7] has made an attempt to achieve initial stability and lack of motion at the cement stem interface, a specific design of the hip prosthesis femoral component was conceived. The deign they considered incorporated a specific geometrical feature in the prosthesis stem, a screw-like cross section profile. They incorporated this feature to avoid axial motion as well as stem subsidence into the cement mantle. The authors also performed numerical analysis along with the finite element analysis and based on the numerical analysis results they concluded that, prosthesis unique design was not responsible for the stem loosening. The authors have used ABAQUS software for the analysis.

H. S. Hedia etal.,[8] studied the fatigue failure of acrylic cement and the resulting disruption of the bone-cement interface. The authors first performed the numerical analysis for different stem shapes and then they optimized stem shapes by using finite element technique to minimize the fatigue notch factor in the cement layer and at interfaces with the bone and stem. The authors built a two-dimensional model of the proximal end of a femur fitted with a total hip prosthesis and they assumed that it is equivalent to a simplified three-dimensional axisymmetric model. The authors minimized the fatigue notch factor in the cement at the cement/stem interface using the ANSYS finite element program by constraining the fatigue notch factor at the cement/bone interface at or below its initial level.

III. OBJECTIVES OF THE WORK

A hip or femur bone plays a very vital role in the human body. It takes all the body weight during different activities of the daily needs like standing, running, jumping, etc. Hence femur bone is subjected to different loading conditions like static, fatigue, dynamic, buckling, etc.

Now a day's failure or fracture of the hip bone is common due to road accidents and diseases like bone cancer, tumour, osteolysis, Paget's disease, etc. Hence, we need to think of replacement mechanism by using artificial bone called prosthesis or implant with the objective of same or improved life. Thus, it is very necessary to design implant against different failures mentioned above. And research work of many others shows that very poor importance was given for buckling and modal analysis and only few implant material models were considered for static, dynamic and fatigue analysis.

Hence the objective of my work includes following:

- Designing the new hip prosthesis geometry that should provide good axial stability, lack of motion at the cement stem interface and ensure hip prosthesis against static, fatigue, buckling and modal failure.
- Optimizing the stem design that had highest stress and displacement to a lowest stress and displacement values.
- To study the static, dynamic and fatigue behaviour of hip prosthesis for different materials and optimizing the hip prosthesis design.

IV. METHODOLOGY

The methodology includes the following steps.

- Collecting the geometry data of hip prosthesis.
- Creating a 3 dimensional surface and solid finite element model of hip prosthesis according to geometry using NX CAD 7.5 software.
- Meshing the model in Hyper mesh v11.0 because of complicated shape.
- Applying material properties, boundary conditions and solving in Msc-Nastran 10.0 software.
- Post processing i.e interpreting the results using Hyper view 11.0.

V. FINITE ELEMENT MODEL DEVELOPMENT

A. Material selected

The various analyses are carried out for the following materials listed below.

Stainless steel 316L: Type 316L is a molybdenum-bearing austenitic stainless steel which is more resistant to general corrosion and pitting/ crevice corrosion than the conventional chromium nickel austenitic stainless steels. This alloy also offers higher creep, stress-to-rupture and tensile strength at elevated temperature.

The Chemical compositions as represented by ASTM A240 and ASME SA-240 specifications are indicated in the table below.

Table 2. Chemical Composition of Ss 316l

Element	Percentage by Weight
Chromium	17.2
Nickel	10.9
Molybdenum	2.1
Manganese	1.6
Carbon	0.02
Iron	Balance

Cobalt chromium alloy: It is a fine powder mixture which produces parts in a cobalt-chrome-molybdenum-based super alloy. This class of super alloy is characterized by having excellent mechanical properties (strength, hardness etc.), corrosion and temperature resistance. Such alloys are commonly used in biomedical applications such as dental and medical implants and also for high-temperature engineering applications such as in aero engines.

