FINITE ELEMENT ANALYSIS OF THE REAL LIFE LOADINGS ON THE TI-27NB HIP BONE IMPLANT

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ABSTRACT

Bone is an important part of all vertebrates. It support the body and homes the marrow. The bone may be damaged by number of reasons. The objective of this paper is to investigate the real life loading on the Ti-27Nb hip bone implant by using FEA. The model of the implant was generated using CREO PARAMETRIC software. Two weight categories 75Kg and 100 Kg with four different daily life activities stand up, sit down, knee bend and walking were considered in this study. The FEA analysis was performed using commercial FEA software ANSYS. The implant model was meshed using tetrahedral element type. The simulation result show that maximum stress occurs at the neck of the implant for each loading case. The stress level was approximately equal to the strength of Ti-27Nb in 100 Kg, stand up position case.

KEYWORDS: *Ti-27Nb, Hip Implant, Finite Element Analysis, Von-Mises Stress*

INTRODUCTION

Bone is an important part of all vertebrates. It support the body and homes the marrow. The bone may be damaged by number of reasons. To replace or substitute damaged bones, bone grafting is common from past few decades. The hip joint is one of the most significant joints in the human body. It stands our body weight while we sit, stand, walk, or run. Luckily, it is particularly flexible, and allows for a great range of motion.

Total hip replacement THR is a surgical technique in which parts of the hip joint are removed and exchanged with artificial parts, known as the prosthesis (Park & Bronzino 2002). This is one of the most successful surgery operation in orthopedic that can restore the functioning of hip and reduces pain effectively (Knight, Aujla *et al.,* 2011).

As population are growing in world, people are expecting longer life, more physical activities, hip-related problems and injuries which are requiring hip arthroplasty increases rapidly in more older age persons as well in active younger patients (Kurtz, Lau *et al.,* 2009). According to the Centers for Disease Control and Prevention (CDC), 332,000 total hip replacements are performed in the United States each year (NIMS 2017). After successful hip implant many of the patients returning to their healthy life activities (Bergmann, Bender *et al.,* 2016).

Titanium-based alloys, especially Ti-6Al-4V & Ti-6Al-7Nb, were the mainly used materials for joint prostheses, being listed in ASTM standard as biomaterials (Colic, Sedmak *et al.,* 2016). Due to the toxic effects of aluminum and vanadium within the human body, new compatible biomaterials are also introduced in total hip replacement which may have more yield strength and low young modulus to avoid stress shielding (Banks & Kastin 1989). Titanium-based alloys for hip bone implants are extensively studied for their fatigue and static load behavior in literature. Beside the toxicity, difference in young modulus of bone and implant alloy cause stress shielding. Stress shielding refers to the reduction in bone density as a result of removal of typical stress from the bone by an implant that is the femoral component of a hip prosthesis (Ridzwan, Shuib *et al.,* 2007). In surgical operation of hip implant and during handling of implant it is inevitable to appear scratches on the surface of implant that will produce stress concentration and ultimately path of crack growth propagation (Colic *et al.,* 2016). Figure 1 shows the failed artificial hip implant. So mechanical properties, design of implant, biocompatible nontoxic material, handling and proper surgery are the main parameter for the success of THR. In literature, static finite element analyses are typically performed using loads with a magnitude corresponding to body weight, gait and hip contact force during different routine activities in hip patients (Bergmann, Deuretzbacher *et al.,* 2001). However, the effects of weight and sudden movement can increase the load in daily life gait pattern

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movements to which the prosthesis is subjected by up to 15-30%. In some cases even more increase in load may be expected. This situation must be taken into account when estimating whether the prosthetic will fracture or fail due to fatigue. In order to investigate the difference in results predicted by standard tests of implants and real loads that can occur in practice, it is required to analyze the prosthesis under static loads corresponding to the body weight, as well as under maximum real load conditions that is expected to occur during the different daily activities (Colic *et al.,* 2016).

Ti-27Nb titanium alloy is the most suitable material for hip bone implants because of its superior corrosion resistance, high strength, low modulus, shape memory property, super elasticity and biocompatible (Van Humbeeck 1997) (Semlitsch, Weber *et al.,* 1992) (Briant-Evans, Norton *et al.,* 2007) . However, the behavior of the material for real life loading need to be explored experimentally and/or finite element analysis techniques. The objective of this study is to numerically investigate the stress strain behavior of Ti-27Nb hip bone implant. In this research work the effect of predicated loads during different activities of normal routine life were applied on the hip bone model and simulated using commercial FEA software ANSYS.

