STATIC FINITE ELEMENT ANALYSIS OF LOWER LIMB

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Abstract

This paper deals with a simulation by means of finite element method of a natural lower limb after a knee joint arthroplasty in a full extension. Our last static model serving as a starting point for our future dynamic analysis is presented now. Aside a total knee endoprosthesis Medin Modulár provided by MedinOrthopedics, a.s., two long bones, femur and tibia were used. Compared with our former results, this model gives reduced stress and contact pressures values which were given by more realistic ankle and hip joint definition. Their distributions also correspond better the experimental findings.

[Engineering of Biomaterials, 63-64, (2007), 6-7]

Introduction

In this paper we publish our last finite element model dealing with a total knee joint replacement under a load in a full extension (a one leg stance). It follows our previous published research [1-3].

Finite element (FE) is commonly used in mechanics but in biomechanics, using FEA means to undergo many compromises and simplifications. All these simplifications have to be reasonable and must take into account as many tissue characteristics as possible. With respect to this fact we are trying to set up a valuable finite element analysis serving for total knee joint development and verification. A next step is already to introduce a dynamic model driven by forces in main lower extremity muscles.

As for the presented work, some differences between the former and the current model are evident. The first one is a replacement size and the second one is changes in boundary conditions. These modifications are necessary due to our goal to create a complex model of a lower limb with the implanted total knee replacement [4]. This complex model would serve to analyze the current knee replacements and also to keep on development of zirconia femoral component already designed, implanted and tested (even *in vivo* experiences have been made) [5].

Materials and methods

For our nonlinear static analyses, solved in Abaqus CAE, a size 76 of a knee endoprosthesis Medin Modulár (produced by Medin Orthopedics, a.s.) have been chosen to fit the best a femoral and a tibial bone of a male cadaver reconstructed from CT scans provided by a National Library of Medicine, Visible Human Project [4,6]. For future analyses we also implemented into the model a pelvic bone. It has been taken from a model library of the BEL Repository, managed by the Istituti Ortopedici Rizzoli, Bologna, Italy [7]. The collected model served for designing the mechanical axis of the leg. It was positioned regarding positions of several anatomic points (FIG.1). This assembly served for a mesh generation in presented model.

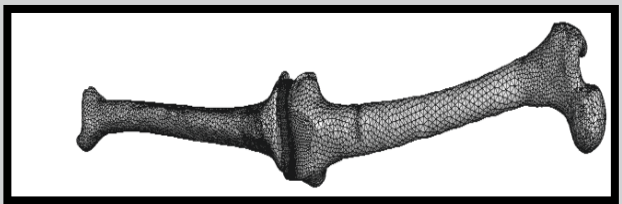

FIG.1. Lower limb geometric model.

The Medin Modulár endoprosthesis itself is made up of several parts to cover several operation demands but for our model we used only its three main components, i.e. a metal femoral component and a tibial component, which consists of a plastic tibial plateau and a metal tibial tray (FIG.2).

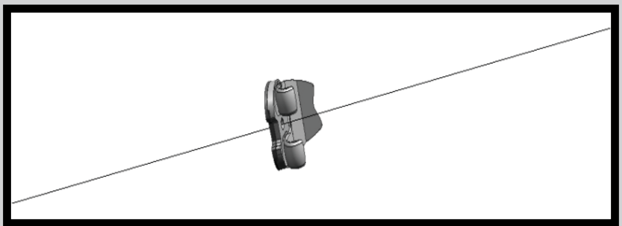

FIG.2. Analyzed assembly of the TKR.

Position of the TKR on the corresponding bones has been made on the basis of the formerly designed mechanical axis. We respected producer's recommendations to a surgeon concerning an endoprosthesis implantation which arise in fact from the mechanical axis direction.

Having already the replacement well positioned on the mechanical axis as well as on the bones we used the mechanical axis for a load application.

Despite of some mechanical tests made in our laboratory with all common materials used for the TKR production, former isotropic homogenous material models remain the same as before [1-3] in order to be able to see the difference between the analyses results (TABLE 1). The metal components behave according to Hook's low; the tibial plateau is defined as an ideal elasto-plastic material.

As mentioned above, some changes were applied in case of boundary conditions. The main modification compared to previous models is a use of so called reference points which were placed approx. in centers of a hip joint and an ankle, lying on the mechanical axis. These points allowed a more realistic definition of boundary conditions. Aside the proximal-distal shift allowed already in former models, there was allowed the rotation of the femoral component around the anterio-posterial axis going through the reference point in the center of the femoral head and the rotation around the mechanical axis, the tibial component could rotate around the mediolateral axis defined in the center of the ankle. Since there were not yet implemented muscles and ligaments into the current FE analysis, the mechanical axis (represented by both reference points defined on its proximal and lateral end) served also for a load direction definition; the force of 2100 N was applied in a center of a "femoral head", in the reference point in fact, already specified.