The Chemical compositions of Cobalt chromium alloy is as follows:

Table 3. Chemical Composition of Co Cr Alloy

Element	*Percentage by Weight*
Cobalt	60-65
Chromium	26-30
Molybdenum	5-7
Silicon	1
Manganese	1
Iron	0.75
Carbon	0.16
Nickel	0.1

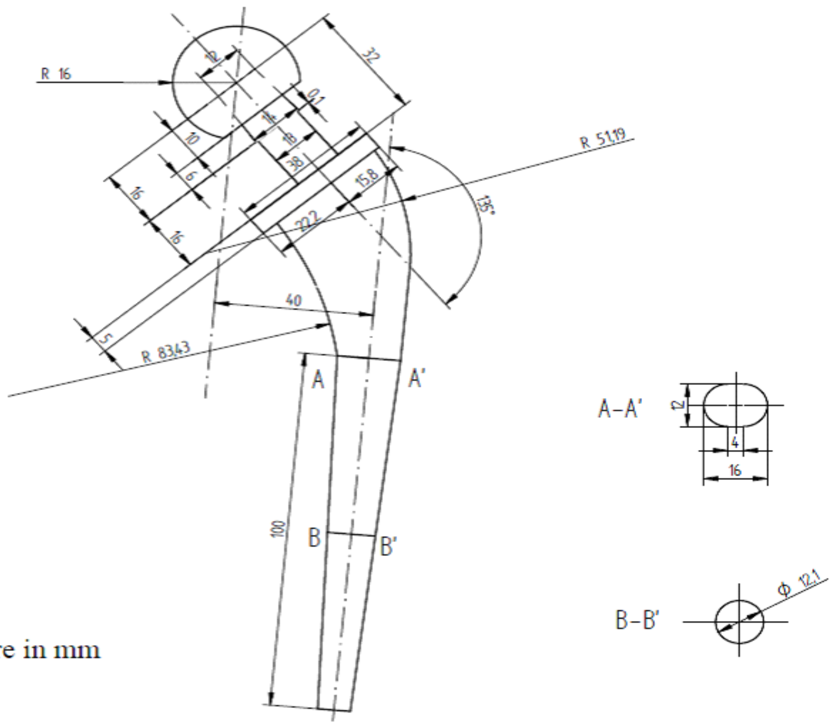
Ti-6Al-4V: The high strength, low weight ratio and outstanding corrosion resistance inherent to titanium and its alloys has led to a wide and diversified range of successful applications which demand high levels of reliable performance in surgery and medicine as well as in aerospace, automotive, chemical plant, power generation, oil and gas extraction, sports, and other major industries.

The chemical composition is as follows:

Table 4. Chemical Composition of Ti-6al-4v

Element	*Percentage by Weight*
Titanium	90
Aluminium	6
Vanadium	4
Iron	0.25
Oxygen	0.2

B. Geometry of the model



All dimensions are in mm

Fig.6. Geometry of the hip prosthesis

The above geometry of the hip prosthesis shows all the dimensions data and all dimensions in the above 2D drawing are represented in mm. Creating a 3D solid model

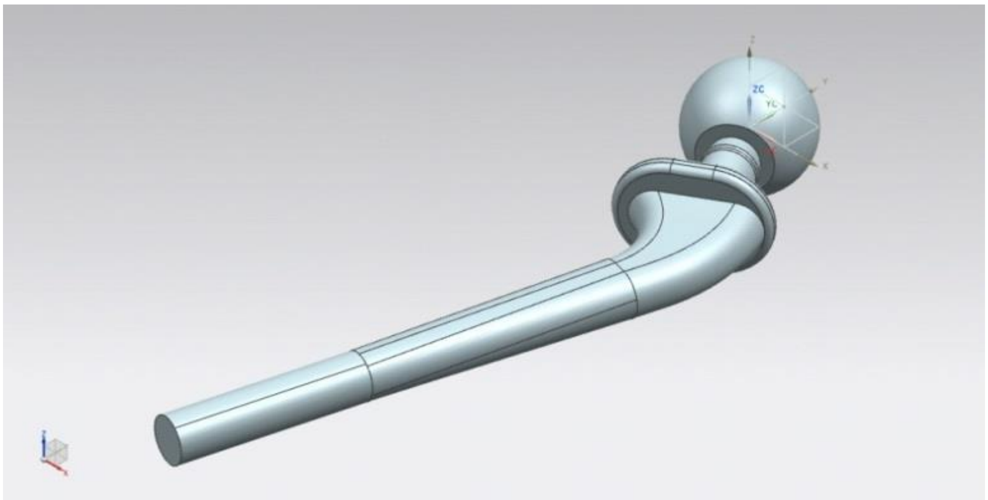


Fig 7. 3D hip prosthesis model

The 3D hip prosthesis model is created by using the NX-CAD 7.5 software according to the dimensions specified in the 2D drawing in fig.3

The following mechanical properties of the material are used in the analysis.

