International Journal of Computational Bioinformatics and In Silico Modeling
Vol. 3, No. 3 (2014): 393-397
Research Article
Open Access

ISSN: 2320-0634

3D Computer Model of the Hip Joint Cartilage

Magdalena Karczewska*

Gdansk University of Technology, Poland.

*Corresponding author: Magdalena Karczewska; e-mail: mj.karczewska@gmail.com

Received: 06 May 2014 Accepted: 25 May 2014 Online: 28 May 2014

ABSTRACT

This paper presents 3D computer model of the hip joint cartilage in the ANSYS program. Model is made on the basis of anatomy and collected data on the material constants of bone and cartilage components. Analysis and comparison of biochemical model, viscoelastic and molecular mixed - aggregation serves to facilitate the creation of the next model of reality, which could be used in the design of joint prostheses. The correctness of the model was tested in a series of simulations for three different cases in which distinguished 15 variants of the "stickiness - order". The results for one of them is presented in the form of graphs.

Keywords: hip, articular cartilage, a computer model

INTRODUCTION

Over the past 30 years there have been many theoretical models of joint cartilage, but so far none of them have fully reflected the strength properties of the tissue. Several models describe complex heterogeneous mechanical properties, but they do not bind to other complex traits cartilage, ie anisotropy, and non-linearity [1, 2].

In order to create a 3D computer model of articular cartilage following models were analyzed: biochemical, viscoelastic, mixture-based extended and molecular mixed – aggregation. Table 1 compares these models of articular cartilage.

MATERIALS AND METHODS

Prior to the calculation, the geometric model of the hip was adequately parameterized:

- radius of the femoral head,
- thickness of the cartilage,
- load on the joint,
- coefficient of friction of cartilage

and modified (assumed symmetry structures and modeled $^1/_4$ joint). This procedure was designed to facilitate and shorten the time for further work in the ANSYS program.

The individual elements are assigned the appropriate material constants, ie the modulus of elasticity and Poisson's ratio (Table 2).

In addition, a description of the cartilage structures enriched with hydrodynamic friction coefficient, determined from the formula [1]:

$$\mu = \frac{\eta \cdot \frac{V}{\delta} \cdot A}{F} \qquad (1)$$

Where: $\eta - dynamic\ viscosity\ of\ synovial\ fluid\ (3 - 10\ cP)$,

$V - flow\ velocity\ in\ the\ joint\ (0{,}1\ ^m/_s)$,

$\delta - oil\ gap\ width\ (5 \cdot 10^{-7} m)$,

$A - joint\ friction\ surface\ [m^2]$,

$F - load\ of\ the\ hip\ joint\ [N]$

Table 1. A comparative table presented models of articular cartilage [1-3]

Articular cartilage architecture	**Models**			**Biochemical**	**Viscoelastic**	**Mixture –based extended**	**Molecular mixed-agregation**
Solid (collagen and proteoglycans) Anisotropy, depth dependence, nonlinearity and large deformation	**Stres-strain relationship**	Isotropy			✓	✓	✓
		Anisotropy				✓	✓
		Homogeneity			✓	✓	✓
		Heterogeneity				✓	✓
		Linearity			✓	✓	✓
		Nonlinearity				✓	✓
		Small strain			✓	✓	✓
		Large strain					✓
Fluid Anisotropy, depth and strain dependence	**Continuity equation**	Darcy's law[1]				✓	
		Permeability	Constant		✓		
			Strain dependence			✓	✓
			Position dependence				✓
			Isotropy		✓	✓	✓
			Anisotropy	✓		✓	
FCD	**Osmosis**	Effects of stress		✓		✓	✓
		Effects of depth		✓			✓
Total [%]				**18.75**	**37.5**	**75**	**81.25**

[1] **Darcy's law** – experimental linear filtration law expressing the proportionality of the speed of filtration of hydraulic gradient [6].

Table 2. The material constants of cartilage and bone [4, 5].

