Simulation of human gait for orthotropic model of pelvis-femur set

Antoni John[1] and Mateusz Duda[2]

[1]Department of Strength of Materials and Computational Mechanics, Silesian University of Technology
ul. Konarskiego 18a,44-100 Gliwice, Poland
e-mail: antoni.john@polsl.pl, mateusz.duda@polsl.pl

Abstract

In this paper the method of achieved FEM model corresponding to anatomical and physiological correct state of pelvis-femur set and the results of conducted dynamic analysis are presented. The model is created on the base of CT scans of pelvis and femur specimens, and traditional CAD modelling. The numerical representation of pelvis-femur set consist of linear orthotropic models of materials obtained by using appropriate equations. The dynamic analysis is conducted with boundary conditions mimicking the motion of stance phase of human gait with time-changing muscles' forces acting to pelvis. The influence of different coefficient of friction acting between cartilages on femur head and pelvic acetabulum was examined, too.

Keywords: FEM, CT, pelvis, femur, orthotropic materials, human gait, dynamic analysis, coefficient of friction.

1. Introduction

Nowadays a sedentary way of life is amplified by poor quality of food and watching television instead of doing any sport etc. This conditions are leading to bad state of human body already in early time of life. It may lead to damage of such parts of human body like joints rather in normal condition of functionality, not only in high overloaded states. The reason for such state it could be weakening of bone, cartilage and synovial liquid. Studying the influence of friction on correct work in joint in hip of human body was the reason for conducting investigation in this area. The quality of friction is the effect of acting the synovial liquid in reality. Dynamic analysis of pelvis-femur set, mimicking the human gait with time-changing muscles' forces is presented in this work. The biomechanical objects are one of the most difficult to examine, because of complex construction and conditions of work. This problem was solved by building very complex FEM model. The twenty eight linear orthotropic models of materials represent the heterogeneity of humans bones and one linear model represents the cartilage material [4][5][6][7]. The time-changing muscles' forces were used for accurate mimic of loads in appropriate stage of gait's stance phase [3]. The different values of coefficient of friction simulate the influence of synovial liquid on the work of cooperating surfaces on pelvic acetabulum, femur head and the state of cartilages [1].

2. The method of creating numerical model.

The way of creating numerical model was similar to the one presented in our previous work [1]. The models of bone specimens were created on the basis of CT scans, took with high accuracy (0.347mm). The elements representing the cartilage of femur head and pelvic acetabulum were created manually because of damage of specimens. After building and assembling the CAD models were divided into high value of finite elements. Preparing of the finite element model was the most time consuming stage. The parts of femur and cartilage on femur head as well as pelvis and cartilage on pelvis acetabulum have node connections. The cooperating surfaces representing hip joint are spherical surfaces with the same origin of coordinate system to get the possibility to simulate human's gait. The next step it was to assign material data to each element. The special equations were used at this step [4][5]. The equations for cancellous bone of femur sometimes described material characteristic for pelvis due to lack of appropriate data [5].In this work authors decided to use expressions for lumbar spine instead of the femur's expression. The justification of this approach was found in trials by sampling specific equations to convert the Hounsfield's unit (HU) to properly values of elastic modulus. The expression for femur cortical bone was also used to describe the pelvis cortical bone for the same reason like previous. The Poisson's ratio modulus for all objects and mineral density, Young modulus of cartilage were obtained by comparison data from literature [6][7]. The final results are shown in Table 1.

2.1. Boundary conditions

The twenty three muscles' forces were applied to pelvis to mimic stance phase of human gait according to Thompson M.S work [3]. The stance phase was divided into five stages (Figure 2). The time of movement was established on 0.8s equal the 60% of all time gait phase and the range of motion on 40 degree, -10 degrees from frontal plane into direction of sagittal axis to 30 degrees in opposite direction. These parameters were determined by measurement. The body mass was amount to 75 kg. The force system corresponding to the weight of upper body part acting on pelvic bone was changed into the equivalent force system shown in Figure 1. The quality of synovial liquid was simulated by different value of coefficient of friction between cooperating surfaces on cartilages equalling: 0.003, 0.01. The model of friction was the coulomb stick-slip model which could be chosen in MSC Marc software where analyses were conducted. The degrees of freedom were taken in vertical direction in pubic bone and in connection of pelvis bone with spine.