Table 5. Mechanical Properties of Implants

Sr. No	Materials Used	Young's modulus(GPa)	Poisson's ratio	Yield strength(Mpa)	Density*10^{-6} (kg/mm^{3})
1	Stainless steel 316L	110	0.24	666	7.9
2	Cobalt chromium alloy	220	0.30	720	8.5
3	Ti-6Al-4V	200	0.30	800	4.4

C. Meshing

Meshing is the process of converting infinite Degrees of Freedom (DOF) to finite Degrees of Freedom. The structure is Tetra meshed due to complicated geometry of the model. The Jacobian measures the deviation of an element from its ideal or "perfect" shape. The Jacobian value ranges from 0.0 to 1.0, where 1.0 represents a perfectly shaped element. In the case of Jacobian evaluation values of 0.7 and above are generally acceptable.

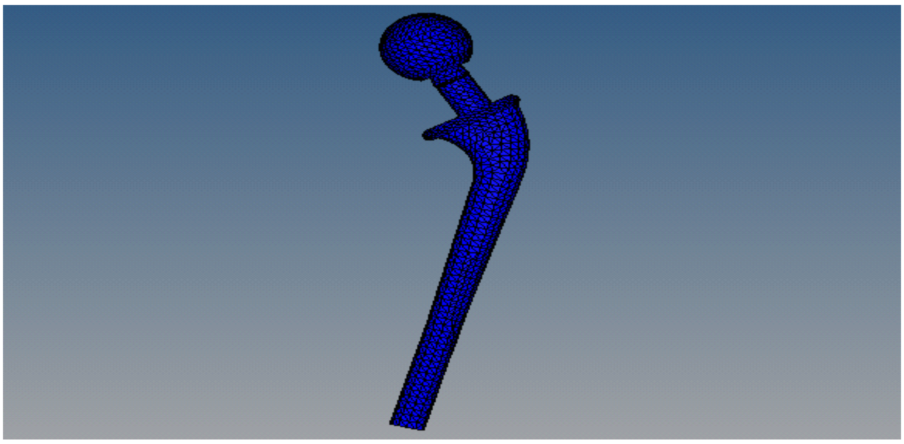


Fig 8. Meshed model

Mesh details of the model

Type of mesh = Tetra mesh

Type of element = 4 node Tetrahedron

Number of elements = 7719

Number of nodes = 2126

Jacobian value = 0.7

D. Elements used

4 Nodes Tetrahedral Element

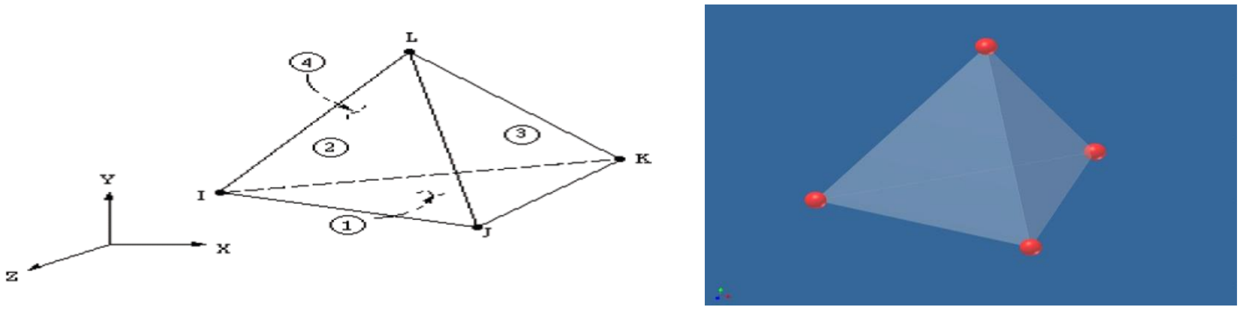


Fig 9. 4 node tetrahedral element

The 4 node tetrahedral element is a three dimensional element with 4 nodes at its corners. It is well suited to model irregular meshes. The element is defined by four nodes having six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z directions.

