FINITE ELEMENT ANALYSIS OF HUMAN HIP JOINT

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Introduction

Understanding causes of arthritic disease beginning also depends on exact description and clear definition of mechanical properties of human articular cartilage. This project deals the mathematical modeling of biological tissues, the methodology and realization of experimental measurement of human hyaline cartilage is documented and carried out in vitro. The material characteristics of cartilage are presented on the basis of statistical analysis. The transversal isotropic material was chosen for its mathematical characterization and the constants E_i, G_{ij}, μ_{ij} (i,j=1,2,3) were determined in compliance matrix Sij. These results were used for the finite element submodel of cartilage that was subsequently integrated into the entire model of the human hip joint.

Materials and methods

The specimens for measuring were prepared from the resection caput femoris, see FIG.1.
The donor was a man (age 21, weigth 75 kg, height 180 cm). The specimens had a block shape with these proportions - 2 x 2.5 x 5 mm. They were stored in physiological solution at temperature 5°C.
Before and during the measuring they were preserved in physiological solution at the room teperature (23°C). The specimens were loaded under the stress ranging between 1 - 10 MPa. [1] The orientation system were lines between trochanter major - fovea capitis femoris - crista intertrochanterica see FIG.2.
These material constants were used for FEM submodel of articular cartilage in hip joint [5,6].
The choice of mathematical model was also influenced by experimental measurement results. In our experiment - each measured sample was loaded and unloaded by loading force in several cycles and the liquid was pressed out. For this reason it wasn't necessary to explain the hysteresis effect in first loading cycles and it was also possible to describe the behaviour of measured material by equations of a smal

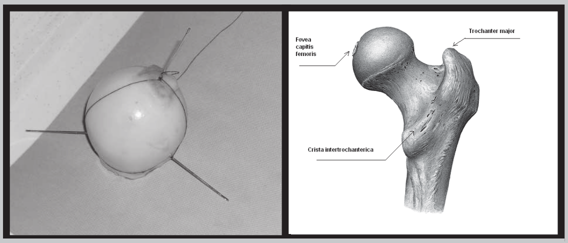

FIG.1,2. The resection caput femoris and proximal femur with the orientation system

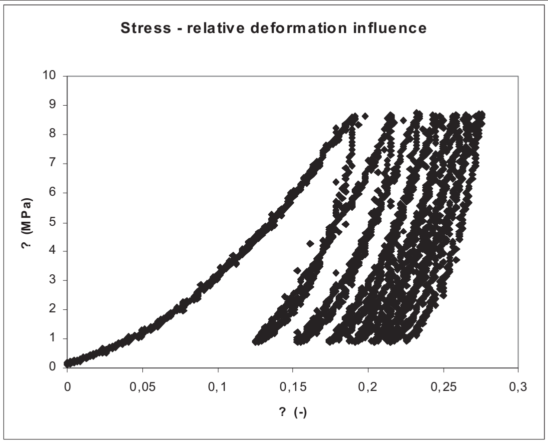

FIG. 3. Loading cycles.

l deformations range (Hooke's law). After several loading cycles (app. 20% of initial dimensions deformation) the behaviour of material became linear, see FIG.3.
The measurements have been carried out in Laboratory of Biomechanics on the Faculty of Mechanical Engineering of the CTU in Prague. The mechanical tests have been carried out on test device MTS 858.2 Mini Bionix. The measured values were elaborated with statistical analysis using programme Statgraphics Plus 3.1.

The mathematical model of transversal isotropic material based on these mechanical tests was performed. These experimantal results were installed into the complience matrix Sij:

$$S_{ij} = \begin{vmatrix} 1/E_1 & -\mu_{21}/E_2 & -\mu_{31}/E_3 & 0 & 0 & 0 \\ -\mu_{21}/E_2 & 1/E_2 & -\mu_{23}/E_3 & 0 & 0 & 0 \\ -\mu_{31}/E_1 & -\mu_{32}/E_2 & 1/E_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{13} & 0 \\ 0 & 0 & 0 & 0 & & 1/G_{12} \end{vmatrix}$$

The resulting values were determined as the arithmetical mean values in each direction. The same principle was used for Poisson`s ratio detemination and the modulus of elasticity in shear was calculated based on equations.

