Short communication

Finite Element Model Analysis of Coxofemoral Joint Using Composite Materials

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Numerous studies have shown that the geometry of the femur and pelvis affects the distribution of the occurring tensions and movements. The study was performed on the 3D model (three dimensional), of the coxofemoral joint which was achieved through CT images (tomography computer). The results confirmed that the values of tensions and displacements slightly differ from those in the literature due to the geometry and the properties of the used material.

Keywords: finite element analysis, hip joint, mechanical properties, modelling

It is necessary to design more reliable endoprostheses as hip arthroplasty has grown to be one of the most common surgical procedures [1-2].

The bone continually rebuilds its structure depending on the forces exerted. Reducing these forces causes changes to the mass and density of the bone, as it adapts to the new conditions. This change in density of the bone is very dangerous because it may lead to implant loss. To reduce this probability, it must be considered the mechanical behavior of the coxofemoral joint in the designing process of the endoprostheses. This way, the FEM analysis (Finite Element Method), which is made on the endoprosthesis, could have results that are closer to reality [3, 7].

The amount and distribution of the forces acting upon the coxo-femoral joint are different from one person to another because the bone characteristics are influenced by their day to day activities and also the geometry of the bone is different from person to person.

In order to design more reliable endoprostheses, the 3D model of the natural joint must be developed and analyzed with the FEM method. The data retrieved from such analysis are used for running the FEM analysis of the endoprosthesis [4-5].

This study presents a 3D designing process of the coxo-femoral joint by using the properties of the composite materials and the FEM analysis.

Experimental part

Designing the Coxofemoral Joint

Images needed were retrieved from a CT investigation and were processed to remove those that are not needed for a three-dimensional (3D) reconstruction.

The designing process of the 3D model was developed by using the Mimics program. The first step was to select the CT images that represent the anatomical part we were interested in, then set the parameters required for 3D model generation and processing, followed by processing it with the Magics software to reduce the triangles. The last step was to smooth the surfaces and export the 3D model (fig. 1) into the simulation and analysis program.

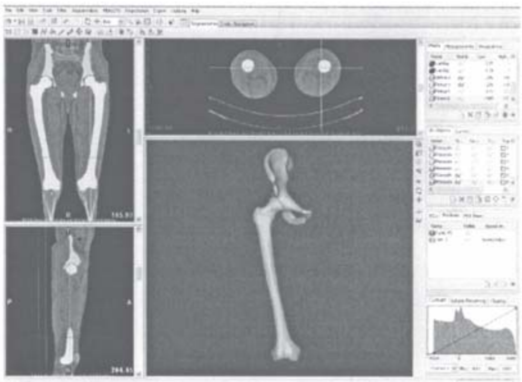

Fig.1. The generated 3D model

Finite Element Model Analysis

The generated 3D model was divided into eight regions as shown in figure 2. Each region was considered homogenous, isotropic and linearly elastic. Properties of the materials corresponding to the used regions, used in FEM analysis, are those presented in table 1 [4, 6].

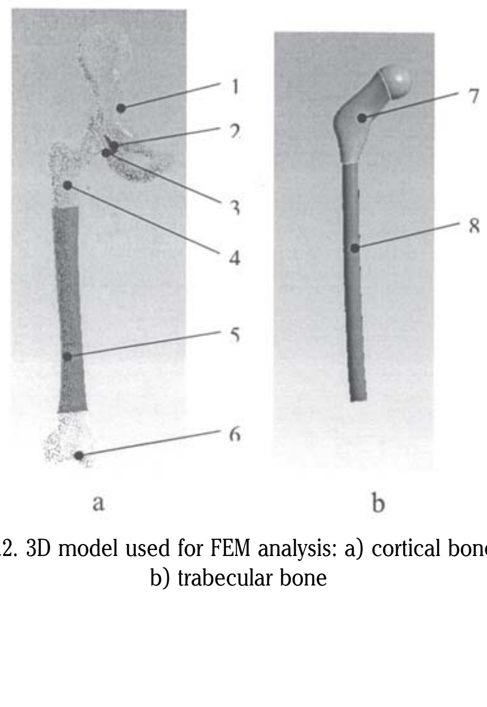

Fig.2. 3D model used for FEM analysis: a) cortical bone, b) trabecular bone

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Table 1
PROPERTIES OF THE MATERIALS USED FOR
FEM ANALYSIS (ADOPTED FROM [4, 6]