Degrees of Freedom: - UX, UY, UZ, ROTX, ROTY, ROTZ

VI. STATIC ANALYSIS OF HIP PROSTHESIS

A. Load & Boundary conditions Applied

After creating a solid 3D model the next step in Finite element analysis is pre-processing that is the entire load and boundary conditions are inputted to Hyper mesh 11.0 software.

The static analysis is carried out by assuming the weight of a person 70kg, hence a load of 70 kg that is 70*9.81=686.7N is applied on the femoral head of the hip prosthesis and distal end that is bottom end of the hip prosthesis is constrained for all DOF as shown in above fig.

Then this finite element model is exported to .dat file format which is the input format file for Msc-Nastran 10.0 solver software and it is solved in Msc-Nastran 10.0 software and the results are plotted by using Hyper view11.0 software.

B. Results and discussions

For Stainless steel 316L

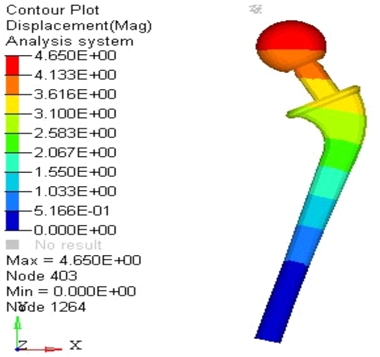


Fig 10. Displacement plot

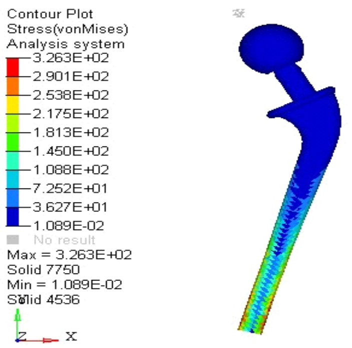


Fig 11. Stress plot

For Cobalt chromium alloy

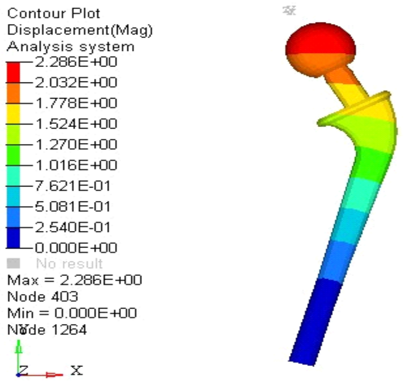


Fig 12. Displacement plot

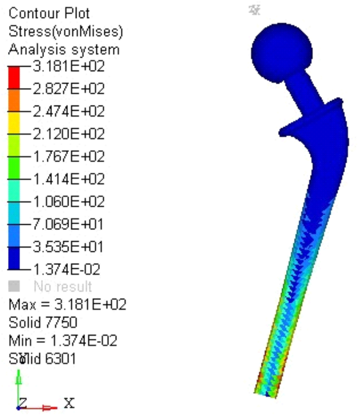


Fig 13. Stress plot

For Ti-6Al-4V

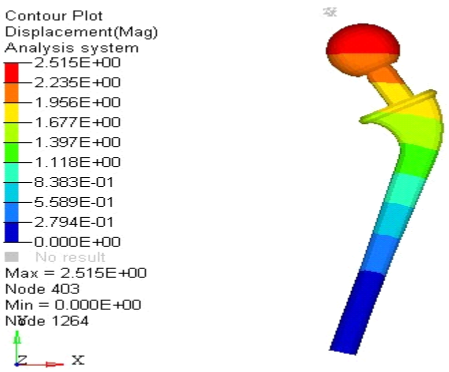


Fig 14. Displacement plot

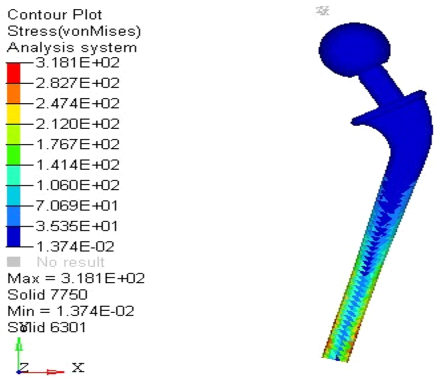


Fig 15. Stress plot

The displacement and stress plots for the different materials are shown in the above fig. which are plotted by using Hyper view 11.0 software.

