

Computational Modelling and Movement Analysis of Hip Joint with Muscles

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Abstract. In this study, the model of hip joint and the main muscles are modelled by finite elements. The parts included in the model are hip joint, hemi pelvis, gluteus maximus, quadratus femoris and gamellus inferior. The materials that used in these model are isotropic elastic, Mooney Rivlin and Neo-hookean. The hip resultant force of the normal gait and stair climbing are applied on the model of hip joint. The responses of displacement, stress and strain of the muscles are then recorded. FEBio non-linear solver for biomechanics is employed to conduct the simulation of the model of hip joint with muscles. The contact interfaces that used in this model are sliding contact and tied contact. From the analysis results, the gluteus maximus has the maximum displacement, stress and strain in the stair climbing. Quadratus femoris and gamellus inferior has the maximum displacement and strain in the normal gait however the maximum stress in the stair climbing. Besides that, the computational model of hip joint with muscles is produced for research and investigation platform. The model can be used as a visualization platform of hip joint.

1. Introduction

Hip joint also known as acetabulofemoral joint which is a joint that located between the femur and acetabulum of the pelvis. Hip joint brings a good mobility to human such as walking, sitting and squatting in life. There are severals of movement of the femur wih the hip joint which is abduction and adduction, flexion and extension, inward and outward rotation. These movements are constrained by ligaments, muscles and bony structure of the hip.

According to Anthony Chila [1], hip joint can require high muscle contraction forces under load conditions. When a combination of ground reaction force and the muscle contraction forces directed into the hip joint, the joint reaction forces are also high relative to the body weight. Joint reaction forces are important in consideration of stresses on the hip joint in replacement.

Muscle, acetabular cup and ligaments are provided translational hip stability. However, muscles are only responsible for rotational stability. The full function of the hip is dependent on the coordination of bones, muscles, tendons, ligaments and nerves. Hence, a hip joint modeling is needed and important to do a comprehensive simulation before it is manufactured for a real joint replacement. The model should consist of bone and muscles.

The purpose of this study was to simulate loaded condition on the model of hip joint with muscles.



2. Literature Review

An initial finding that hip adductors muscles such as adductor longus, adductor brevis, adductor magnus, and gracilis muscles are mostly suffer contusions and strains occurring in the pelvis region has been revealed by Ozkaya and his coworkers in 1991 [2].

Sir John Charnley, a British Orthopaedic surgeon, developed the fundamental principles of the artificial hip. He designed a hip prosthesis in the mid to late 1960's as recorded by Jackson [3]. After the original prosthesis is introduced, several variants of the artificial hip joint have been developed and none have proved to be superior in the clinical setting. The longevity of the Charnley prosthesis appears to be enhanced by the smaller diameter head, which reduces friction and the amount of wear debris produced and results in a lower incidence of acetabular

loosening.[4,5]

Siopack [6] found that there are many early complications and late complications occur after replacing a prosthesis joint. The complications are include fracture in arthroplasties with non-cemented prostheses, nerve injury, dislocation of the femoral head component out of the acetabular socket, wound complications, infections and loosening. From previous study of Kadaba et al, [7], electromyographic studies of tensor fasciae latae and the gluteus medius showed that tendon in normal subjects during the gait cycle and in isolated abduction of the lower limb. Surface electrodes were used in all subject as good correlation had been obtained with fine wire electrodes in four subjects.

According to Gottschalk et al. [8], they propose a new model of the anatomy and function of the glutei, whereby the gluteus medius is a segmented muscle with each part separately innervated and with a phasic action in different directions. This anatomical configuration suggests a different function for each of the three parts rather than a total single muscle action.

For the material properties, Sivasankar and his team's research [9] suggests the general modulus of elasticity, ultimate tensile strength and tensile yield strength of a number materials used for any surgical implants. In soft tissue, it is very difficult to be considered in global models as the used to analyze prostheses and implants because the complexity to the different biological tissues and great amount of non-linearities do the convergence practically unfeasible [10].

