Load Analysis of Knee Joint Replacement during Daily Life Activity for Obese Weight Subjects

Ateyah Alzahrani, Dhia K. Suker, Sajid Riaz

***Abstract*— this paper shows the outcomes of an investigation of the response onto knee joint replacement during daily life activity. Obese weight category has been studied for this investigation during six activities of daily life activity. A model of knee joint replacement has been designed for this study and the simulation of model has been done by using ANSYS software. The outcomes of this study illustrates that one legged activity occurred the minimum effect of the forces and moments on the knee joint replacement. While the ascending stair activity cause the maximum effect of knee joint replacement. Knee bend and Stand up / sit down seem to have the same results while the level walking has an average values**

***Index Terms*— TKR, modeling, ANSYS, Forces, Moments, Healthy Weight Group.**

I. INTRODUCTION

A lot of stresses and forces could effect on the human body during daily life activity, which might directly effect on the frame structure of body. The Knee joint consider one of the most important parts in the human body. Knee joint endured a lot of forces an moments during daily life activity. And the high amounts of forces and moments on knee joint could effect on the function of knee which might need a medical or surgical operations [1]. The problems of knee could happen during the common daily life activities, loads, forces, moments should be analyzed and studied to increase the power and safety of knee and also to decrease the proportion of knee problems [2]. During the last ten years the number of people who visit physiotherapy doctor increased and some patients need to implant knee joint replacement. From 1950 the experts are looking for the best solutions of knee joint problems by researching [3]. Previous studies have been studied to observe the forces and moments of knee joint replacements. Some of these studies used an instruments in lab to measure the forces and moments during several activities [4][5].

Computer modeling has been used to predict the kinematics and kinetics of knee joint replacement. The developments of computer modeling that used three dimensional techniques to get the accurate results and values [6]. Several studies has been considered the mass of body weight during daily life activities to evaluate the forces and moments of knee joint replacement [7][8].

This paper investigates the load analysis of knee joint replacement during six activities of daily life activity for obese weight subjects by using finite element modeling. This paper following to previous study by the same authors [7].

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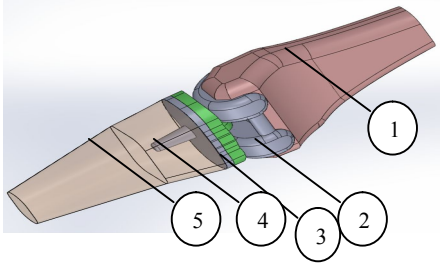
II. METHODOLOGY

A. *Geometry of Knee Model*

The model of this study is the right femur of total knee replacement component from ATTUNE® Knee System (DePuy Synthes, 2015) as described in the following section. The lower end of femur has been scanned using 3D scanned tool as shown in Figure 1.

Figure 1. The lower end of femur

Based on the geometry of lower end of femur, the total knee replacement model has been created as shown in Figure 2.



1. Upper Bone.
2. Femur
3. Polyethylene insert
4. Tibia Insert
5. Lower Bone

Figure 2. Total Knee Replacement model

B. *Model Description*

The model has been designed by mechanical design software called SolidWorks, the femur has been scanned in lab by using three dimensions scanning machine. The software is used to design and modeling different types of mechanical components under various conditions. There are 5 parts in this model: upper bone, lower bone, polyethylene insert, tibia insert and femur insert. All the parts have been designed using

CAD. The CAD file converted to IGES format file, then it exported the IGES file to ANSYS R.15. It follows with assignment of material properties within the solid model then the generation of element called meshing is performed.

C. Boundary Conditions

The boundary conditions of knee model are fixed at the lower bone segment. Force is applied onto the upper bone with different angles as refer to six daily activities. The reaction forces are in contact area between the lower end of femur and polyethylene insert. The model is considered as a default model. The lower end of femur is stainless steel fitted together with the polyethylene insert and the tibia insert which is made of a stainless steel. Lower and upper bone has a density of 1 g/cm^3 bone mineral density which is normal bone density as shown in Figure 3.

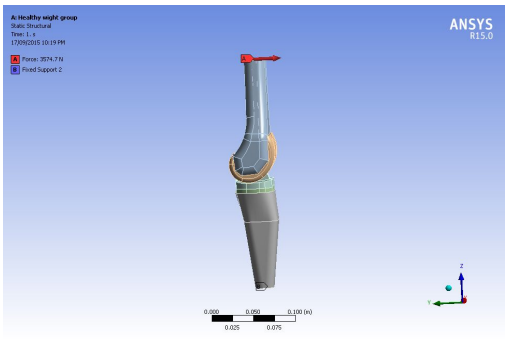


Figure 3. The boundary condition of model

D. Coordinates of the Model

The knee joint replacement has been model to predict the forces and moment in three direction which is known Fx frontal plane, Fy sagittal and Fz vertical axis and Mx in the sagittal plane, My in the frontal plane and Mz in the vertical plane. As shown in Figure 3.