	Cartilage	Bone
Density [g/cm³]	1	1,92
Young's modulus [GPa]	0,15	20,7
Kirchoff's modulud [GPa]	0,1163	3,14
Poisson's ratio	0,4	0,3
Yield stress [MPa]	40	121
Tensile strength [MPa]	7	130
Compressive strength [MPa]	3,5	160
Thermal conductivity [W/m·K]	0,3	0,3
Specific heat [J/g°C]	1,44	1,44
Damping factor [s]	0,4	-

RESULTS AND DISCUSSION

Simulations were performed for three cases of anatomical size and load of the hip: a man with a mass of 100 kg, a woman weighing 60 kg, child weighing 30 kg.

Each case was considered in terms of loads due to walking, running and extreme physical activity (such as lifting weights). Table 3 presents data on the load of the hip joint according to the cultivated physical activity.

Table 3. The hip joint load depending on the physical activity [1]

	Hip joint load [N]		
Physical activity	Man weighing 100 kg	Woman weighing 60 kg	Child weighing 30 kg
Walking (400% of body weight)	4000	2400	1200
Running (550% of body weight)	5500	3300	1650
Extreme activity (700% of body weight)	7000	4200	2100

Coefficients of cartilage friction dependent the load of the hip joint and synovial fluid viscosity (for values 0.001, 0.003, 0.0065, 0.01 and 0.03 Pa • s), calculated according to the formula 1.

Data :

$$\eta = 0.001\,[Pa\cdot s]$$

$$V = 0.1\,[m/s]$$

$$\delta = 5\cdot 10^{-7}\,[m]$$

$$F = 4000\,[N]$$

$$A = 0.5\cdot(4\cdot\pi\cdot r^2) = 0.0056\,[m^2]$$

for $r = 29mm$, adopted regular geometry of friction surface

Calculations :

$$\mu = \frac{\eta\cdot\frac{V}{\delta}\cdot A}{F} = \frac{0.001\cdot\frac{0.1}{5\cdot 10^{-7}}\cdot 0.0056}{4000} \approx 0{,}0002825$$

For each of the case load data from the simulation is presented in the form of graphs showing the relationship:

- cartilage friction coefficient on the viscosity of synovial fluid (Figure 1),
- a minimum of stress in the hip joint on the viscosity of synovial fluid (Figure 2),
- a maximum stress in the hip joint on the viscosity of synovial fluid (Figure 3),
- a summary of the hip displacements on the viscosity of synovial fluid (Figure 4).

Analyzing example of man weighing 100 kg can be seen the hips in case of overload, ie the overweight, it is important to maintain the proper consistency of the synovial fluid.

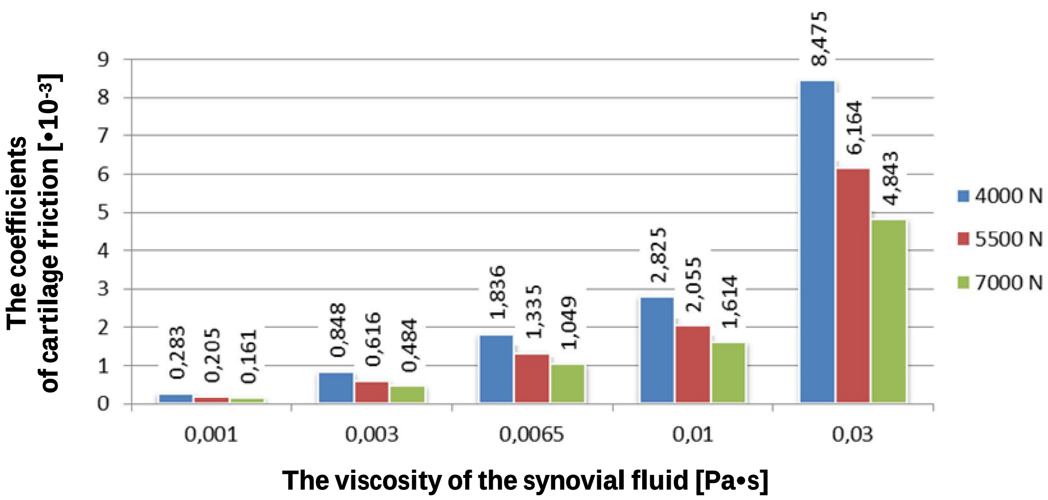

Figure 1. Effect of viscosity of synovial fluid [Pa•s] to the coefficient of friction of cartilage depending on the load of the hip joint for a man weighing 100 kg. The shaded area defines the scope of proper friction coefficient (0.001 - 0.003) [1].