Region	Young's modul (MPa)	Poisson	Density (kg/m^3)
1	8000	0.3	1.8*10^{-6}
4	2000	0.3	1.8*10^{-6}
5	1900	0.34	6*10^{-6}
6	1900	0.34	6*10^{-6}
7	600	0.3	1*10^{-6}
8	600	0.3	1*10^{-6}
2	15	0.45	1*10^{-6}
3	15	0.45	1*10^{-6}

The mesh contains 107.921 nodes and 57.429 tetraedic elements, the latter having the maximum length of the largest side of 2 mm.

The model was loaded with a force of 1954 N positioned at 10° in the frontal plane and a force of 1300 N which is the force of the abductor muscles. The values of the forces were calculated using the formulas from [8].

In terms of constraints, pelvic displacement was allowed in the sagittal plane whereas the distal part of the femur was firm. A sliding motion was permitted between the surfaces of the cartilages, but no leaving was involved. These conditions correspond to the position of walking monopodal support (fig.3.) [4].

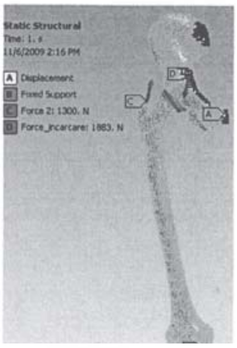

Fig. 3. Conditions of the FEM analysis

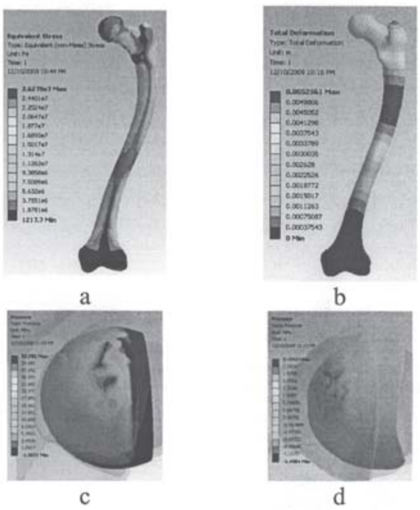

Fig.4. Results: a) equivalent tensions that appeared in the femur, b) total deformation that occurred in the femur, c) the pressure exerted on the cartilage of the femoral head, d) the pressure exerted on the femoral head

Results and discussions

The results of the FEM analysis presented in figure 4 illustrate the distribution of the equivalent tensions and total movements in the femoral in the head, cervix and diaphysis. The pressures that occur in the femoral head and associated cartilage are also presented.

These results show that the value of the equivalent tensions is about 23 MPa, the maximum total strain is 5 mm, the maximum pressure exerted on the cartilage of the femur is about 32 MPa and 2.4 MPa for the femoral head.

From figure 4 it can be observed that the values of the equivalent tensions and of the total strains are very high in the proximal femur.

Considering these results, one can argue that in order to design a personalized hip endoprosthesis it is advisable to perform a FEM analysis of the natural joint of the patient following the steps shown in this study. Thus, by using this data for the FEM analysis of the custom designed endoprosthesis, it is a clear fact that revision surgery may occur much later or not at all.

Conclusions

This study presents solutions about the conditions and materials (their properties) used for the FEM analysis and about the design of the 3D model of the joint.

The 3D model and the results of the analysis presented will be used in the FEM analysis of a set of three custom endoprostheses that are going to be designed.

The FEM analysis presented is helpful because it provides knowledge about the distribution of the equivalent tensions and total strains that occur in the joint of the patient.

Further studies are required in order to increase the reliability of the results, even if they involve a lot of time, highly efficient computers and last, but not least, CT investigations.

In the future, a set of 3 custom prostheses using the data and the 3D model presented in this study is to be designed. The necessary FEM analysis will be performed in order to decide which of these endoprostheses is more appropriate for the patient.

The subject was also studied by other researchers [9, 10].

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