Musculoskeletal simulation of human movement commonly use Hill muscle models to predict muscles force. Hill component models represent the active and passive properties of the musculo-tendinous unit [11]. This is consistent with a typical postprocessor display overlays colored contours representing stress levels on the model, showing a full field picture similar to that of photoelastic or moire experimental results found in [12].

Van Leeuwen [13] introduced a muscle model with the behaviour of a muscle can be separated into a passive and an active state. The input parameters for the passive properties are muscle density, Poisson's ratio and the stress-strain relation [14]. The application of boundary conditions in biomechanical FEA is based on assumptions including forces and pressures acting in the human body. The muscle forces acting at the hip joint as well as the hip resultant during normal gait and during stair climbing were extracted from telemetric measurements and corresponding calculations.[4,15-16] Klues research [17] shows the attachment areas of the simulated muscle forces in the FE-model acting at the hip joint.

3. Methodology

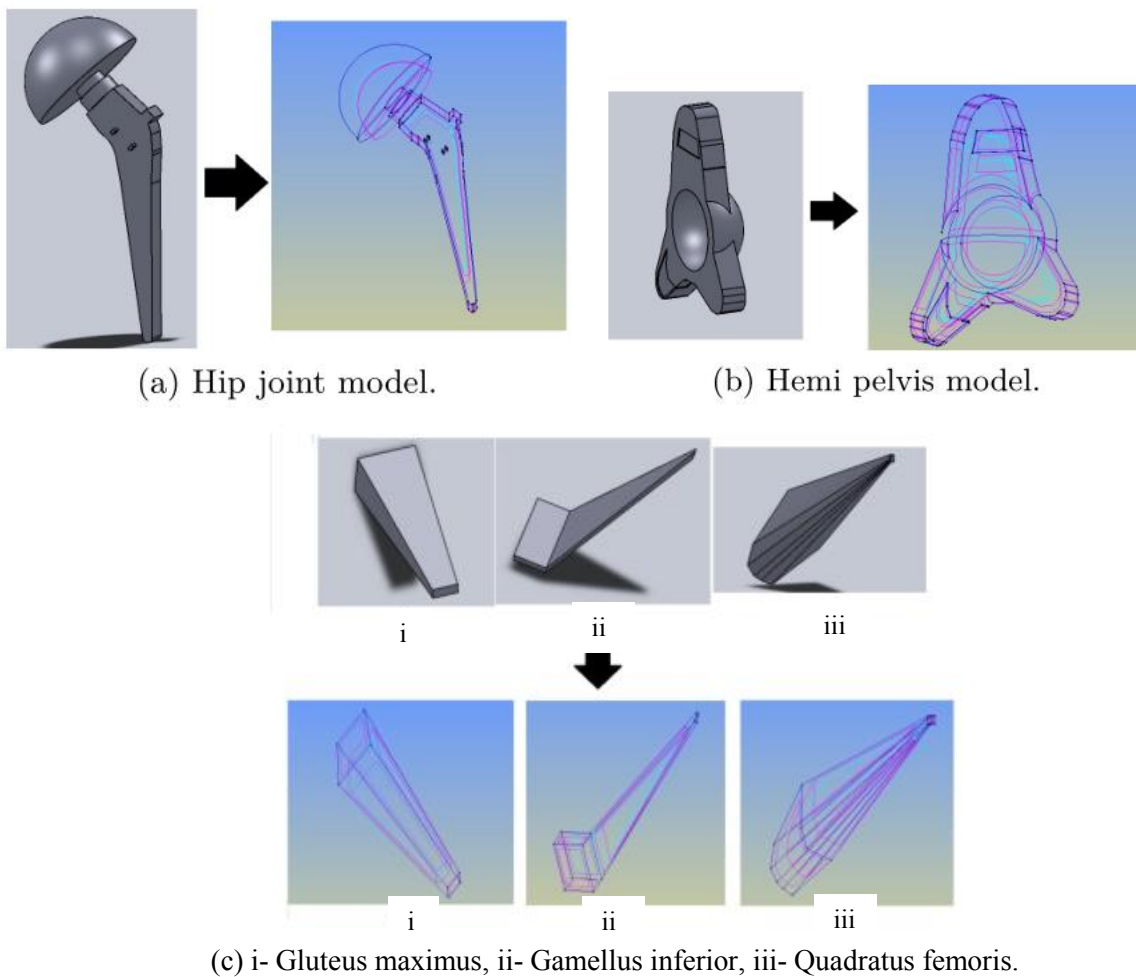
In this research work, the simulation is conducted in FEBio finite element program [18]. FEBio has been verified to be reliable as reported in ref [19]. The hip model and the muscles are firstly drawn in SolidWorks then mesh in GiD [20]. The finite element meshing is then transferred to FeBIO in gmsh format. The material properties used are listed in Table 1.