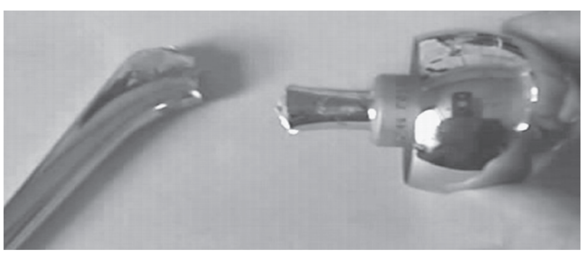

Figure 1: Artificial Hip Implant Failure (Briant-Evans et al., 2007)

Detailed stress analysis is performed on hip prosthesis during different patient activities such as walking, Knee Bend, stand up and sit down in the extreme cases.

The loads used in this research work were taken from Bergman et al. (Bergmann *et al.,* 2016) on different cases of patients varying in age and body weight from 30-65 years and 75-100 kg respectively. The next section describe the detailed FEA modeling of the hip bone implant. Section 3 presents the results of the investigation. The conclusion and future recommendations of the study are presented in the last section of the paper.

FEA modeling

Static load selected for the numerical analysis characterizes for average weighing of 75-100 kg that is from average to maximum and the loads given in Table 1.

Table 1. Loading of Hip Joint for Different Activities

Sr. No.	Activity	Maximum force in joint (N)	
		Average 75 Kg	High 100 Kg
1	Sit Down	1360	2935
2	Stand Up	1600	3839
3	Knee Bend	1699	3145
4	Walking	1925	2880

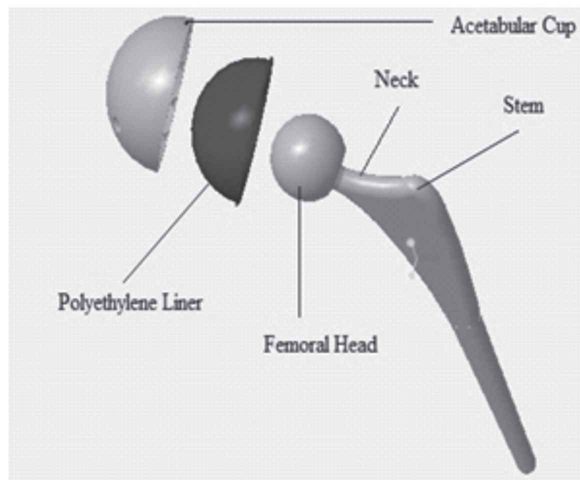

Figure 2a. Exploded View of Hip Implant

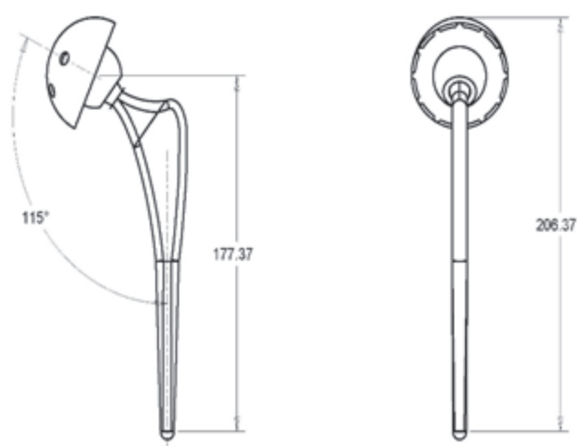

Figure 2b. 2d Views of Hip Implant

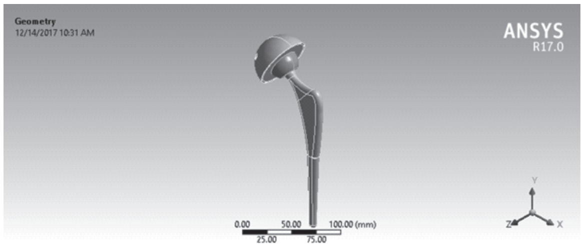

Figure 3. Geometry of Hip Implant

Modeling of charnley type hip implant was done in CREO PARAMETRIC software by using different catalogues of hip prosthesis (Galbeño 2014). The geometry and 2D view drawing of the hip implant is shown in Figure 2a and 2b.

The model was imported to ANSYS workbench using STP file transfer as shown in Figure 3.

The model was meshed using SOLID 185 tetrahedral element. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The total number of elements and nodes were 247762 and 51780 respectively. The meshed model is shown in Figure 4.

