1.Introduction

Total hip arthroplasty is a surgical procedure in which the arthritic or dysfunctional hip joint is replaced entirely by an artificial implant called prosthesis. Prosthesis is composed of an acetabular component and a femoral component. There are two different techniques to secure the fixation of the hip prosthesis to the bone. These methods are diversified according to the use of the acrylic bone cement. They are cemented and cementless techniques. In both fixation methods, the main goal is to assure the long-term contact between the prosthesis and the bone so as to prevent micromotion and loosening of the implant which provokes pain to the patient and leads to revision surgery. Over the last centuries total hip arthroplasty is considered one of the most successful surgical interventions ever developed. [8] The increased use of hip replacements by more active patients and especially young people creates the need of long-lasting and more functional hip prostheses.

The hip prosthesis used in this study is a tapered rectangular press-fit femoral design of Karl Zweymuller. It's the third generation of Zweymuller's stem designs since 1979. [10] Primary stability is achieved due to its longitudinal taper and rectangular cross-section, while secondary stability is achieved by the osseointegration to the grit-blasted titanium-alumium-niobium surface of the stem. [9]

2. Finite element modelling

Geometry of the prosthesis was created using CAD software TopSolid 2005 of Missler Software company. The prosthesis designed was then imported as a CAD file (*.iges) into a finite element software program. The finite element model was generated, analysed and post-processed using the Comsol Multiphysics Version 3.2. software program. The FE model of the prosthesis was consisted of 14.833 three-dimensional tetrahedral triangular finite elements having in total 75678 degrees of freedom. The finite element analysis performed was static analysis. Static analysis has no explicit or implicit time dependencies while boundary conditions and material properties remain constant during the analysis.

- **Materials**

Three different materials were used: the Ti-6Al-4V alloy, the stainless steel 316L and the CoCr alloy. These materials were chosen since they are commonly used as implant materials. Given that these materials are not included in the material library of Comsol Multiphysics 3.2, they were defined through a material library dialog box by entering explicitly the material properties i.e. typing the corresponding value.

Information regarding material properties was provided from CES Edupack 2008 software package of Granta Company. Each material property presented in CES Edupack 2008 range from a minimum to a maximum value. Therefore, only minimum values have been used in describing the materials in Comsol Multiphysics.

The CoCr alloy selected from CES Edupack data base was a wrought alloy composed by 35% Cobalt, 35% Nickel, 20% Chromium, 10% Molybdenum and it is originally called MP35N. [1] It is a multiphase alloy and it is solution treated, cold worked and aged. The Ti-6Al-4V alloy used was an alpha-beta alloy annealed composed by 90% Titanium, 6% Aluminium and 4% Vanadium. The stainless steel used was wrought austenitic stainless steel AISI 316L annealed composed by 61.4%-72% Fe and 0-0.03% C, 16-18.5% Cr, 0-2%Mn, 2-3%Mo, 10-14% Ni, 0-0,045 P, 0-0,03% S, 0-1% Si. According to the American Society of Testing and Materials (ASTM) the use of type 316L is recommended rather than type 316 for implant fabrication. [1]The only difference between 316L and 316 stainless steel regarding their composition is the maximum content of carbon which is 0,03% and 0,08% respectively.

All the materials used in this study were considered ductile and isotropic. The arbitrary division between a ductile and a brittle behaviour of a material depends on its elongation at fracture. If the elongation is more than 5% the material is considered to be ductile, else is considered to be brittle. [5]

Table 1. Certain characteristic properties of the materials used as provided from CES Edupack 2008.

Properties/Materials		Ti-6Al-4V		SS 316L		CoCr	
	Units	MIN	MAX	MIN	MAX	MIN	MAX
Elongation	%	5	18	30	50	8	9,3
Density	kg/m³	4430	4510	7870	8070	8370	8460
Young's Modulus	GPa	110	119	190	205	234	245
Poisson's Ratio	-	0,31	0,37	0,27	0,275	0,37	0,385
Thermal expansion coefficient	μstrain/°C	8,7	9,1	15	18	12,8	13,4
Heat capacity	J/kg.K	553	570	490	530	420	460
Thermal conductivity	W/m.K	7,1	7,3	13	17	11,1	12

- **Boundary conditions**

The finite element analysis was performed for two different cases of fixation of the prosthesis. In the first case, the prosthesis was assumed to be stable in the distal 50mm of the stem. This according to ASTM F 1440-92 assumes a "worst case" scenario where proximal support for the stem has been lost. [2] In the second case examined, the points below 80mm from the point of load application were constrained so as to have a zero displacement to comply with the fixation of the stem as reported in the British Standard for testing total hip prostheses (BS 7251: Part 1: 1990). [3] Since the total length of the stem was approximately 160mm, the prosthesis was supposed to be fixed 80mm from the distal end of the stem. These two cases of fixation of the femoral component examined do not intent to mimic the situation in vivo, but they were used so as to facilitate a comparison of the results obtained from the FE analysis with the results of a future mechanical testing using the above mentioned standards.

- **Force R without torsion**

The static finite element analysis was performed for different values of the force applied to the hip prosthesis in the one-legged stance ranging from 2000N to 3500N. Regarding the position of the force acting on the femoral component, it can be determined by angles φ_1 and θ_1 in saggital and frontal plane respectively as depicted in figure 1. This force, denoted here as R, passes through the center of the femoral head. The values of angles φ_1 and θ_1 were estimated taking into consideration a comparative study of F. Skittides who used, analysed and compared experimental results of Bergmann's et al, Rydell's et al and Davy's in vivo studies concerning the measurement of joint forces. [4] This comparative study has shown that when angle φ_1 is increased, torsion applied in the femoral component is also increased, whereas flexion is increased as θ_1 is increased. The angle φ_1 is increased with an increase in the velocity of the patient, while θ_1 remains almost stable in this case. This study has concluded that when a hip prosthesis is tested successfully under a load determined by angles of $\varphi_1=20^o$ and $\theta_1=80^o$ during walking or running, the prosthesis will be able to cover most loads a patient will confront after the implantation. In the finite element analysis performed in the present study, force R is supposed to be applied to the hip prosthesis without torsion, meaning that φ_1 is considered to have a zero value. In this case, force R is supposed to act only in the frontal plane having only two components.

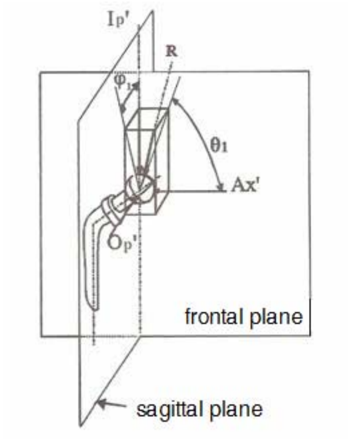

Figure 1. Force R acting on the femoral head of the prosthesis.

- **Von Mises, Total Displacement**

In order to evaluate the results derived from the finite element analysis for a multiaxial state of stress, the Von Mises failure criterion under static loading, also known as Distortion Energy Theory, was used. The Von Mises failure theory is an acceptable theory for ductile materials, since it agrees best with experimental results for these materials compared to other theories dealing with the prediction of yielding in complex stress systems. [5, 6] This theory is based on the assumption that yielding occurs when the distortion energy in a unit volume equals the distortion energy in the same volume when it is uniaxially stressed to the yield strength. The total displacement of a hip prosthesis is also important to be studied bearing in mind that if the head of the femoral component displaces too much, it will come out of the inner liner.[7] This dislocation of the femoral head of the prosthesis will lead finally to a revision operation, therefore it has to be prevented.

References

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