Finite Element Analysis in Posterior Stabilized Total Knee Arthroplasty on Kneeling

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***Abstract*—The objective of this study was to identify the biomechanics of commercial total knee arthroplasty in kneeling position by Finite Element Method (FEM). Two commercial total knee arthroplasties were created on a 3D Finite Element model of both knee implants at 0, 30, 60, 90, and 120 degrees of knee implant flexion. To identify the contact area and pressure on polyethylene component of both knee implants by Finite Element Method, the largest contact pressures on polyethylene of LPS-Flex and Genesis II are 2.909 and 3.910 MPa presented at 120 degrees on knee implant flexion. The fewest contact pressures on polyethylene are 0.1596 and 0.6389 MPa presented at 0 degree on knee implant flexion. In the same way, the largest contact area of LPS-Flex and Genesis II are 309.786 and 368.68 mm^2 presented at 0 degree on knee implant flexion. The fewest contact area of LPS-Flex and Genesis II are 96.2699 and 129.027 mm^2 presented at 120 degrees on knee implant flexion. The Finite Element Analysis (FEA) was an effective method to identify contact pressures and contact areas of 3D Finite Element model of both knee prostheses.**

***Index Terms*—Finite Element Analysis, posterior stabilized total knee arthroplasty, kneeling**

I. Introduction

Kneeling is an activity which frequently do in daily life. It is related to occupational, religious, and individual recreational activities. [1]-[3] Therefore, the knee needs high range of motion and endurance in common activities [2]. Referring to the patients who suffer from severe osteoarthritis, the patients requires medication and surgery such as total knee arthroplasty. After receiving knee implant, patient always question about what activity should be avoided after receiving knee implant for prolong use. One of the activities is kneeling [4]. It could cause damage or failure to knee implant. The biomechanics is important and necessary for knee implant. For the example, the range of motions or the kinetics while using knee implant. According to the research found that kneeling position increase contact pressure of tibiofemoral joint on knee implant [5]. The pressure contact surface between femoral part and polyethylene part of knee implant affect the durability of knee implant. Therefore, durability and biomechanics of knee implant should be considered in the designing process of the knee implant [6], [7]. Therefore, Finite Element Analysis (FEA) is the method that aids to analyze the biomechanics on different designs of knee prostheses [3], [8]. However, the effect of pressure contact on tibiofemoral joint after receiving total knee arthroplasty is unknown. The study of this research was to identify the biomechanics of commercial total knee arthroplasty in kneeling position by Finite Element Analysis.

II. Method

First of all, preparing a real model of posterior stabilized total knee arthroplasty which is LPS-flex of Zimmer and Genesis II of Smith & Nephew. Subsequently, making 3D models of posterior stabilized total knee arthroplasty were used by laser scanner. Laser scanner machine in Fig. 1 is a three dimensional scanner that uses non-contact laser method which generates a 3D model in simulation. The scanning method uses rotational scan technique and planar scan technique to scan the knee implant (LPX-Flex and Genesis II). The resolution of scanning method is 0.2 mm. Using small resolution while scanning helps to improve the accuracy of the 3D model of the knee implant.

Figure 1. The scanner machine - PICZA 3D laser scanner LPX-60.

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After making a 3D model, using Finite Element Analysis program to analyze biomechanics of the 3D Finite Element model of posterior stabilized total knee arthroplasty by ABAQUS FEA software. At the beginning of the analysis, it requires to set material properties of femoral and polyethylene components of the 3D Finite Element. In the Finite Element Analysis, set the material property of femoral component is cobalt chromium molybdenum alloy and polyethylene which is ultrahigh molecular weight polyethylene. Subsequently, set value of Poisson's ratio and Young's modulus of femoral component are 0.3 and 210,000 MPa [9]-[11]. The value of Poisson's ratio and Young's modulus of polyethylene component are 0.25 and 2,300 MPa [12], [13]. The density of cobalt chromium molybdenum alloy is 8.28 g/cm^3 [11] and ultrahigh molecular weight polyethylene is 0.94 g/cm^3 [14]. From previous Finite Element research, the coefficient of friction between cobalt chromium molybdenum alloy and polyethylene is 0.04 [8], [15], [16].