On Figure 1 presented the shaded area with the proper scope of the coefficient of friction (0.001 - 0.003). The coefficients of friction during walking (4000 N load), the speed (5500 N) and extreme overload arthritis (7000 N) occurs when the viscosity of the synovial fluid is contained within the upper limits of the generally accepted standards of care (0.0065 - 0.01 Pa • s).

Figures 2 and 3 illustrate the dependence arising as a result of physical activity minimal / maximal stresses in the joint in relation to the viscosity of synovial fluid. None of the options "viscosity – load" showed alarming changes.

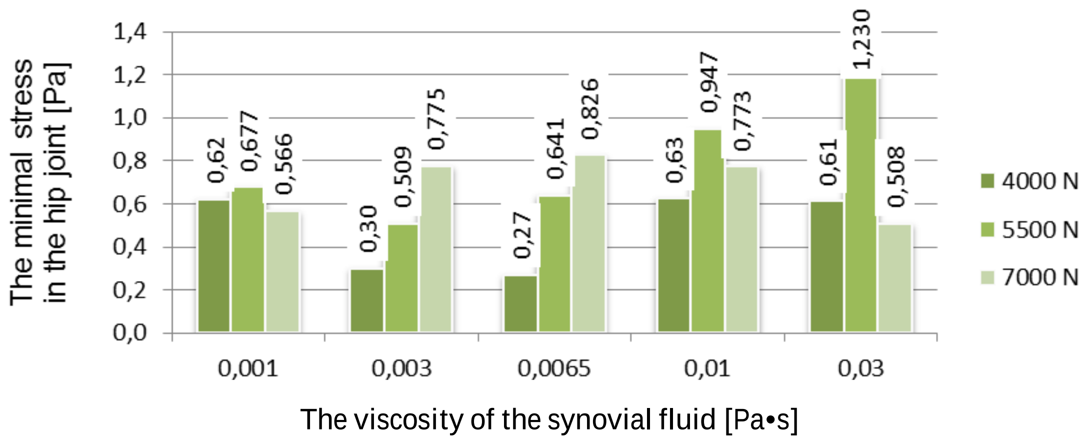

Figure 2. Effect of synovial fluid viscosity [Pa•s] on the minimal stresses [Pa] depending on the load of the hip joint for a man weighing 100 kg [1].

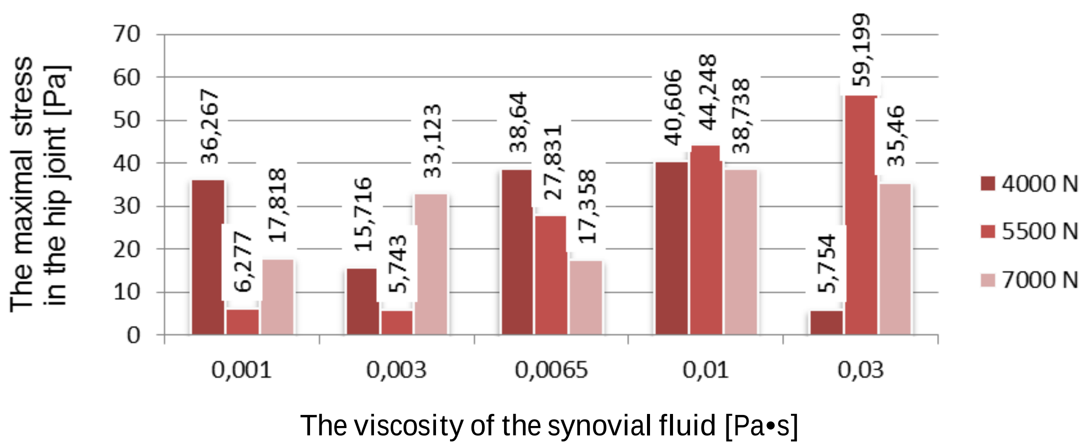

Figure 3. Effect of synovial fluid viscosity [Pa•s] on the maximal stresses [Pa] depending on the load of the hip joint for a man weighing 100 kg [1]

