Analysis of Artificial Hip Joint with various Defects during Walking

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***Abstract*— The analysis is done on a prosthetic joint of described dimensions which carries a joint load of 4.9BW and muscle forces of 1.79BW and 0.6BW of abductor and adductor muscles respectively. A walking motion involving 310 flexion to 110 extension has been applied at 50 steps for materials CoCr forged, SS316L, Titanium alloys – Ti-6Al-4V, Ti-35Nb-7Zr-5Ta for joint and UHMWPE for acetabular cup. The method used here is Finite Element Modelling and Analysis. The 3D model of the prosthetic hip joint has been done by using advanced CAD software. This constrained model is imported in FEA software for solving and plot of results. The response to static and dynamic loads caused during walking are determined. Results obtained for different combinations of materials have been compared to select optimum design for which the Titanium alloy Ti-6Al-4V is best suited due to its high Young's modulus and lightness in weight.**

***Index Terms*— THR-Total Hip Replacement, THA-Total Hip Arthroplasty, BW-Body Weight, UHMWPE-Ultra High Molecular Weight Poly-Ethylene, CAD-Computer Aided Design, FEA-Finite Element Analysis.**

I. INTRODUCTION

Every time the patient moves from place to place the hip also moves. That is why a painful hip joint can be very frustrating and cause a lot of problems in the day to day life of patient. Hip pain can affect people of all ages and it may keep them away from activities they want to enjoy. A painful hip may even prevent patient from keeping up with daily activities. Some of the causes of hip may include an old fracture that didn't heal appropriately, a systemic disease and wear and tear from years of constant used, known as osteoarthritis. Some causes of the hip joint damage include osteoarthritis, inflammatory arthritis, fractures, avascular necrosis, etc. The surgical replacement of the hip joint with an artificial prosthesis has been one of the most effective and successful orthopaedic inventions for many decades as it reproducibly restores function and reduces pain in formerly pathologic hip joints. THR has been regularly proven to have significant positive impact while being cost effective compared to the other procedures. It is applied for several pathologies, mainly in arthrosis, but also as a very beneficial treatment in osteonecrosis of the femoral head and femoral neck fractures. Currently there are two methodological options for THR, cement and cement less implant. Controversy exists regarding the optimal method. There are no guidelines or clear clinical recommendations currently in practice on the choice of a cemented or an uncemented THR for a specific patient. Many different designs are used both for cemented and uncemented THR where large studies have shown different outcomes differentiating between cemented and uncemented methods. Cemented THR has a higher 10 years survival rate than uncemented THR, i.e. a lower risk of revision surgery. Problems associated with artificial prosthesis: Post surgery of THR, there arises a need for secondary surgery due to various defected associated with it. Defects such as wear and cracks due to prolonged use of the implant causes harmful carcinogenic materials to enter the blood stream which needs to be avoided. Also, impingement occurs due to reduced freedom of movement and heavy loads over a period of time [1-5].

The hip joint is the body's largest weight bearing joint. It is a ball and socket type joint. The ball consists of the femoral head and the socket which is also known as the acetabulum. This type of joint offers some stability and a large range of motion. The parts of the hip include bones, cartilage, muscles, tendons and ligaments. The goals of THR are to provide relief of pain and discomfort, improve function and enhance joint stability. In a THR, the joint surgeon implants a combination of metal and plastic that forms a new ball and socket joint that will guide smoothly. In THR an incision about 10 inches long is made down the side of the hip. Some of the soft tissue is cut to expose the hip joint. The damaged femoral head is then removed and the surface of the old socket is reamed. The prosthetic is then placed in the pelvis or hip bone. The prosthetic stem is placed into the femur (thigh bone) and the new ball and socket joint are articulated or joined. Once the prosthesis is in place, the muscles and soft tissue are re-approximated with sutures and the skin is closed with staples. There are currently several methods used for attaching the prosthesis to the bone and providing stable fixation. Some methods include use of bone cement, press fit and biological growth. In use of bone cement, the polymethyl methacrylate acts like glue or grouting material. In press fit, there will be a very tight fit of the device into the bone. In biological ingrowth, the metal prosthesis is fabricated with a porous coating, which allows the bone to actually grow into the prosthesis. The type of prosthesis used for the surgery is usually determined by the surgeon and is based on a number of factors such height, weight, age and bone structures. But the statistics given in many hip registry show that the hip replacement surgeries have been increasing over the years. The statistics also reveal that after primary surgeries, many patients are subjected secondary surgery (revision surgery) due to pain because of failure of artificial hip joint for various reasons. The revision surgery will not only deteriorate the quality of patient's life over time but also will reduce the life expectancy. The main objective of this work is to contribute for the reduction of revision surgeries by improving the life of prosthetic joint and ensuring its efficiency, in this regard an attempt has been through the finite element analysis of the hip joint with defects namely dislocation and crack[6-8].

II. Anatomy of Hip Joint

The hip joint movements and their range of motion from the neutral zero is given in Table 1 below [9-10].

Table 1: Hip Joint movements and their ranges

Movements	Range of motion from the neutral zero
Lateral or external rotation	30^0 with the hip extended 50^0 with the hip flexed
Medial or internal rotation	40^0
Extension or retroversion	20^0
Flexion or anteversion	140^0
Abduction	50^0 with hip extended 80^0 with hip flexed
Adduction	30^0 with hip extended 20^0 with hip flexed

The forces acting on the hip joint for activities is given in Table 2 below [9-10].