The results are tabulated as follows.

Table 6. Static Analysis Result for All Three Materials

Sr.No.	Material	Max. deformation(mm)	Max. Von-Misses stress(MPa)
1	Stainless steel 316L	4.650	326.3
2	Cobalt chromium alloy	2.286	318.1
3	Ti-6Al-4V	2.515	318.1

C. Conclusion for static analysis

From the results obtained for static analysis of load 70 kg, it can be seen that displacement and stress are Maximum for stainless steel 316L which are 4.650mm and 326.3MPa respectively. And minimum displacement and stress are seen for Ti-6Al-4V which are 2.515mm and 318.1 MPa respectively. Hence Ti-6Al-4V alloy is preferred for using hip implant in Total hip Arthroplasty surgery compared to other materials in the Static analysis.

VIII. BUCKLING ANALYSIS OF HIP PROSTHESIS

A. Load & boundary conditions applied

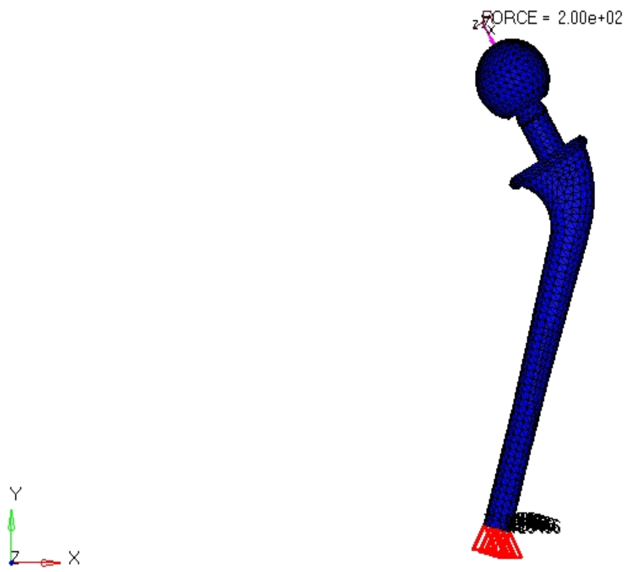


Fig 16. Model with Boundary Condition

In buckling analysis also the load is applied at the femoral head of the hip prosthesis and distal (bottom) end of hip prosthesis is constrained as in the case of static analysis. Here the aim is to determine the failure load for buckling. Hence the loads of different magnitudes are applied on the femoral head. Due to space constraints only a load case of 200N applied on femoral head is shown in the above Fig.

B. Results and discussions

1) For Ti-6Al-4V

We know that Yield strength of Ti-6Al-4V=800MPa.

Factor of safety considered = 2

Hence, Allowable stress = yield strength/Factor of safety

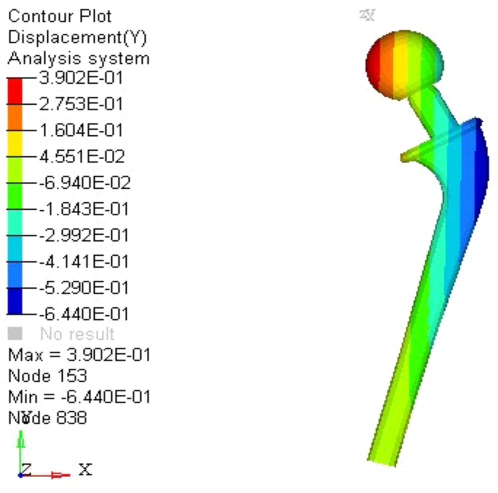
= 800/2

Allowable stress = 400MPa

Table 7. Buckling Analysis Result for Ti-6al-4v Materials

Sr.No	*Load Applied in N*	*Von misses stress in MPa*	*End shortening in mm*
1	200	92.64	0.09023
2	400	185.3	0.18
3	600	277.9	0.2707
4	800	370.5	0.369
5	850	393.7	0.3835
6	860	398.3	0.388
7	865	400.7	0.3902
8	870	403	0.3925

The above table shows the von misses stress induced and end shortening for the Ti-6Al-4V material at different load cases. In order to design prosthesis against the buckling failure the induced von misses stress in the material should be lesser than the allowable stress. Hence a failure load in buckling is found to be 865N. Due to space constraints the von-misses stress plot and displacement plot are shown only for failure load case.