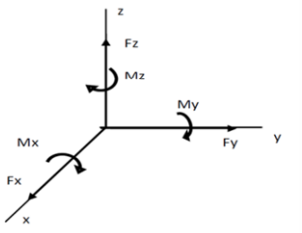


Figure 3. Direction of forces and moments of model

III. KNEE LOADING AND RESPONSE

The obese weight group has been classified based on body mass index (BMI) as shown in Table 1. The forces on knee joint replacement consider the body weight of 5 subjects during 6 daily activities. The six daily activities involved are One-legged (OL), Level Walking (LW), Stand up /Sit down (ST), Knee Bend (KB), Ascending Stair (AS) and Descending Stair (DS).

Table 1. The obese weight group data

Name	Age (year)	Length (cm)	Weight (kg)	BMI
O1	22	172	135	45.6
O2	21	170	118	40.8
O3	29	162	102.5	39
O4	28	180	104	32
O5	38	180	112	34.5

Body weight percentage of loads applied onto knee are derived from study by (Kutzner et al. 2010) who measured forces and moments during 6 activities by using lab instrument This is used as a knee load coefficient, as presented in Table 2. Input forces are derived using these coefficients, and later used as an input in finite element simulations as shown in Table 3.

Table 2. Load Coefficient of knee joint model

Daily Activity	K1L (kN)	K2L (kN)	K3R (kN)	K4R (kN)	K5R (kN)
LW	2.85	2.23	2.64	2.97	2.36
AS	3.13	3.45	2.98	2.99	3.25
DS	3.59	3.37	3.37	3.23	3.74
O-L	2.89	2.41	2.61	2.4	2.65
KB	2.99	2.61	2.56	1.85	2.62
ST	2.7	2.29	2.27	2.05	2.47

Table 3. The input force of obese weight subjects

Activity	O1 (kN)	O2 (kN)	O3 (kN)	O4 (kN)	O5 (kN)
LW	3.773	2.580	2.653	3.029	2.592
AS	3.622	3.46	3.039	3.28	3.569
DS	3.608	3.437	3.701	3.294	4.107
OL	2.947	2.647	2.623	2.447	2.910
KB	3.284	3.02	2.573	1.886	2.877
ST	3.574	2.650	2.281	2.090	2.713

The shown values in Table 3 are input forces which applied onto knee replacement model based on the angle of every activity in Table 4.

Table 4. The angles of motion during activity

Activity	Angle
Level walking	10°
Ascending stairs	65°
Descending stairs	30°
Knee bend	95°
One-legged stance	0°
Stand up/sit down	90°

IV. RESULTS AND DISCUSSION

The input load was applied on the upper bone, which resulted in forces in three directions and Moments in three directions. The results has been plotted with magnitude for related subjects as shown in Tables 5 and 6.

Table 5. Resultant Reaction Forces of 5 Obese Weight Subjects

	Reaction resultant forces (Kn)				
Activity	O1	O2	O3	O4	O5
OL	3.49	3.14	3.11	2.90	3.455
LW	5.01	3.43	3.52	4.02	3.44
ST	6.52	4.84	4.16	3.81	4.95
KB	6.12	5.62	4.79	3.51	5.36
DS	5.88	5.60	6.03	5.37	6.69
AS	6.94	6.64	6.86	6.29	6.83

Table 6. Resultant Reaction Moments of 5 Obese Weight Subjects

Resultant Reaction Moments(N.m)					
Activity	O1	O2	O3	O4	O5
OL	24.48	21.944	27.79	20.33	24.18
LW	136.46	93.891	96.55	110.21	94.31
ST	581.53	431.11	371.21	340.14	441.36
KB	534.55	491.61	418.85	307.12	468.4
DS	319.35	327.55	327.55	291.52	363.5
AS	546.67	523.41	458.78	495.63	538.77

Resultant reaction force observed that one – legged activity is the smallest in magnitude while the ascending stair activity is the highest. The graph in Figure 4 shows that there is a gradually increase in forces .The one legged activity from 2.90 kN to 3.49 kN, level walking activity from 3.43 kN to 5.01 kN, stand up / sit down has changed from 3.81 kN to 6.52 kN, knee bend activity between 3.51 kN to 6.12 kN, the descending stair 5.37 kN to 6.69 kN and ascending stair from 6.29 kN to 6.94 kN. The maximum resultant force is in O1 with a magnitude of 6.94 kN during ascending stair and smallest in O4 with a magnitude of reaction 2.90 kN during One–legged activity as shown in Figure 4.