Table 1: Physical and mechanical properties.

Model	Material	Young's Modulus, E (GPa)	Bulk Modulus, K (GPa)	Density, ρ (Mkg/l)	Poisson's Ratio, ν	Mooney Rivlin Constant, a_{10} (GPa)	Mooney Rivlin Constant, a_{01} (GPa)
Hip joint	Isotropic elastic	110	107.84	4.5×10^{-6}	0.33	-	-
Hemi pelvis	Neo-hookean	12.4	7.38	1.7×10^{-6}	0.22	-	-
Muscles	Mooney Rivlin	0.0012	2	1×10^{-9}	0.4999	10	0

3.1. Geometry Modelling

The finite element modelling started with designing the model of hip joint, hemi pelvis, glutues maximus, quadratus femoris and gamellus inferior in SolidWorks. Since PreView preprocessor in FEBio cannot import file directly from SolidWorks, the model need to be converted in another format (gmsh) in GiD. The hip model and the muscles are shown in Figure 1.

**Figure 1:** Hip joint model with muscles.

3.2. Type of FEM Meshing

The tetrahedral meshing elements were used in the model of hip joint with muscles. The meshed FEM model developed by GiD is shown in Figure 2.

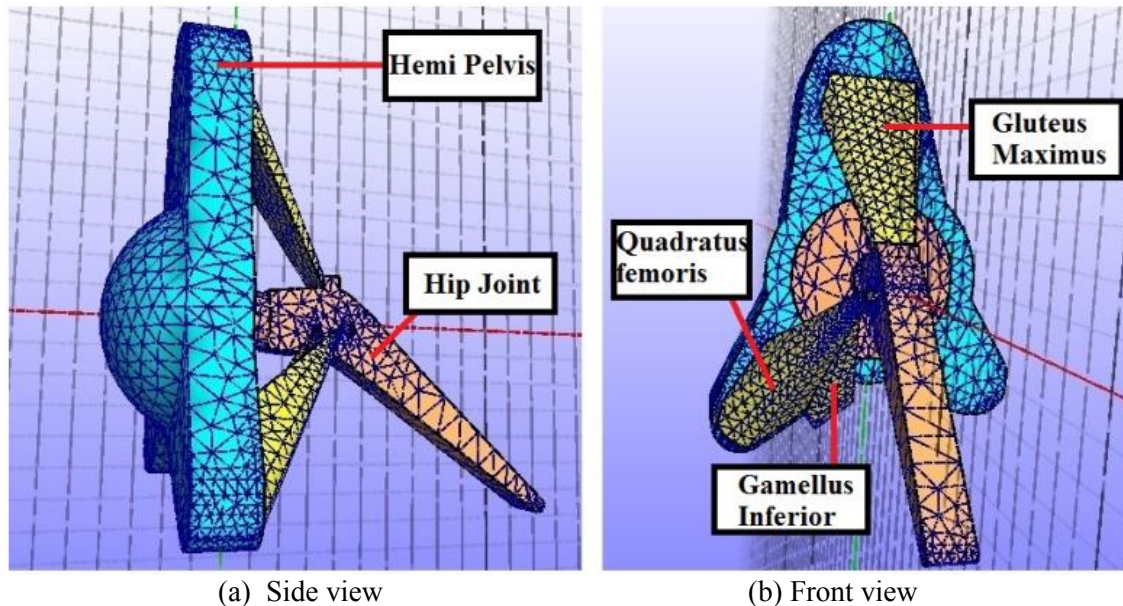


Figure 2: FEM meshing of hip joint model with muscles.

The total nodes and tetrahedral elements for the entire model is depicted in the Table 2.

Table 2: Total nodes and tetrahedral elements of the model.

Model	Total nodes	Total tetrahedral elements
Hip joint	804	2373
Hemi pelvis	2141	6923
Gluteus maximus	244	687
Gamellus inferior	169	436
Quadratus femoris	448	1332

3.3. Type of Interface

There are two types of contact surfaces are involved i.e. sliding contact and tied contact.