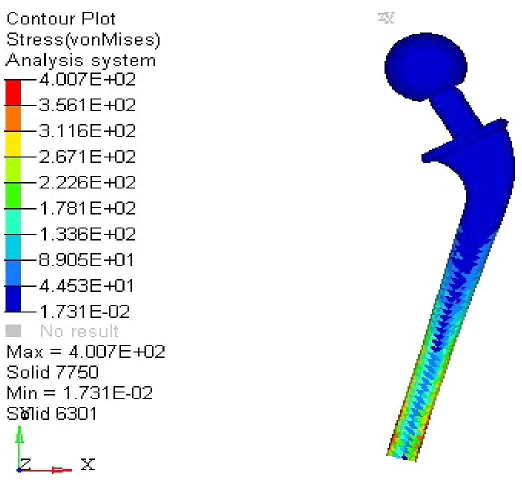


Fig 17. Displacement plot Fig 18. Stress plot

The von misses stress vs end shortening and load vs end shortening graphs are drawn shown above. The end shortening or displacement due to buckling and also induced stress increases with increase in applied load.

2) For Cobalt chromium alloy

We know that Yield strength of Co Cr=720MPa.

Factor of safety considered = 2

Hence, Allowable stress = yield strength/Factor of safety

= 720/2

Allowable stress = 360MPa

Table 8. Buckling Analysis Result for Cobalt Chromium Alloy

Sr.No	Load Applied in N	Von misses stress in MPa	End shortening in mm
1	200	92.64	0.082
2	400	185.3	0.164
3	600	277.9	0.246
4	700	324.2	0.2871
5	720	333.5	0.2953
6	740	342.8	0.3035
7	760	352	0.3117
8	780	361.3	0.3199
9	800	370.5	0.3281

The above table shows the von misses stress induced and end shortening for the Co Cr material at different load cases. In order to design prosthesis against the buckling failure the induced von mises stress in the material should be lesser than the allowable stress. Hence a failure load in buckling is found to be 780 N. Due to space constraints the von-misses stress plot and displacement plot are shown only for failure load case.