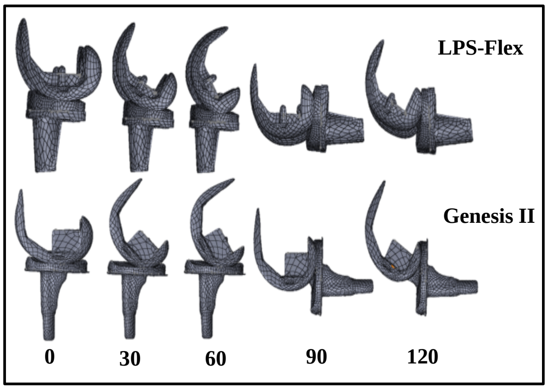

Figure 2. 3D Finite Element models of posterior stabilized total knee arthroplasty of LPX-Flex and Genesis II in 0, 30, 60, 90, and 120 degrees on knee implant flexion

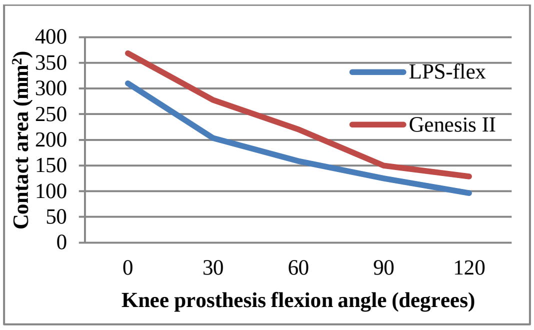

Figure 3. Relationship between contact areas and knee flexion angle of femoral and polyethylene component of LPS-Flex and Genesis II

The angle between femoral part and polyethylene of 3D Finite Element models of posterior stabilized total knee arthroplasty of LPX-Flex and Genesis II in 0, 30, 60, 90, and 120 degrees on knee implant flexion were set by interaction between femoral component axis and tibial component axis. This simulation used tibial axis because of polyethylene part attached with tibial component of knee implant. The several angle in3D model of knee implant of LPS-Flex ana Genesis II is presented in Fig. 2.

In the simulation, using the same force on all simulation models by adding concentrate force pass through the femoral axis on femoral component of all simulation models. The direction of force simulate from the biomechanics of movement from standing position to kneeling position. In consequence, these simulations focus on interaction between femoral component and polyethylene component of both knee implants, focusing on the different effects of stress and contact area in 0, 30, 60, 90, and 120 degrees of knee implant flexion.

III. Result

Joint contact areas between femoral and polyethylene component of both knee implant, LPS-flex of Zimmer and Genesis II of Smith & Nephew, the contact areas on knee implant decreased in response to increasing knee flexion angle. Contact areas of knee flexion angle at 0, 30, 60, 90, and 120 degrees are presented in Fig. 3. The most contact area between femoral component and polyethylene is presented at 0 degree of both knee prostheses. The amount of contact areas at 0 degree of LPS-Flex and Genesis II are 309.786 and 368.68 mm^2. Nevertheless, the fewest contact area is presented at 120 degrees of knee implant flexion by Finite Element Analysis. The amount of contact areas at 120 degrees of LPS-Flex and Genesis II are 96.2699 and 129.027 mm^2. The relationship graph between contact areas and knee implant flexion angle are presented in Fig. 3.

The mean contact pressures (75% average Von Mises Stress) between femoral component and polyethylene component of both knee prostheses increased in changing from knee implant flexion angle. The data of contact pressures are presented in Fig. 4. The largest contact pressure on polyethylene appears at 120 degrees of both knee prostheses. The mean 75% Von Mises Stresses of LPS-Flex and Genesis II are 2.909 and 3.910 MPa. The fewest contact pressures on polyethylene appear at 0 degree of knee implant flexion. The data from Finite Element Method of mean 75% Von Mises Stress on polyethylene component at 0 degree of LPS-Flex and Genesis II are 0.1596 and 0.6389 MPa. The relationship between contact pressures and knee implant flexion angle data are shown in Fig. 4.

The contact area positions and quantities of 75% average Von Mises Stress between femoral component and polyethylene component are different in any degrees of knee implant flexion. The contact area positions on polyethylene of both knee implants initiated at anterior part of polyethylene; when increasing angle of knee implant flexion, the contact areas position shift to posterior part of polyethylene and size of contact areas are decreased. Relationship between contact area and knee flexion angles of both knee implants is presented in Fig. 5 and Fig. 6.

The quantities of 75% average Von Mises Stress are enlarged by increasing angle of knee implant flexion. High stress areas are presented in red and lower stress areas are presented in green area, when increasing knee implant flexion angle in simulations, it increased the amount of red areas (where high stress occurred) on polyethylene component of the knee implant. The contact areas and quantities of 75% average Von Mises Stress are presented in Fig. 5 and Fig. 6.