Sliding contact is applied to the surface between the hip joint and pelvis and the surface between the gamellus inferior and quadratus femoris with the hip joint when the hip joint is moved in different direction. Tied contact is applied to the contact of the muscles with the hemi pelvis and hip joint model, so it will become a complete modeling hip joint with muscles.

4. Results and Discussion

The muscles are divided into three cases A, B and C, representing for Gluteus maximus, Quadratus femoris and Gamellus inferior, respectively. The summary of the simulation results are documented and compared in Table 3 and Table 4.

The results of the normal gait and stair climbing will be compared and analyzed. Table 3 shows the comparison of the total displacement between normal gait and stair climbing. From the overall graph, the displacement of the muscles for stair climbing is higher than normal gait. For case A, the maximum displacement of the gluteus maximus for normal gait and stair climbing are 9.31mm and 10.45mm. Thus, the gluteus maximus of the stair climbing is stretched more than normal gait. For case B, the maximum displacement of the quadratus femoris for normal gait and stair climbing are 6.21mm and 5.77mm.

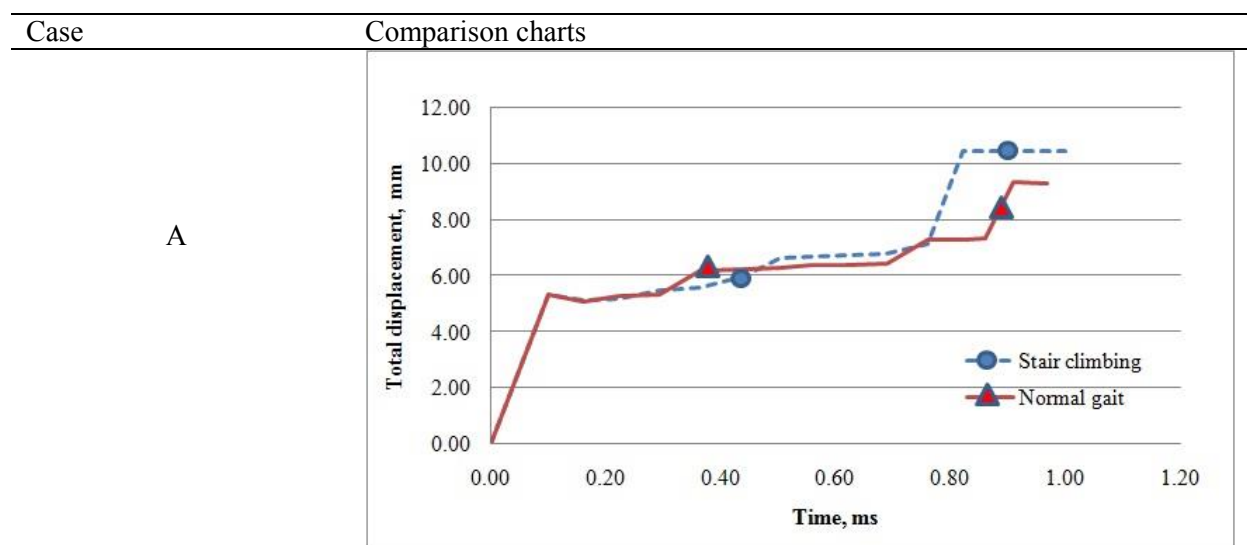
The quadratus femoris of the normal gait is stretched more than stair climbing. For case C, the maximum displacement of the gamellus inferior for normal gait and stair climbing are 8.05mm and 7.66mm. The gamellus inferior of the normal gait is stretched more than stair climbing.

