Study of the Response of Knee joint Replacement under Daily life Activity Loads for Healthy Weight subjects

I. Jusoh , A. A. Alzahrani

Abstract— **This paper presents results of an investigation of the effect of daily life activity loads onto total knee replacement. The category of people which has been studied in this investigation is the healthy weight group. The model has been designed for the knee replacement and the analysis has been done by using ANSYS software. The results of this study shows that one legged activity cause minimum effect of forces and the moments on the knee joint replacement .While the ascending stair activity cause maximum forces and moment on the knee. Knee bend and stand up/sit down seem to have the closer values while level walking has an average values.**

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

I. INTRODUCTION

During daily life activities, human body experiences a lot of stresses and forces which might affect the frame structure of human body. The knee joint is one of the most important part in the human body with respect to applied forces and moments it endured during daily different activities. These variations can directly affect the function and movement of the knee in the long term. The number of people who visit physiotherapy doctors increased gradually during the last ten years[1]. Some of them need to change knee joint to knee joint replacement. Researchers from 1950 until now looking for best solution for people with knee problems.[2], [3]. Daily activities can bring about problems in the knee joint, which can directly affect the function and movement of the knee, necessitating surgery or replacement. Subsequently, moments and forces affect the knee joint replacement during daily activities – these need to be studied and analyzed to improve performance and decrease probability of knee problems after surgery.[4], [5].

Several studies have been made to predict the forces and moments onto Knee Joint Replacement using lab instrument to measure the loads during hard activities.[4], [6] Most of researchers did not consider the weight group and body mass indicator of subjects.

Computer modeling is used to predict total knee replacement kinematics and evaluate the mechanical behavior of prosthesis components. Computer models have been developed three dimensional model to predict total knee replacement response and examine how total knee replacement designed ligaments restraints influence joint motion.[7]

This research focused on thee response of knee joint replacement during 6 activities of daily life activities using Finite Element modeling.

Manuscript received Dec 17, 2015

I. Jusoh, Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia

A. A. Alzahrani, Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia

II. METHODOLOGY

A. GEOMETRY OF KNEE MODEL

The model used in 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

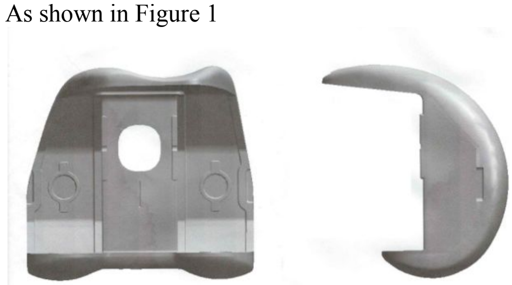

Figure 1. The lower end of femur after scanned

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

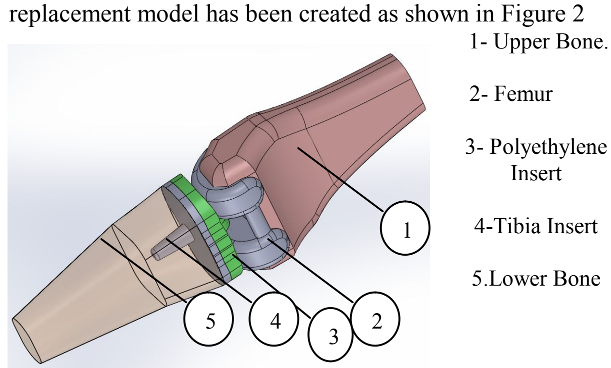

Figure 2. Total knee replacement model

B. MODEL DESCRIBTION

The knee model was designed in Solid Work, except the femur stainless steel that was scanned using 3D scanning tool. Solid Work is a design software use for modeling and verification of mechanical components under various conditions. The model consists of 5 parts namely lower bone , upper bone, polyethylene insert, tibia insert and femur insert as shown in Figure 2 . these parts of model were deformed under loading conditions as described in the following sections.

