A three-dimensional computational fluid-structure interaction analysis in the hip-joint prosthesis during transition toward prostration and bowing in the salat activity

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ABSTRACT – In this paper, the lubrication performance of the non-Newtonian synovial fluid in the Diponegoro University artificial hip joint (AHJ) model in the bowing position and the transition toward prostration of salat activity is discussed based on the two-way FSI model. The results show that the Diponegoro University AHJ model is not recommended to perform the transition toward prostration movement due to the inadequate synovial fluid load support. It needs modification such as surface texturing or increasing the clearance to improve the lubrication performance.

1. INTRODUCTION

Permanent damage to the hip joint due to calcification, aging or accidents requires the act of total hip replacement. Fricka et al. [1] showed that total hip arthroplasty (THA) dislocation rates after artificial hip joint (AHJ) replacement were about 10% -25%, whereas according to Woo and Morrey [2] of 10,500 THA patients were 3.2% dislocated. Khan et al. [3] showed that 2.1% of the 6774 THA patients experienced a dislocation. There are two types of dislocations, namely early dislocation and late dislocation [4]. Early dislocation is commonly associated with the impingement of AHJ [4-5], while late dislocation is usually related to wear [4]. Early dislocation is usually caused by extreme movements that exceed the Range of Motion (RoM), and the activity of salat is one of these extreme activities.

There is still narrow information about the effect of salat activity on AHJ. Jamari et al. [6] use the Virtual Skeleton (VS) method to mimic and analyze salat movements with Google SketchUp 8. The drawback of the aforementioned study was that the presence of the synovial fluid as the lubricant on the hip joint was disregarded. Therefore, this study is aimed to analyze the contact of the artificial hip-joint during transition toward prostration and bowing considering the existence of the synovial lubricant by addressing the load support.

2. METHODOLOGY

The AHJ (Figure 1) model used is the Diponegoro University AHJ model with geometrical and material parameters which are shown in Table 1. The ground reaction force (GRF) measurements in each movement are analyzed using the static structure and biomechanical methods. Range of Motion (RoM) in this study uses the results of the aforementioned study [6]. The angular velocity is obtained by deriving the RoM to the time required by each prayer movement. GRF and angular velocity are the boundary conditions in this study. To analyze the effect of synovial fluid on AHJ, the Navier-Stokes and the continuity equations are then solved in ANSYS Workbench 16.0 with the two-way fluid-structure interaction (FSI) method. The non-Newtonian fluid and cross viscosity model are used in this study [7].

In this present study two different salat positions are; i.e. (1) the bowing position and, (2) the transition from standing toward prostration are analyzed. The rotation around *x, y, z* represents the flexion-extension, abduction-adduction, and internal-external rotation movement respectively. The velocity load in bowing and prostration movement respectively ω_x=0.76 rad/s, ω_y=0 rad/s, ω_z=0 rad/s, ω_x=0.11 rad/s, ω_y=-0.05 rad/s, ω_z=0.06 rad/s. The synovial fluid that interact with femoral head considered as moving wall, and stationary wall interact with inner liner.

In the bowing condition as discussed in the previous study [6], the impingement did not occur in the bowing position, whereas the impingement occurred in the transition from standing toward prostration. The lubrication performance is presented by the load support and the shear-thinning properties in each of the position.

Table 1 Geometrical and material parameter of AHJ Diponegoro University model.

Diametrical clearance, cd	100 µm
Head radius, R_H	14.1 mm
Head to inner liner radius, R_c cup thickness	6.9 mm
Elastic modulus of metal (stainless steel 316L)	$2x10^{11}$ Pa
Elastic modulus of polyethylene (UHMWPE)	$1.1x10^{9}$ Pa
Poisson’s ratio of metal	0.265
Poisson’s ratio of polyethylene	0.42
Viscosity of synovial fluid at zero shear rate	40 Pas
Viscosity of synovial fluid at infinite shear rate	0.9 mPas
Viscosity power law index	0.27

The simulation is initialized by solving the initial lubrication simulation on the steady state fluid dynamic simulation in each salat position to give the initial load to the transient structural mechanics simulation. Later in a two-way FSI analysis, the transient fluid dynamic simulation is coupled to the transient mechanics structural simulation to obtain the elastohydrodynamic (EHL) solution.

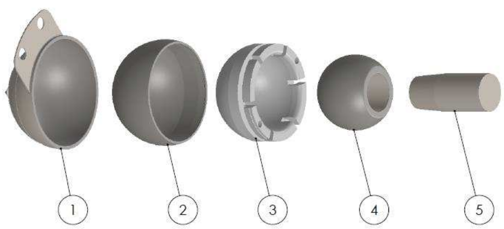

Figure 1 Artificial Hip Joint Components (Note: 1. Acetabular Cup, 2. Outer Liner, 3. Inner Liner, 4. Femoral Head, 5. Stem)

3. RESULTS AND DISCUSSION

Figure 2 represents the hydrodynamic pressure distribution in the bowing and the transition from standing toward prostration. The hydrodynamic pressure distribution in the bowing shows the positive trend with the maximum pressure of 4581 Pa at 135° and the minimum pressure of -11010 Pa at 0°. On the other hand, the hydrodynamic pressure in the transition toward prostration shows the different trend with the maximum pressure of 7380 Pa at 180°and minimum pressure of -2432.6 Pa at 18°.

Table 2 shows the bowing synovial fluid load support is -2.992 Pa.m^2, whereas the transition toward prostration synovial fluid load support is 1.951 Pa.m^2. The negative load support result of the bowing position indicates the lubrication failure. The synovial fluid on the bowing position does not provide an adequate load support and cause the occurrence of the contact between the femoral head and the inner liner of the AHJ.

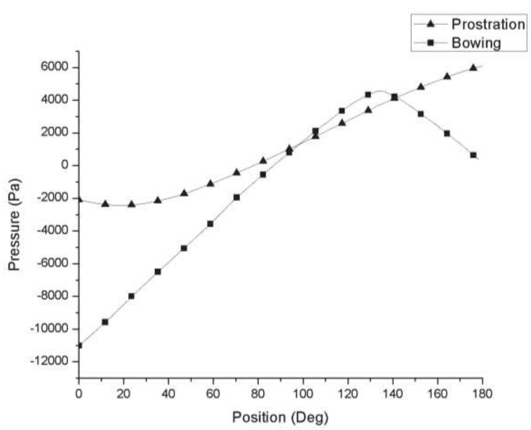

Figure 2 The hydrodynamic pressure distribution.

Table 2 Load support and maximum hydrodynamic pressure.

Movement	Load support	Max. pressure
Bowing	-2.992 mPa^2	4581 Pa
Prostration	1.951 mPa^2	7380 Pa

4. CONCLUSION

The hydrodynamic pressure distribution and the load support results show that the Diponegoro University AHJ model is not recommended to perform any salat positions. It is because the synovial fluid does not provide an adequate load support to prevent the occurrence of contact between the femoral head and the inner liner. The contact may result in patient discomfort or AHJ failure. To enhance the lubrication performance, geometry modifications such as surface texturing or increasing the clearance between the femoral head and the inner liner can be made.

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