Table 2: Forces acting on Hip joint

Type of activity	Forces (X g)	Angle of flexion of foot
Slow walk	4.9	-19^0 to -26^0
Normal walking	4.9	-19^0 to -26^0
Fast walking	7.6	-19^0 to -26^0
Walking up slope	5.9	-19^0 to -26^0
Downward slope	5.1	-19^0 to -26^0
Walking up stairs	7.2	-19^0 to -26^0
Downward stairs	7.1	-19^0 to -26^0

III. Methodology

The body weight of 700N has been considered for the analysis. The joint force acting at the acetabular cup apex is 4.9BW, abductor muscle force is 1.79BW and adductor muscle for is 0.6BW. An artificial hip joint and its structural components are subjected to loads which cause stresses, strains and displacements in the components. To achieve a quality design i.e. having a longer fatigue life, reduced cost, reduced weight, it becomes necessary to use materials of appropriate strength and stiffness properties with most appropriate geometry. One way to achieve this is parametric design and design optimization using FEA analysis. The analysis is done on a prosthetic joint of standard dimensions which carries a joint load of 4.9BW and muscle forces of 1.79BW and 0.6BW of abductor and adductor muscles respectively. A walking motion involving 310 flexion to 110 extension has been applied at 50 steps for materials CoCr forged, SS316L, Titanium alloys – Ti-6Al-4V, Ti-35Nb-7Zr-5Ta for joint and UHMWPE for acetabular cup. The method used is finite element modelling and analysis. The 3D model of the prosthetic hip joint has been modelled using advanced CAD software. This constrained model is imported in analysis software for solving and plot of results. The response to static and dynamic loads caused during walking are determined for a healthy (without defects) joint and with defects (dislocation and crack).

IV. Results and Discussion

Following Table 3 and Table 4 gives the deformation and stress values obtained for a healthy hip joint.

Table 3: Total Deformation in healthy hip joint

Material	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
Deformation (mm)	0.4623	0.27298	0.26765	0.96752

Table 4: Maximum Stress in healthy hip joint

Material	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
Stress (MPa)	444.24	448.25	448.25	444.24

Following Table 5 gives the deformation values obtained for a dislocated hip joint. The geometry of the acetabular cup changed abruptly showing that the joint failed under the dislocation defect with very high deformation values.

Table 5: Total Deformation in dislocated hip joint

Material	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
Deformation (mm)	5.6411	5.6003	5.5993	5.7589

Following Table 6 and Table 7 gives the deformation and stress values obtained for a crack induced joint for various degrees of flexion and extension.

Table 6: Total Stress (MPa) in cracked hip joint

Type of Motion	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
31^0 Flexion	948.37	951.81	951.81	948.37
25^0 Flexion	841.67	843.73	843.73	841.67
20^0 Flexion	744.09	747.66	747.66	744.09
15^0 Flexion	639.08	643.11	643.11	639.08
10^0 Flexion	532.67	536.50	536.50	532.67
5^0 Flexion	414.47	418.53	418.53	414.47
0^0	430.61	428.65	428.65	430.61
5^0 Extension	452.25	450.59	450.59	452.25
11^0 Extension	501.58	506.23	506.23	501.58

Table 7: Total Deformation (mm) in cracked hip joint

Type of Motion	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
31^0 Flexion	0.36911	0.22034	0.21617	0.76482
25^0 Flexion	0.28997	0.17391	0.17066	0.59829
20^0 Flexion	0.26477	0.15916	0.15621	0.54505
15^0 Flexion	0.28865	0.17304	0.16982	0.59549
10^0 Flexion	0.3515	0.20986	0.2059	0.72789
5^0 Flexion	0.4355	0.25921	0.25428	0.9041
0^0	0.52883	0.31426	0.30824	1.0995
5^0 Extension	0.62503	0.37103	0.3696	1.3008
11^0 Extension	0.73985	0.43886	0.43041	1.5408

Following Table 8 gives the yield strength of the materials.

Table 8: Yield Strength of Materials

Material	Ti6Al4V	SS316L	CoCr Forged	Ti35Nb7Zr5Ta
Yield Strength (MPa)	950	500-700	1000	548

The stress was found to be maximum at the crack region for higher degrees of flexion while it was maximum near the neck for lower degrees of flexion. The maximum stress occurred at 31^0 flexion movement of the hip joint while it was found to be minimum for 5^0 flexion. As seen from the tables above, the maximum stress obtained exceed the yield strength of the materials SS316L and Ti35Nb7Zr5Ta and the hip joint fails. However, the materials CoCr Forged and Ti6Al4V perform well with crack under different loading conditions.

V. CONCLUSION

In this paper an attempt has been made to analyse a prosthetic hip joint. Due to the poor sustainability of the natural hip joint it is necessary to design a joint which can endure the loads and perform well under complications. The materials compared are the CoCr forged, SS316L, Titanium alloys – Ti-6Al-4V, Ti-35Nb-7Zr-5Ta. Since Ti-6Al-4V and Ti-35Nb-7Zr-5Ta are low density materials compared to SS316L and CoCr, which have excellent bio compatible and mechanical properties, it is ideal for the use of an implant in surgeries. Based on the analysis it can be concluded that the SS316L (7970kg/m3), CoCr (8500kg/m3) are high density material for implantation, it makes the patients feel heavy to move their leg. Based on the analysis results Ti-6Al-4V can be suggested as the best materials to sustain the loads and perform well within the acceptable limits of stress and deformation.

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