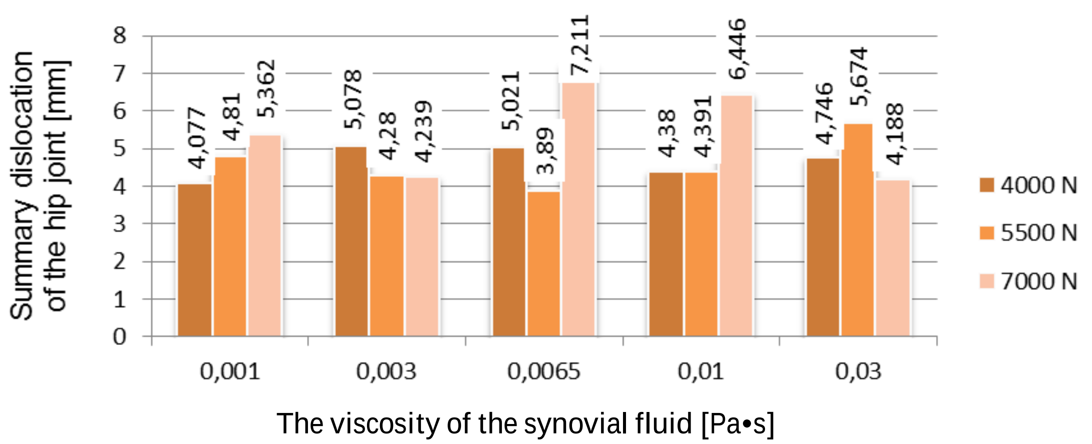

Figure 4. Effect of viscosity of synovial fluid [Pa•s] to summary displacement [mm] of the hip joint man weighing 100 kg, depending on the joint loading [1].

For special attention deserves the Figure 4, showing a summary of the hip dislocation depending on the viscosity of synovial fluid. In each of the options under consideration was observed quite like the structure of the bone deformation (~ 4-7 mm), which if left untreated can lead to serious disturbances in joint biomechanics (eg abarticulation, valgosity).

CONCLUSION

3D computer model of the hip joint, created in ANSYS program, allows to simulate the relative motion of the femoral head in the acetabulum pelvis. To perform the numerical analysis, it is necessary to collect data on the viscosity of synovial fluid, the size of anatomical structures and patients body weight. On this basis it is possible to determine the theoretical coefficient of friction of cartilage surfaces. Universality of the model is achieved by the appropriate parameterization. Thanks to this the simulations can be successfully used both for diagnostic as well as to a certain stage in the design of joint prosthesis (eg, choice of operating characteristics of materials). In medical practice may be particularly important imaging of joint displacements, which in the simplest way allows to understand phenomena of synovial node and predict their effect on bone. This would facilitate to determine the medical orders and perhaps contributed to shorten treatment time and improve the condition of the joint.

REFERENCES

1. Karczewska M.: Biotribological aspects of friction and lubrication of the articular cartilage, Master Thesis, Gdansk University of Technology, 2012
2. Thanh Cong Nguyen: Mathematical modeling of the biomechanical properties of articular cartilage, Australia, 2005
3. Gadomski A, Pawlak Z.: Biotribological and molecular – aggregation aspects of friction and lubrication of the articular cartilage: model in confrontation with the experiment and practical application, Lublin – Poland, 2010
4. Gzik-Zroska B., Tejszerska D., Wolański W.: Stress analysis in funnel chest after stabilization with a plate, Modelling in Engineering 34 (2007), 37-42
5. John A., Wysota P.: Non-linear strenght analysus of the plate stablilizer POLFIX, Modelling in Engineering 33 (2007), 66-72
6. Ecological dictionary: Darcy's law [online]: http://slownik.ekologia.pl/869_Slownik_hydrogeologiczny/6752_7_d_0_Darcy_ego_prawo.html

*****