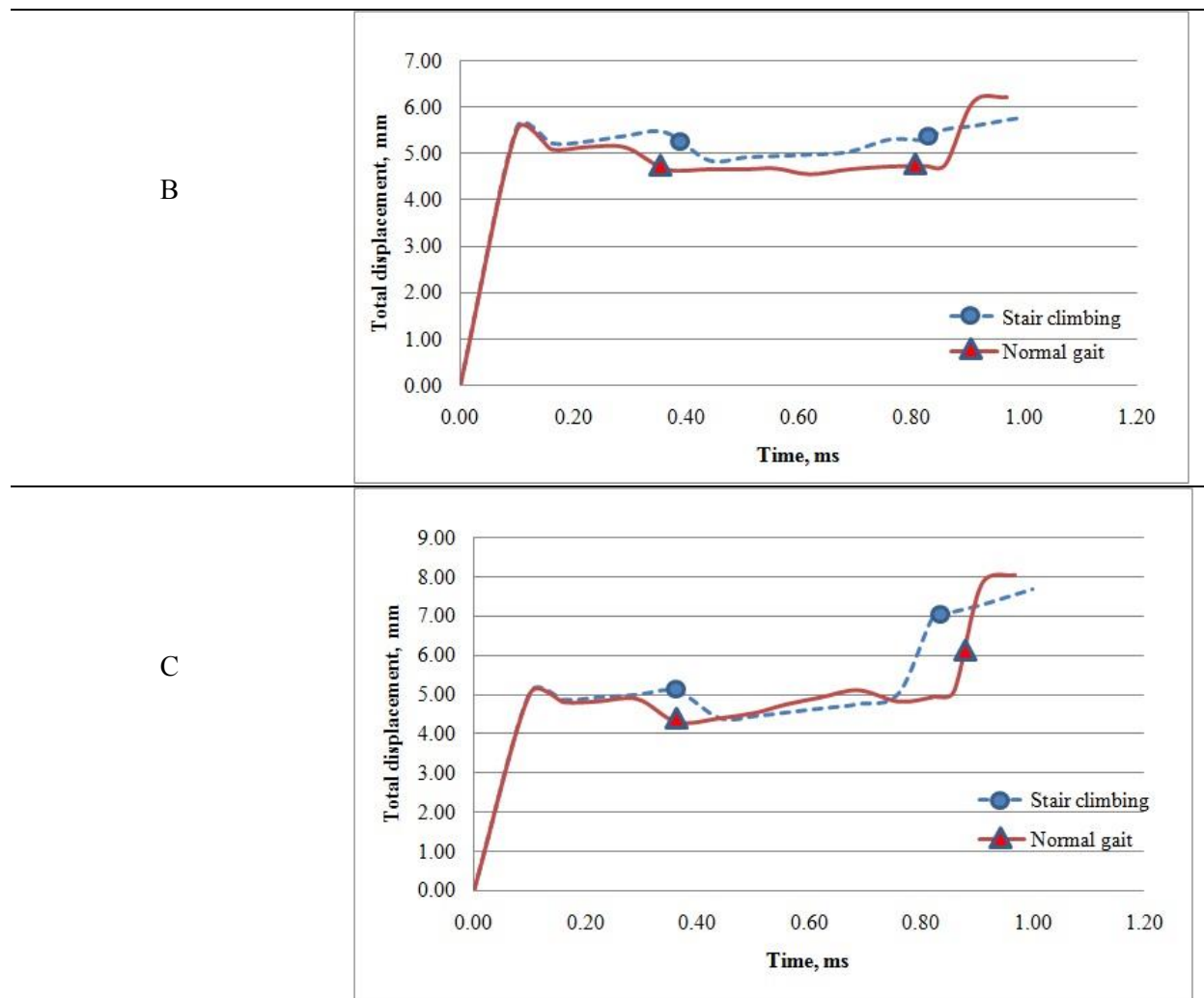
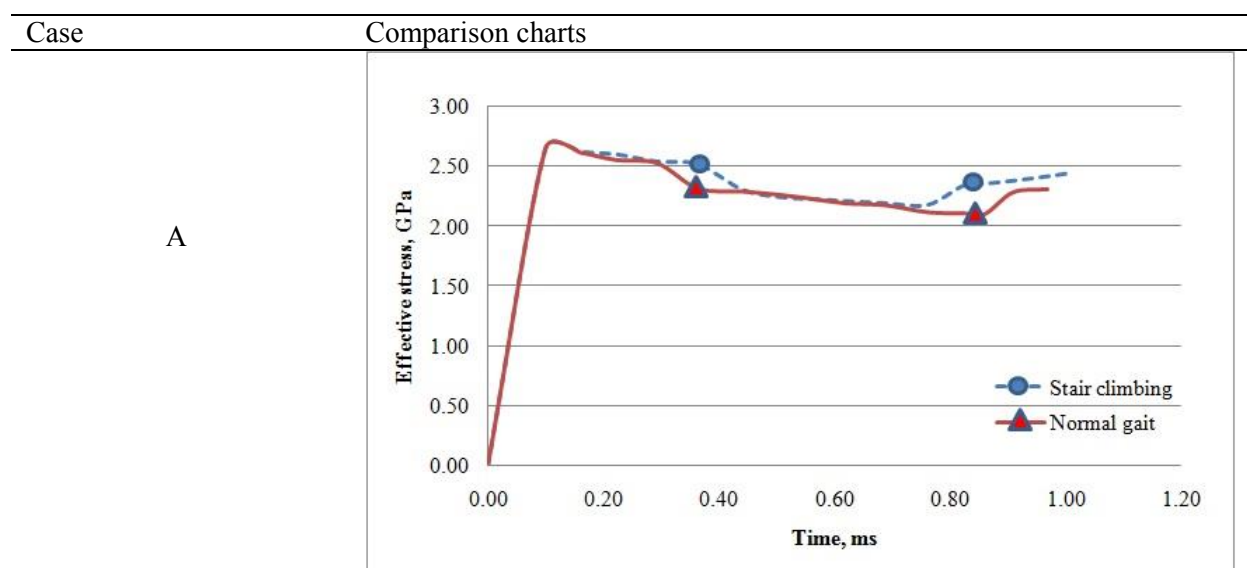
The graph of the effective stress versus time for the normal gait and stair climbing shows in Table 4. The stress of the muscle is low when there is some stretching occurs, so that the muscle can contract and expand easily. For case A, the maximum stress of the normal gait and stair climbing are 2.65GPa and 2.66GPa. For case B, the maximum stress of the normal gait and stair climbing are 6.67GPa and 6.69GPa. For case C, the maximum stress of the normal gait and stair climbing are 9.33GPa and 9.39GPa. From the three cases, the muscles of the stair climbing are more stress than normal gait.

