The Effect of Daily Life Activity Loads on Knee Joint Replacement of Overweight Subjects

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***Abstract*--- Knee joint experienced several magnitude of loadings in relation to usual daily life activities. Those activities vary from simple walking to climbing and ascending stairs. This paper presents result of study on the effect of loads onto Knee Replacement during six daily life activities for overweight subject group. The knee replacement has been modeled and simulated using ANSYS finite element software. The result shows that one legged activity cause minimum effect of forces and the moments on the knee joint replacement. Maximum forces and moment on the knee were caused by the stair ascending activity. Stand-up /sit-down and knee bend activities gives rather similar response magnitudes while level walking has an average values**

***Index Terms*—** TKR, modeling, ANSYS, Forces, Moments, Overweight Subjects Group**.**

I. INTRODUCTION

Human body experiences a lot of stresses under numerous daily life activities. These loads and stresses might have effects on the frame structure of the body. One of the most important part in the human body with respect to applied forces and moments is the knee joint. It endured variation of loads during daily different activities. These variations can directly affect the function and movement of the knee in the long term. These may be referred to number of people who visit physiotherapy doctors in the last ten years [1]. It shows a gradually increase in trend during that period of time and knee joint replacement are required for many of them. Earlier researchers strived for best solution for people with knee problems [2], [3].

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Common daily activities can bring about problems in the knee joint, that can directly affect the function and movement of the knee which necessitating surgery or replacement. External loads, forces and moments due to daily activities need to be studied and analyzed to improve the safety of knee joint and decrease the probability of knee problems. [4], [5].

Several studies have been conducted to estimate the forces and moments onto Knee Joint Replacement using computer simulation [6] and lab instrument to measure the loads during hard activities [4], [7]. Body weight grouping as well as body mass index (BMI) has been considered to study the loads and response on the knee joint. It follows with computer modeling and simulation to predict total knee replacement kinematics and evaluate the mechanical behavior of prosthesis components [6]. Three dimensional model has been developed to predict total knee replacement responses and examine how total knee replacement designed ligaments restraints influence joint motion [8].

This paper investigates the response of knee joint replacement of overweight subjects during 6 daily life activities using Finite Element modeling and simulation. It is a continuation to the previous study by the same authors [6].

II. METHODOLOGY

A. KNEE MODEL GEOMETRY

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

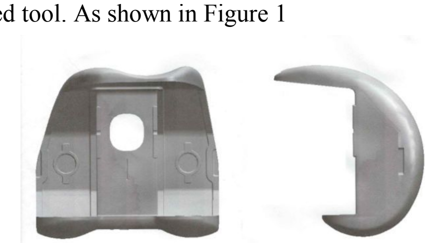

Figure 1. The lower end of femur

Figure 2 shows the geometry of the lower end of femur for the total knee replacement model that has been modeled.

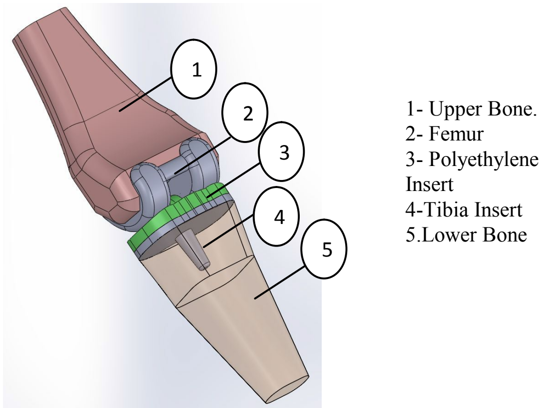

Figure 2. total knee replacement model

B. MODEL DESCRIPTION

Solid Work software has been used to design the knee model with exception of the stainless steel femur that was scanned using 3D scanning tool. 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 the model were deformed under loading conditions as described in the following Sections. Initially the knee joint replacement is modeled using CAD software. Then the file is converted to IGES format before exported to ANSYS R15.0. It follows with the assignment of material properties within the solid model then the generation of element called meshing is performed.

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 activities. The reaction forces are in contact area between the lower end of femur and polyethylene insert. In this study, the basic model previously described is considered as a default model. The lower end of femur is made from stainless steel, fitted together with the polyethylene insert and the tibia insert which is also made of a stainless steel. Lower and upper bone assigned with a density of 1 g/cm^3 which is normal bone density.