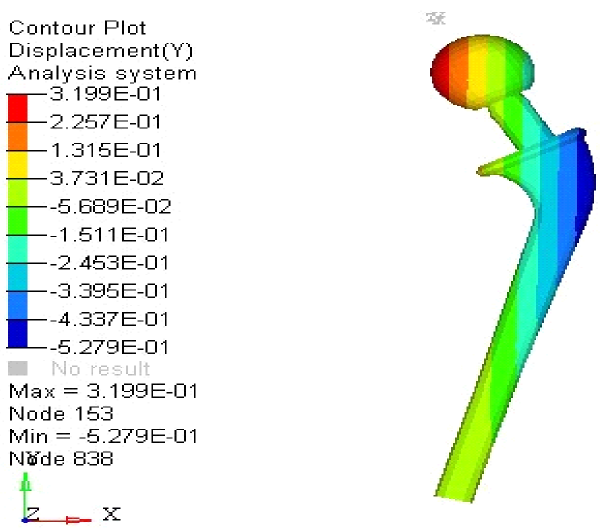


Fig 19. Displacement plot

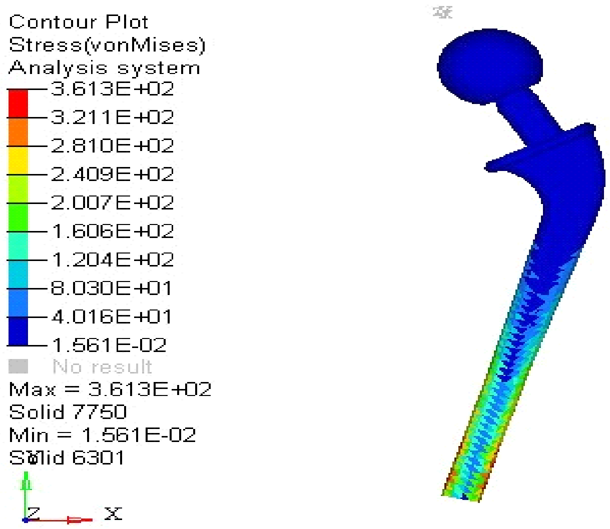


Fig 20. Stress plot

The von misses stress vs end shortening and load vs end shortening graphs are drawn shown above. The end shortening or displacement due to buckling and also induced stress increases with increase in applied load.

3) For Stainless steel 316L

We know that Yield strength of SS 316L=666MPa.

Factor of safety considered = 2

Hence, Allowable stress = yield strength/Factor of safety

= 666/2

Allowable stress = 333MPa

Table 9. Buckling Analysis Result for Stainless Steel 31l Materials

Sr. No	*Load Applied in N*	*Von misses stress in MPa*	*End shortening in mm*
1	200	95.04	0.166
2	400	190.1	0.3327
3	600	285.1	0.499
4	700	332.6	0.5822
5	701	333.1	0.583
6	705	335	0.5864
7	710	337.4	0.5905

The above table shows the von misses stress induced and end shortening for the SS 316 L materials at different load cases. To design prosthesis against the buckling failure the induced von misses stress in the material should be lesser than the allowable stress. Hence a failure load in buckling is found to be 701N.Due to space constraints the von-misses stress plot and displacement plot are shown only for failure load case.

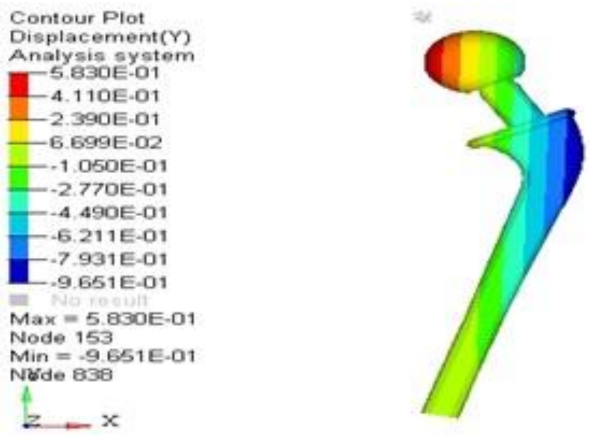


Fig 21. Displacement plot

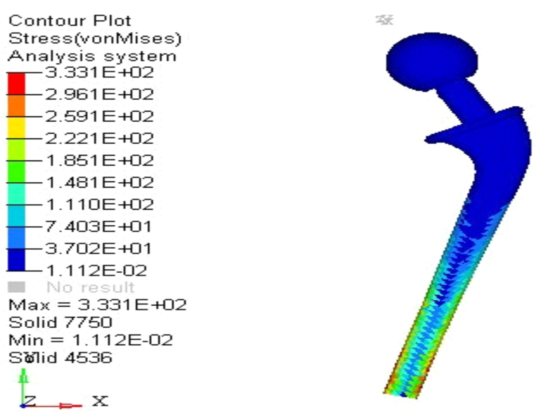


Fig 22. Stress plot

The von misses stress vs end shortening and load vs end shortening graphs are drawn shown above. The end shortening or displacement due to buckling and also induced stress increases with increase in applied load.

The buckling analysis results for all the 3 materials can be tabulated as follows.

Table 10 .The Buckling Analysis Results for All the 3 Materials

Sr. No	*Material*	*Failure load obtained in N*
1	Ti-6Al-4V alloy	865
2	Co Cr alloy	780
3	SS 316L alloy	701

C. Conclusion for buckling analysis

From the above table, it is found that failure load for Ti-6Al-4V is more (865N) compared to other two alloys, hence it will withstand more load against buckling. Hence in buckling Ti-6Al-4V shows good strength and it is preferable.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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