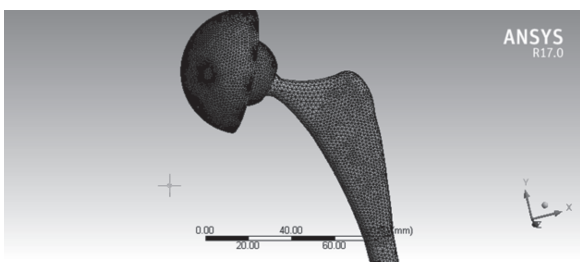

Figure 4. Meshed Model of Hip Implant

The applied load sequence is given in table 1. As we considered cemented hip implant prosthesis, so stem was assumed to be constrained fixed as it reside inside the bone and compressive distributed load was assumed to be applied on acetabulum hip prosthesis. The applied constraints and loads are shown in Figure 5.

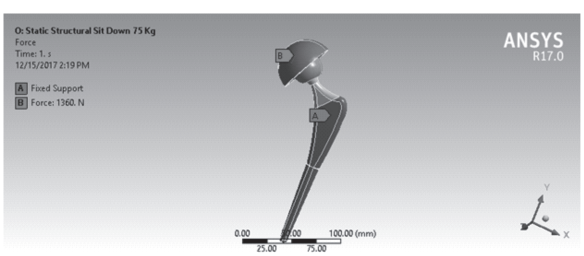

Figure 5. Applied Boundary Conditions

The material properties of Ti-27Nb given in table 2 were applied to the ANSYS workbench model.

Table 2. Mechanical Properties of Ti-27nb, Ceramic Zirconium Zo2 and Polyethylene Uhmwpe (Davis 2003)

Sr. No.	Material	Young's Modulus (GPA)	Ultimate Tensile Strength (MPA)	Poisson's Ratio
1	Titanium Alloy Ti-27Nb	86	860	0.33
2	Ceramic Zirconium ZO2	220	711	0.32
3	Polyethylene UHMWPE	1.10	33	0.42

RESULTS AND DISCUSSION

As mentioned in previous section, two weights of subjects from average to high in four different gait pattern positions were considered for this investigation. The stress distribution results of stand up position for the two weights i.e. 100 Kg and 75 Kg is shown in Figure 6a and 6b respectively.

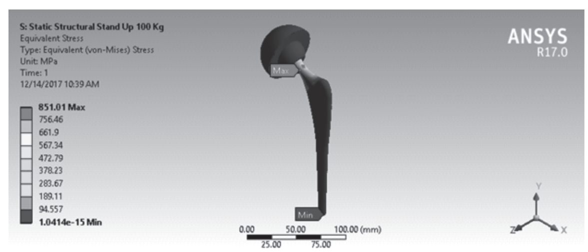

Figure 6a. Equivalent (Von-Mises) Stress for 100 KG Stand Up Activity

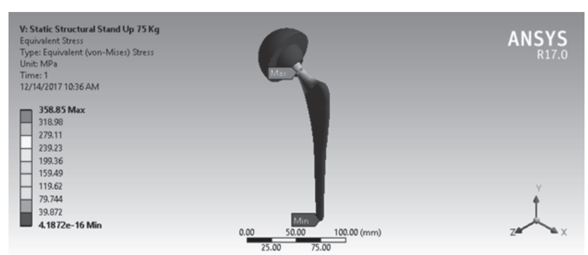

Figure 6b. Equivalent (Von-Mises) Stress for 75 KG Stand Up Activity

The maximum stress for the 100 Kg is 851 MPa and its location is on the neck of implant as shown in Figure 6a. The material in this location is Ti-27Nb. After comparison with the ultimate strength of the Ti-27Nb, the factor of safety (FOS) is approximately equal to 1.

The stress levels on the ZO_2 and UHMWPE are much lower than their corresponding strengths. The results reveals that strength of the Ti-27Nb should be higher to increase the FOS for this position. The properties used in this simulation were that of cast Ti-27Nb. The strength of this material may be increased by adopting annealing process for the manufacturing of the material. The stress distribution for the applied weight 75 Kg for stand up position is shown in Figure 6b. The maximum stress 358 MPa is again on the neck of the implant stem. The FOS for this case is approximately 2.4 which implies that the implant is safe. The stress distribution for 100 Kg weight for sit down, knee bend and walking are shown in Figures 7a, 7b and 7c. The stress distribution for 75 Kg weight for sit down, knee bend and walking are shown in Figure 8a, 8b and 8c. The maximum stress for each weight and position is summarized in table 3.