D. COORDINATE OF MODEL

The model of knee joint replacement employed to estimate the response in term of forces and moments in three directions which is labeled *Fx* and *Mx* in frontal axis, *Fy* and *My* in sagittal axis and *Fz* and *Mz* vertical axis as shown in Figure 3.

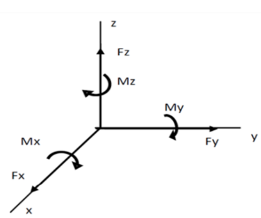

Fig.3 Direction of Forces and Moments

III. LOADING AND RESPONSE

Classification of overweight subject group are 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 involve 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 Overweight Subjects Data

Name	Age (yr.)	Height (cm)	Weight(kg)	BMI
OW1	29	182	86	25.9
OW2	28	170	75	25.9
OW3	27	167	77	27.9
OW4	31	168	77	27.2
OW5	28	166.5	78	28.1

Body weight percentage of loads applied onto knee are derived from earlier that measured forces and moments during 6 activities by using lab instrument [4]. 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

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
OL	2.89	2.41	2.61	2.4	2.65
KB	2.99	2.61	2.56	1.85	2.62
ST	2.70	2.29	2.27	2.05	2.47

Table 3 The input force of overweight subject group

Activity	OW1 (kN)	OW2 (kN)	OW3 (kN)	OW4 (kN)	OW5 (kN)
LW	2.403	1.640	1.993	2.242	1.805
AS	2.639	2.537	2.250	2.257	2.486
DS	3.027	2.478	2.544	2.439	2.860
O-L	2.437	1.772	1.970	1.812	2.027
KB	2.521	1.91	1.933	1.397	2.004
ST	2.277	1.684	1.714	1.548	1.889

The input load in Table 3 was applied onto a model according to prescribed angle as refer to its associated activity as shown in Table 4.

Table 4. The angles of loading 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 concentrated input load was applied on the upper bone, which resulted in the response forces and moments in three directions. The outcome of simulation response is tabulated in magnitude for related subjects as shown in Table 5 and Table 6.

Table 5. Resultant Reaction Forces of 5 Overweight Subjects

	Reaction Resultant Forces (kN)				
Activity	OW1	OW2	OW3	OW4	OW5
OL	2.89	2.10	2.34	2.15	2.41
LW	3.20	2.18	2.65	2.98	2.40
ST	4.19	3.08	3.31	2.83	3.45
KB	4.70	3.58	3.60	2.60	3.74
DS	4.94	4.04	4.15	3.98	4.67
AS	5.06	4.86	4.31	4.33	4.76

Table 6. Resultant Reaction Moments of 5 Overweight Subjects

	Resultant Reaction Moments (Nm)				
Activity	OW1	OW2	OW3	OW4	OW5
OL	20.25	14.73	16.37	15.06	16.84
LW	87.45	59.68	72.518	81.60	65.68
ST	370.46	274.01	278.86	251.83	307.37
KB	410.45	312.46	314.65	227.38	326.21
DS	267.94	219.36	225.2	215.84	253.18
AS	398.43	383.00	339.64	340.77	375.2

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 illustrate there is a gradually increase in forces. The one legged activity from 2.10 kN to 2.89 kN, level walking activity from 2.19 kN to 3.20 kN, stand up / sit down has changed from 2.83 kN to 4.19 kN, knee bend activity between 2.60 kN to 4.70 kN, the descending stair 3.98 kN to 4.94 kN and ascending stair from 4.31 kN to 5.06 kN. The maximum resultant force is in OW1 with a magnitude of 5.06 kN during ascending stair and smallest in OW2 with a magnitude of reaction 2.10 kN during One–legged activity as shown in Figure 4.

Resultant reaction moments show 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 14.73 Nm to 20.25 Nm, level walking activity from 59.68 Nm to 87.45 Nm, stand-up/sit-down has change from 251.83 Nm to 370.46 Nm, knee bend activity between 227.38 Nm to 410.45 Nm, descending stair 215.84 Nm to 267.94 Nm and ascending stair from 339.64 N.m to 398.43 Nm. The maximum resultant moments are in OW1 with 410.45 Nm during knee bend activity and smallest moment is in OW4 with 15.06 Nm during one-legged stand activity as shown in Figure 5.