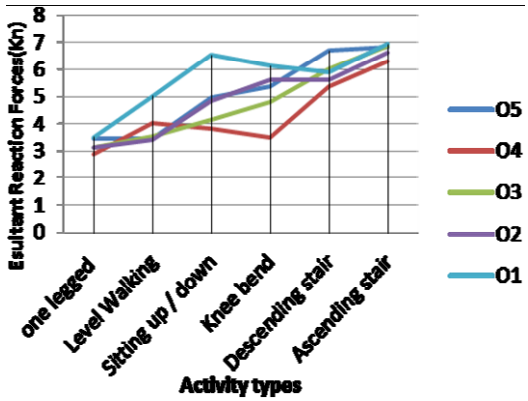


Figure 4. Resultant reaction forces results during 6 activities

Resultant reaction moments noticed that one–legged activity is the smallest in magnitude while the ascending stair activity is the highest in magnitude. The graph illustrates there is a fluctuation in moments. The one legged activity gives rise to an increment from 20.33 N.m to 24.48 N.m, level walking activity from 94.31 N.m to 136.46 N.m, stand up / sit down has change from 340.14 N.m to 581.53 N.m, knee bend activity between 307.12 N.m to 534.55 N.m, descending stair 291.52 N.m to 363.5 N.m and ascending stair from 458.78 N.m to 546.67 N.m. The maximum resultant moments is in H2 with 546.67N.m during ascending stair and smallest in H4 with 20.33 N.m during one-legged activity as shown in Figure 5.

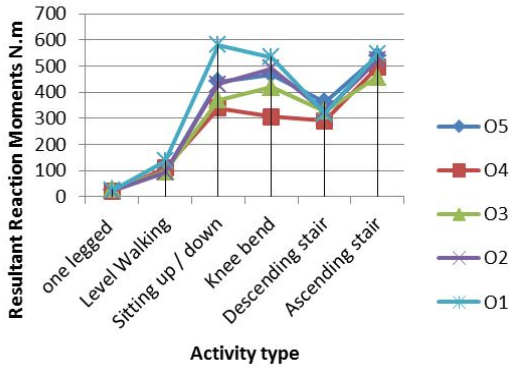


Figure 5. Resultant reaction moments results during 6 activities

The range of results of reaction force for this group of subjects in reaction to input load is between 2.90 kN and 6.94 kN. During level walking activity, it can be clearly seen that there is a steadily increasing and resultant reaction force between 3.43kN and 5.01 kN. However there was a variation resultant force during knee bend activity between 3.51 kN and 6.12 kN. For subject O4 there was a 3.51 kN resultant force during knee bend activity which consider the smallest result compared to other subjects. During descending stair activity, there was a significant rise in reaction force between about 5.37 kN and 6.69 kN. Finally, the number of resultant forces reaction increased steadil from 6.29 kN to 6.94 kN for the case of ascending stair.

The reaction resultant moments for six daily life activities, measured by kilo-Newton per meter. It can be clearly seen that, in comparison, the resultant moments of the one-legged stairs activity is the smallest while the ascending stair activity is the biggest.

During the one-legged activity there is a gradual increase of resultant moment from about 20.33 N.m to around 24.88 N.m. However, there was a dramatically increase from approximately 94.31 N.m to about 136.46 N.m during the level walking activity. This is also seen in the stand up/sit down activity, where there is a rough rise from about 340.14 N.m to around 581.53 N.m. there was a decrease in result of from 319.35 N.m to 291.52 N.m for descending stairs, and there is a gradual increase from about 458.78 N.m to around 546.67 N.m for the ascending stairs activity.

CONCLUSIONS

The study highlighted on the obese weight subjects, which consider an input force during 6 activities of daily life activities. The reaction resultant force during Ascending stair gives the maximum load onto knee joint replacement with the magnitude of 6.94 kN during activity. However the lowest reaction resultant forces during one-legged activity with the magnitude of 2.90 kN. The resultant reaction moments during Ascending stair activity has the highest load during applied forces on knee joint replacement with magnitude of 546.67

N.m., while the resultant reaction moments during one-legged activity with magnitude of 20.33 N.m.

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