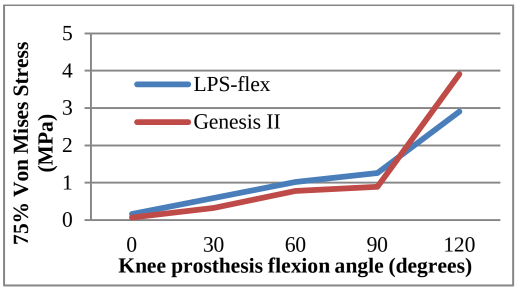

Figure 4. Relationship between 75% Von Mises Stress and knee flexion angle of femoral and polyethylene component of LPS-Flex and Genesis II

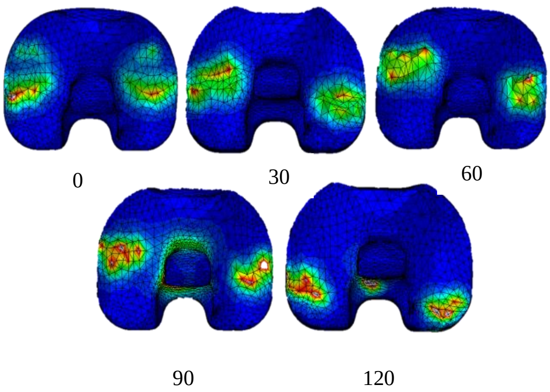

Figure 5. Contact areas on polyethylene part of LPS-Flex at 0, 30, 60, 90, and 120 degrees of knee prostheses flexion

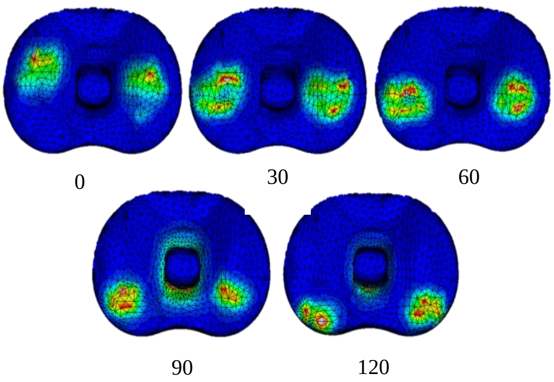

Figure 6. Contact areas on polyethylene part of Genesis II at 0, 30, 60, 90, and 120 degrees of knee prostheses flexion

IV. Discussion

The result of computational Finite Element Analysis on both knee implants (LPS-flex and Genesis II) shows that the average of 75% increased. Von Mises Stress on polyethylene while increasing angle of knee implant flexion. The result also demonstrates the relationship between contact area and contact pressure on polyethylene part of both knee implants while increased angle of knee implant flexion.

The posterior-stabilized total knee arthroplasty designs show a trend of decrease in contact areas with increasing contact pressures. Due to the contact point between femoral component and polyethylene of knee prostheses, while kneeling high percentage of cam of femoral component and post of polyethylene with femoral condylar lift-off [4] occurred. Therefore, increasing angle of knee implant flexion exhibited the decreasing medial and lateral tibiofemoral contact of knee implant on both designs. In consequence, the pressure contact was increased by increasing knee implant flexion angle [17].

The result presented the posterior stabilized total knee arthroplasty cam-spine interaction may receive stresses greater than normal anatomy of knee joint which gives possibility to the cause of early failure to polyethylene. These high forces may occur at tibial spine component. The simulation also shown that the femoral component affect the fracture of tibial spine component according to the clinical reports [18].

From the result, which may suggest the designs of knee implant are important for functional active daily life. The design of knee implant may create the supporting system between femoral cam and tibial spine or set the absorbing system by supporting structures other than the tibial spine [19], [20] or increase conformity of post – cam surface interaction during high flexion of knee implant which affect the functional on knee prostheses [21]-[24].

There are several limitations in this study. First of all, the 3D Finite Element analysis of simulation experiment have complicated mechanical properties and difficult to validate. It is difficult to set simulator experiment as a physiologically knee implant in patient. Furthermore, the 3D Finite Element model should include muscle and ligament forces, because the forces from muscle and ligament around the knee implant may affect the biomechanics of knee implant analysis. The second limitation is that the static simulator experiment at 0, 30, 60, 90, and 120 degrees of knee implant flexion. However, in the active daily life of a patient who has a knee implant should set simulator experiment as dynamic analysis including muscle and ligament forces which may help to improve the result of Finite Element analysis.

V. Conclusion

In conclusion, this study demonstrates the Finite Element Analysis of biomechanics of posterior stabilized total knee arthroplasty in kneeling position of LPS-flex and Genesis II. The largest contact pressure and fewest contact areas on polyethylene of LPS-flex and Genesis II are presented at 120 degrees of both knee prostheses flexion. The fewest contact pressure and the largest contact areas are presented at 0 degree of both knee prostheses flexion. The Finite Element Analysis was an effective method in identifying contact pressures and contact areas of both knee prostheses while kneeling in different angles.

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