For further improvement, the model of hip joint with muscles can improve by adding more group of muscles such as illiacus, gluteus minimus and gluteus medius to make the model become a complete model. Since hemi pelvis has many free form surfaces and the main investigation of this research is to test the simulation of the computational hip joint with muscles, thus the model of hemi pelvis for this research is using predicted dimension.

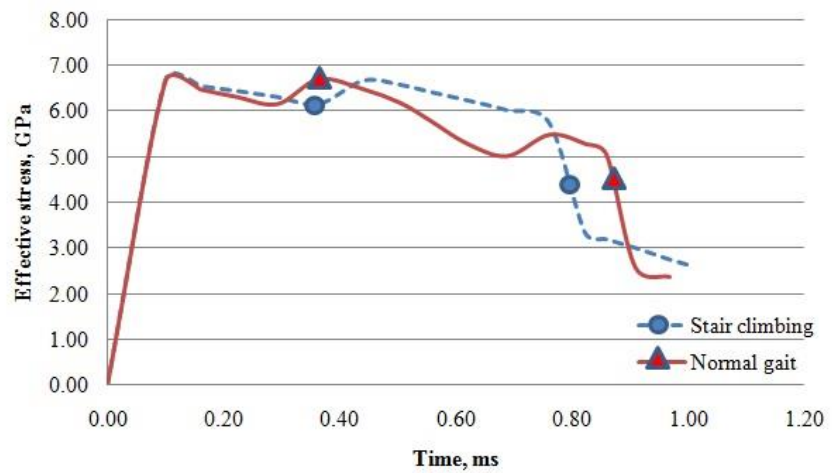
The way to improve the model of hemi pelvis looks more realistic is using 3D scanner to scan the real model of the pelvis to get an accurate results. Besides that, the computational model of hip joint with muscles is used to test the other types of gait pattern such as standing up and down stair to analyzed and get accurate results for the group of muscles.

Table 3: Total displacement versus time off the normal gait and stair climbing in different cases.

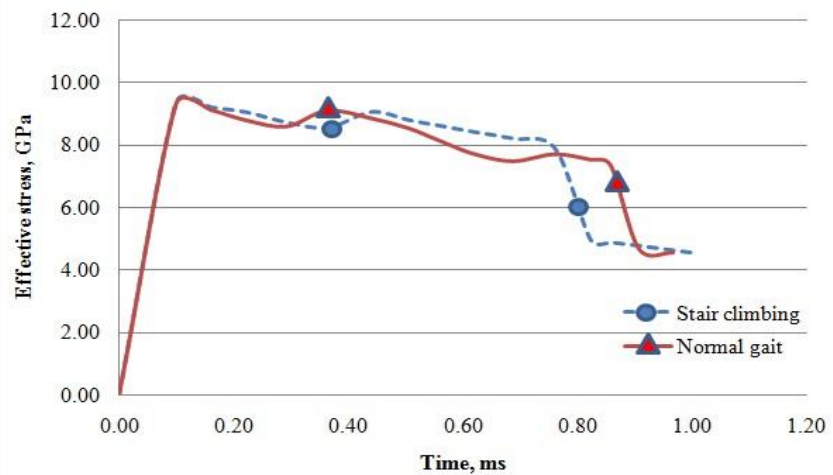


**Table 4:** Effective stress versus time of the normal gait and stair climbing in different cases.

B



C



5. Conclusion

In conclusion, the computational model of hip joint with muscles is produced. The model can be used as a visualization platform of hip joint. The maximum displacement, stress and strain of the muscles that could withstand by the hip joint modeling under loaded condition are obtained.

From the analysis, gluteus maximus shows maximum displacement in the gait pattern of stair climbing. However, the quadratus femoris and gamellus inferior show the maximum displacement in normal gait. The maximum stress is happened in gluteus maximus, quadratus femoris and gamellus inferior, when the model of hip joint with muscles is simulated in the gait pattern of stair climbing. The gluteus maximus has the same maximum strain in the normal gait and stair climbing. The maximum strain of the quadratus femoris and gamellus inferior are occurred in the normal gait.

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