3. Results

The concentration of stress (Huber-Misses hypothesis) and maximal principal strain on femoral neck could be noticed, what is consent with general distribution forces from upper part of body [6]. It could be reason to femoral neck brakes which are considered for orthopaedists to one of most dangerous, especially for older persons. This type of femur damage very often founds treatment in arthroplasty. The results could be discussed on pelvic acetabulum cartilage example. The maximal

Table 1: Example of results of converting CT data to obtain the value of Young and Kirchhoff modulus. The symbols CF, CP means cartilage on femur head and on pelvic acetabulum respectively. Symbols: HU –Hounsfield's units, E-Young modulus, ρ - density, G – Kirchhoff modulus. The index 1,2,3 below E means directions of axes: 1- medial/lateral (or radial), 2-anterior/posterior (or circumferential), 3- superior/inferior (or longitudinal)

		Example converting data									
		Mineral Density [kg/m^3]	Young modulus [GPa]			Kirchhoff modulus [GPa]			Poisson ratio		
			E_1	E_2	E_3	G_{12}	G_{23}	G_{31}	ν_{12}	ν_{23}	ν_{31}
Pelvis	Max.	2211.65	16.03	15.88	24.82	6.13	4.90	11.09	0.307	0.622	0.119
Femur	Min.	611.15	1.24	1.49	2.41	0.48	0.46	1.08	0.307	0.622	0.119
Cortical bone											
Pelvis	Max.	413.6	0.76	0.53	2.15	0.32	0.22	0.89	0.2	0.2	0.2
Cancellous bone	Min.	108.1	0.07	0.05	0.35	0.03	0.02	0.15	0.2	0.2	0.2
Femur	Max.	451.10	0.87	0.86	1.73	0.36	0.36	0.72	0.2	0.2	0.2
Cancellous bone	Min.	184.35	0.07	0.09	0.214	0.03	0.03	0.11	0.2	0.2	0.2
CF		1000	1.5	1.5	1.5	-	-	-	0.32	0.32	0.32
CP		1000	1.5	1.5	1.5	-	-	-	0.32	0.32	0.32

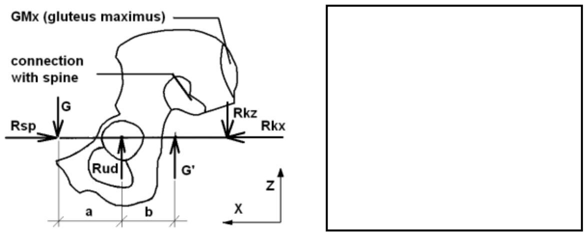

Figure 1: The equivalent force system [2]

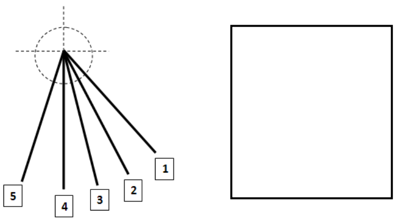

Figure 2: Stages of stance phase of human gait [3]

principal strains were observed during first stage of gait which is the heel strike stage. In this same area the maximal stress were noticed. The stresses' area were occur in pelvis acetabulum during gait, with maximal value in second stage. This could lead to the faster uses and to damaging of pelvis bone. There were not observed any of stress and strains concentration on femur head. The influence of coefficient friction value was significance in strains and stress level. The better value for stress was 0.003, not 0.01 like it was suspected. The value of stress was the lowest in all stages with exceptions of foot flat stage. The level of maximal principal strains was higher for 0.003 coefficient in foot flat stage as well as in stresses' case but also in midstance stage. The difference between coefficient of friction was observed in minimal principal strains. The lower values was for 0.003 in all stages. The areas of concentrations of strains could be observed in upper and frontal part of cartilage. It could be a result like a complex system of femur's motion and force from mass of upper part of body.

4. Discussion

The approach of complex boundary conditions and orthotropic materials' models in dynamic analysis of stance phase of human gait confirmed the predictions shown in the previous work [1]. The influence of coefficient friction on work in human hip joint could be noticed on basis of provided data from analyses. All research will be repeated for hip joint after arthroplasty and compare with conducted investigation in nearly future. It is very important to investigate which parts of femur and pelvis are the most loaded. This information could be very useful to design the prosthesis which will be able to transfer stresses and strains not exposing to damage the hip joint after arthroplasty.

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