· G23 = E2/2(1+ μ23) = E2/2(1+ μ32) (1.1)
· G12 = E1/2(1+ μ12) = E1/2(1+ μ13) (1.2)

These material constants were used for FEM submodel of articular cartilage in hip joint [5,6].

Results

Failure criterion will be determined by further experimental measurements, for the present σ_p=28 MPa is used [7]. The material characteristics were used for mathematical model of articular cartilage created in FEM programme ABAQUS 6.5, see TABLE 1. The results of this project should be used for identification of the significant causes of damaging and degenerative changes of the cartilage that leads to the immobilization of joint.

E_1	E_2	E_3	G_{12}	G_{32}	μ_{32}	μ_3
[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[-]	[-]
144	**209**	**209**	**56**	**83**	**0,26**	**0,28**

TABLE 1.

Conclusions and discussion

The articular cartilage is a material inhomogeneous and anisotropic [3,4]. This biological material is composed of cells (chondrocytes), intercellular amorphous substance and fibrils [1,2]. These components are very hardly separately measurable. Due to this fact it was necessary to consider this material as a finite element of continuum mechanics.
Monitoring the behavior of this material with the help of modern experimental method together with current computational software products could bring answer on causes of beginning of arthritic damage of joint.

Acknowledgements

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FINITE ELEMENT ANALYSES OF MODULAR KNEE JOINT REPLACEMENT

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Introduction

In this work I summarize the up to now progress in a development of a FE model of a knee after a total knee replacement (TKR) operation. Two of them are very simplified and the last one, quite complex but without a soft tissue, is now prepared and introduces only as a geometric model. This problem leads to a dynamic analysis containing in its final version aside all three articulating bones and its replacements also simplified models of main muscles and ligaments.

Methods

Stress analysis of human joints with a FE code is a useful tool especially for a verification of (total) joint replacements. Our laboratory tries to develop a complex FE model because we cooperate on an evolution of a modular TKR system called WDM. WDM system is produced in a metal design (Vitalium) and mechanically and clinically tested also in a ceramic one (Zirconia).
All these models are solved with a software Abaqus/CAE. As for the geometrical models of replacements, they are provided by a producer, Walter, a.s. and if necessary, 3D CAD software Unigraphics is used.

Description of FE models

Two main projects were solved until this moment. Both are static and still very simplified compared to the real joint but they were in fact a simulation of laboratory tests. The first [1] one is a simulation of a test which had as its object to find out critical places of the ceramic knee component of the WDM [2].

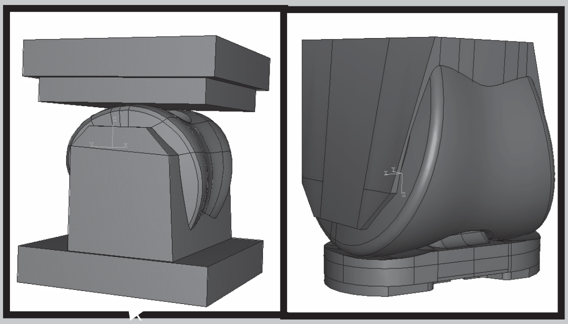

FIG. 1 a, b - Scheme of simple static FE analyses.

The second model [3] serves as pre-test analysis. The aim was to point out all the most loaded areas of a tibial plateau where would be placed a set of four strain gauges to measure deformations of a UHMWPE component. Both models are very similar and in general, they are both static and nonlinear (because of contact formulations), femur is replaced by a simplified homogenous elastic body, tibia and patella are not included. For all the structures, it is supposed that they behave according to an elastic law. For more details, see [1], [3]. All the analysis were performed for a knee in a full extension.

Complex knee joint model

While our laboratory lacks good geometric models of the articulating bones, which are necessary to create an accurate model for the analysis, some corrections had to be made during its preparations. But there is no doubt that several modifications will have to be made before the FE analysis will be carried out. An arrangement of the TKR and also of the bones toward each other in the full flexion hang together with this item.
No bone cement is presented in the problem as well as the patella and all soft tissues. The TKR consists of the femoral part, tibial plateau and its metal base (see. FIG.2).
The problem will solved as a contact static problem (for this instance), 2 tied contacts (bone-implant interfaces) and two penalty contacts - between the TKR components.