Following the CAD modeling of knee joint replacement. the file is converted to IGES format and then imported to ANSYS

R15.0. Then the solid model assigned to the material properties and next generated into smaller units, called meshing. The component assembly is divided into a finite number of elements.

C. BOUNDRY CONDITIONS

The boundary conditions of knee model are fixed at the lower bone segment. Force is applied onto upper bone with different angles as refer to six daily activity. The reaction forces are in contact area between the lower end of femur and polyethylene insert. The model is consider 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.

D. COORDINATE OF 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.

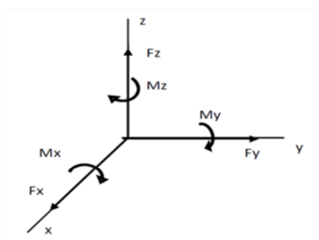

Fig.3 Direction of Forces and Moments of model

III. KNEE LOADING AND RESPONSE

The healthy weight group was 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 involves 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 healthy weight group data

Subject	Age (year)	Height (cm)	Body Weight(kg)	BMI
H1	18	166	60	21.7
H2	28	169	68.5	23.9
H3	28	166.5	66	23.9
H4	29	171	62	21.2
H5	21	168	69	24.4

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 healthy weight

Daily activity	H1(kN)	H2(kN)	H3(kN)	H4(kN)	H5(kN)
LW	1.676	1.498	1.708	1.805	1.596
AS	1.841	2.317	1.928	1.81	2.19
DS	2.112	2.263	2.181	1.96	2.530
OL	1.700	1.618	1.689	1.459	1.79
KB	1.759	1.753	1.656	1.124	1.772
ST	1.588	1.538	1.469	1.24	1.671

During simulation, load apply for every activity with specific angle as shown 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. RESULT AND DISCUSSION

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

Table 5. Resultant Reaction Forces of 5 Healthy Weight Subjects

	Reaction resultant forces				
Activity	H1(KN)	H2(KN)	H3(KN)	H4(KN)	H5(KN)
OL	2.019	1.9222	2.0057	1.7325	2.129
LW	2.2302	1.9923	2.2718	2.4017	2.1239
ST	2.9007	2.8095	2.6833	2.2764	3.0523
KB	3.2792	3.268	3.0884	2.0959	3.3045
DS	3.4452	3.692	3.5573	3.203	4.1273
AS	3.5304	4.4408	3.6956	3.4834	4.2138

Table 6.Resultant Reaction Moments of 5 Healthy Weight Subjects

	Reaction Moments Resultant (N.m)				
Activity	H1(N.m)	H2(N.m)	H3(N.m)	H4(N.m)	H5(N.m)
OL	14.129	13.451	14.036	12.124	14.899
LW	60.997	54.493	62.162	65.865	58.102
ST	258.46	250.27	239.03	202.78	271.91
KB	286.35	285.37	269.37	183.09	288.57
DS	186.92	200.34	193.03	173.8	223.96
AS	277.97	349.78	291.1	274.5	331.91

Resultant reaction force observe that one – legged activity is the smallest in magnitude while the ascending stair activity is the highest. The graph in Figure 4 illustrate there is a gradually increase in forces .The one legged activity from 1.73 kN to 2.29 kN, level walking activity from 1.99 kN to 2.40 kN , stand up / sit down has changed from 2.27 kN to 3.05 kN, knee bend activity between 2.09 kN to 3.27 kN, the descending stair 3.20 kN to 4.12 kN and ascending stair from 3.53 kN to 4.44 kN. The maximum resultant force is in H2 with a magnitude of 4.44 kN during ascending stair and smallest in H4 with a magnitude of reaction 1.73kN during One–legged activity as shown in Figure 4.