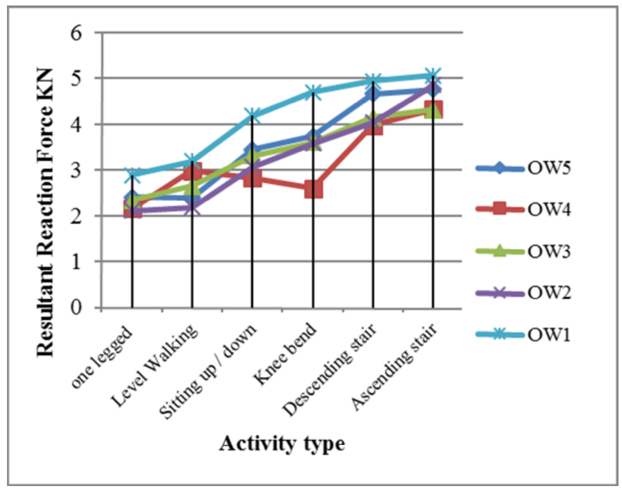

Fig.4 Resultant reaction forces results during 6 activities

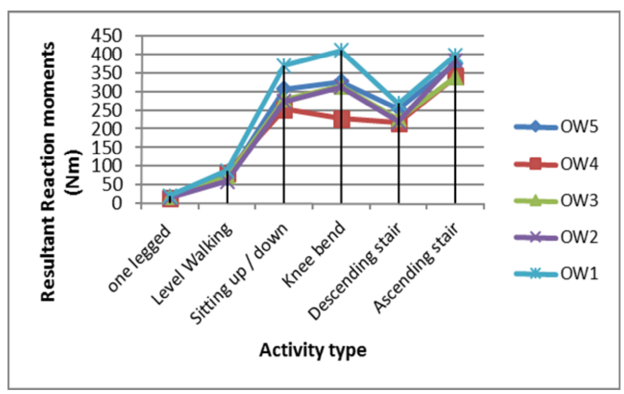

Fig.5 Resultant reaction moments results during 6 activities

The range of results of reaction force for all activities is between 2.10 kN and 5.06 kN. The reaction forces for one-legged stand ranges between 2.10 kN to 2.89 kN. During level walking activity, it can be clearly seen that there is a steadily increasing and resultant reaction force between 2.18 kN and 3.20 kN. In the case of stand-up/sit-down activity, the magnitude of reaction moment fell between 251.83 Nm and 370.46 Nm. However, there was a fluctuating resultant force during knee bend activity between 2.60 kN and 4.70 kN. For subject OW4 there was a significant decrease in resultant force of 2.60 kN as compared to clear increasing trend of other subjects. This may be due to related input force that influenced by the coefficient adopted earlier. During descending stair activity, there was a steady increase in reaction force between about 3.98 kN and 4.94 kN. Finally, the number of resultant reaction forces increased gradually from 4.31 kN to 5.06 kN for the case of ascending stair.

The reaction resultant moments for six daily life activities ranges from 14.73 Nm to 410.45 Nm. In exception of one results of OW1 for knee bend activity that gives the highest resultant moment at 410.45 Nm, other results, as shown in Figure 5, indicate that the ascending stairs gives a highest overall trends for all activities. On the other hand, one-legged stand activity marked the lowest overall resultant moment due to 6 - daily activity loads. Again, this could be contributed by adoption of loading coefficients from previous studies. As compared to earlier study [6], due to the increment in BMI for this group of subjects, the input loads are also increased thus giving a higher magnitude of force and moment resultants.

V. CONCLUSION

From this study the following conclusions may be drawn in the light of available data;

1. Results presented focused on input loads for overweight subject group, based on their BMI. These input loads on knee joint replacement associated with six main daily life activities usually performed by human body.
2. Highest magnitude of reaction force on the knee joint replacement is associated to ascending stair activity (5.06 kN), while the lowest magnitude due to one-legged stand activity (2.10 kN).
3. The highest magnitude of reaction moment is 410.45 Nm, associated with knee bend activity of OW1 subject while the lowest is 14.73 Nm for one-legged stand activity.
4. However, the overall highest magnitude of resultant moment responses for are due to ascending stair activity.

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