There was defined only one contact in the analysis. Between the both articulating parts of the knee joint replacement the contact was solved as a "hard-contact" with a coefficient of friction equaled to 0.1. There was defined in fact another contact; it was the one between the tibial plateau and the tibial tray which was supposed to be a tied contact.

Entity	Young's modulus / elasto-plastic model definition [MPa] / [MPa] [%]	Poisson's ratio
Femoral component	113000	0,342
Tibial plateau	820/σ=21..ε=0, σ=35...ε=3	0,44
Tibial tray	113000	0,342
Bones	14000	0,36

TABLE 1. Material properties.

A mash was created semi-automatically using tetrahedral elements. See a FIGURE 3 for detailed view of the TKR assembly.

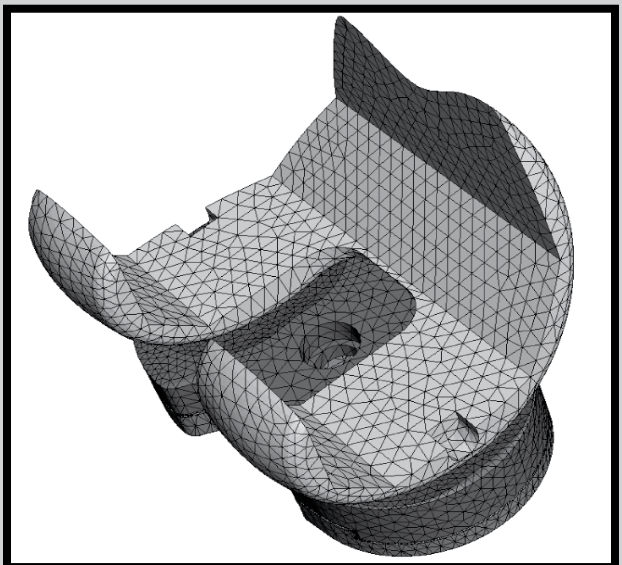

FIG.3. Detailed view of the mesh of the TKR assembly.

Results

As the weakest part of the endoprosthesis using UH-MWPE plateau is the plateau itself, only results for a tibial plateau are published; it means contact pressure between tibial and femoral component and stress field on the plateau are presented. Magnitudes of contact pressures and stresses and even their distributions can significantly change a lifespan of the replacement.

Firstly, the contact pressure results between a femoral and a tibial component can be seen in the FIG.4. As for a magnitude, maximum value of approx. 46 MPa occurred on a medial side. The value corresponds with our experimental findings (using special contact films). In comparison to our former analyses, this magnitude is lower due to different boundary conditions matching better the reality.

In the matter of stress values and distributions (FIG.5), the highest value (28.5 MPa), slightly under the contact surface, was calculated under an impact of a lateral condyle, but as well as for the contact stress there is not a big difference between the results on the lateral and the medial side. The maximal values on both condyles are slightly under the contact surface.

At first glance, the contact area which occurred on the medial side of the lateral condyle could seem quite strange but a specially designed shape of the contact surface in this region (as well as the lateral area of the medial condyle) serves for better stabilization of the artificial knee lacking some important natural ligamentous stabilizers.

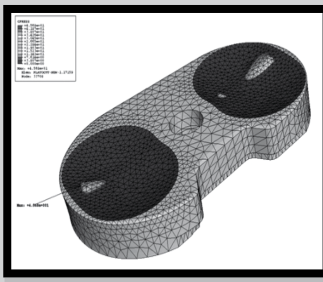

FIG.4. Contact pressure results between the femoral component and the tibial plateau [MPa].

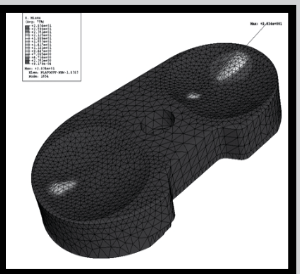

FIG.5. Stress distribution (HMH) on the surface.

Conclusions

Since Laboratory of Biomechanics participates among others on a development of a zirconia knee joint endoprosthesis, already constructed and even implanted, our aim is to introduce a valuable complex lower limb model serving for farther innovation of this implant.

Main advantages of a presented model are obvious. Since there are not yet any muscles and ligaments in the model, simplified model showed the right choice of a use of a mechanical axis for boundary condition definitions. A femoral and a tibial part could move around the corresponding reference points defined on both ends of the axis independently. These findings will be useful soon as well as results of the presented analysis. Dynamic model of the lower limb, taking into account the influence of muscles and ligaments is being prepared and it will be compared with these simpler models. In our opinion, no relevant comparison of the finite element analysis (FEA) results could be done with other authors analyzing the knee endoprosthesis by means of the FEA because of different design of the replacements.

Acknowledgements

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