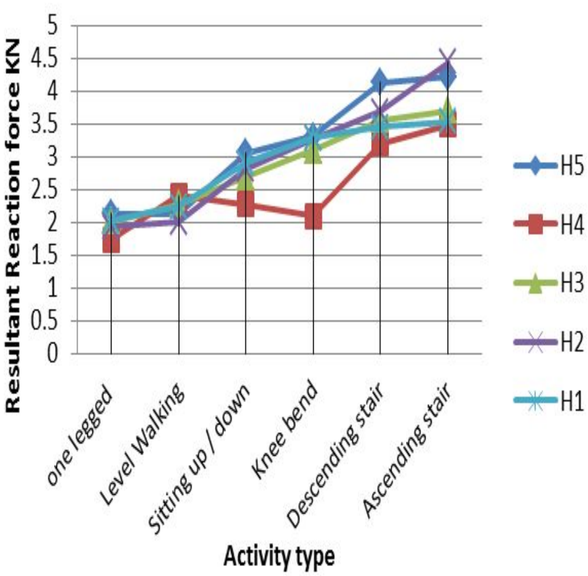

Fig.4 Resultant reaction forces results during 6 activities

Resultant reaction moments shows that one–legged activity is the smallest in magnitude while the ascending stair activity is the highest in magnitude. The graph illustrate there is a fluctuation in moments. The one legged activity gives rise to an increment from 12.12 N.m to 14.89 N.m ,level walking activity from 54.49 N.m to 65.86 N.m , stand up / sit down has change from 202.78 N.m to 271.91 N.m, knee bend activity between 183.09 N.m to 286.35 N.m, descending stair 173.8 N.m to 223.96 N.m and ascending stair from 274.5 N.m to 349.78 N.m. The maximum resultant moments is in H2 with 349.78 N.m during ascending stair and smallest in H4 with 12.12 N.m during one -legged activity as shown in Figure 5.

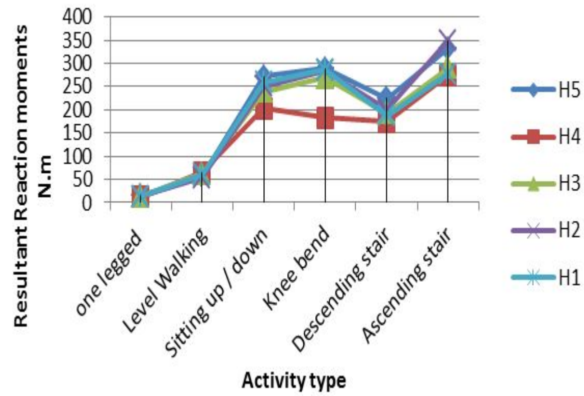

Fig.5 Resultant reaction moments results during 6 activities

The range of results of reaction force for this group of subjects in reaction to input load is between 1.7 kN and 2.2 kN. During level walking activity, it can be clearly seen that there is a steadily increasing and resultant reaction force between 2 kN and 3 kN. However there was a fluctuating resultant force during knee bend activity between 3 kN and 3.5 kN. For subject H4 there was a 2 kN resultant force. During descending stair activity, there was a dramatic increase in reaction force between about 3.2 kN and 4.2 kN. Finally, the number of resultant forces reaction increased gradually from 3.5 kN to 4.44 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 lowest while the ascending stair activity is the highest.

During the one-legged activity there is a steady increase of resultant moment from about 20 N.m to around 50 N.m. However, there s a dramatic increase from approximately 50 N.m to about 250 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 260 N.m to around 280 N.m. There is a gradual decline from about 280 N.m to 180 N.m for descending stairs, and there is a gradual increase from about 200 N.m to around 300 N.m for the ascending stairs activity.

CONCLUSIONS

- Group of people were selected based on their body weight namely healthy weight (H).
- Loading forces on the knee joint replacement were studied as an input based on six daily activities .
- Ascending stair gives the biggest load response at knee joint replacement with the magnitude of 4.44 kN during activity .
- One-legged activity gives the lowest load response in the magnitude 1.73 kN during activity.
- The maximum resultant moments during ascending stair is 349.78 N.m of H2 subjects.
- The lowest resultant moments during one-legged is 12.12 N.m of H4 subject.

ACKNOWELEDGEMENT

The authors acknowledges with gratitude the financial support received from Umm Al-Qura University, Saudi Arabia.

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