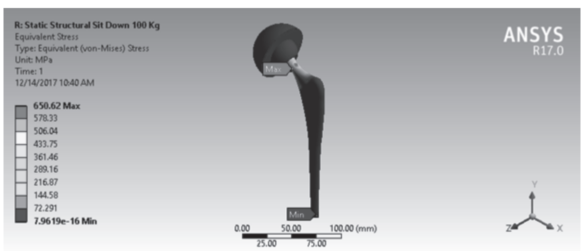

Figure 7a. Equivalent (Von-Mises) Stress for 100 KG Sit Down Activity

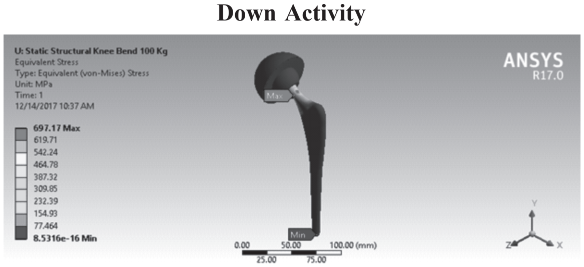

Figure 7b. Equivalent (Von-Mises) Stress for 100 KG Knee Bend Activity

Figure 7c. Equivalent (Von-Mises) Stress for 100 KG Walking Activity

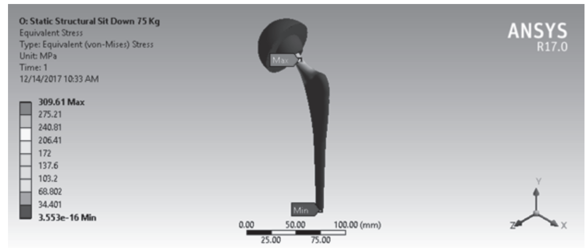

Figure 8a. Equivalent (Von-Mises) Stress for 75 KG Sit Down Activity

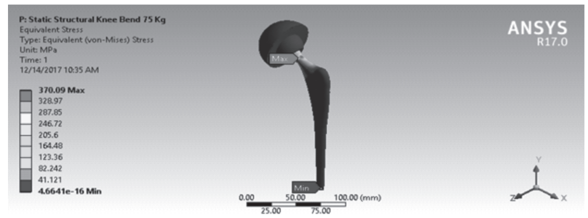

Figure 8b. Equivalent (Von-Mises) Stress for 75 KG Knee Bend Activity

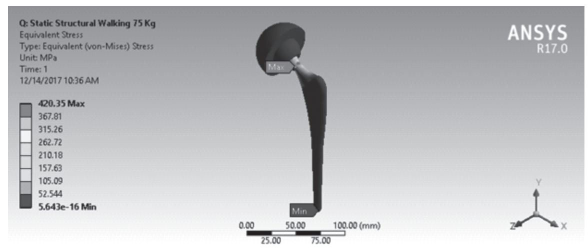

Figure 8c. Equivalent (Von-Mises) Stress for 75 KG Knee Bend Activity

Table 3. Results of Fea Analysis of Hip Implant Model

Sr. No.	Activity	Maximum Von Mises Stress (MPa)	
		Average 75 Kg	**High 100 Kg**
1	Sit Down	309.61	650.62
2	Stand Up	358.85	851.01
3	Knee Bend	370.09	697.17
4	Walking	420.35	638.43

The literature studies (Colic *et al.,* 2016) show that the FOS calculated is less than 2 for different hip joint implants materials for the described geometry. This value show that it quite lower for use in the human body due to its critical nature. The lowest proposed value for mechanical structures where human safety is involved is four (J. E. Shigley, C. R. Mischke *et al.,* 2002). This imply that material properties should be enhanced for implants because we are restricted to retain the geometry of the implant due to fix nature of the human's hip joint bone. However the side effects for increasing the strength such as increase in the elasticity should be addressed for mechanical compatibility reasons (Khan, ur Rahman *et al.,* 2016). The geometry of the stem's neck (location of maximum stress) is critical and may require redesigning (Senalp, Kayabasi *et al.,* 2007). Has proposed different design solution for the geometry of the stem and neck portion that need to be checked for the current load cases.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

In this paper the effect of different loading from average to high due to different body positions on the hip joint implant of Ti-27Nb has been investigated using FEA. The results reveals that stresses increase with the increase of the body weight. Maximum stress occurs for higher weights in the standing position. The location of maximum stress is the neck of the implant.(Grupp, Weik *et al.,* 2010) The materials strength needs to be enhanced to achieve higher FOS keeping in view the elastic modulus of the material. It is recommended that further investigation is carried out using other neck configurations and human's body environment. The femoral head and polyethylene lining materials thickness should strong enough to withstand the applied loading.

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