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MUSCLE UNBALANCE INFLUENCE TO HIP IMPLANT MIGRATION

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Summary: *In general all orthopaedic operations may cause the change of muscle balance. This unbalance various not only range of movement but also the loading vector during the movement. In case of hemiarthroplasty when the new joint is created by femoral replacement and intact acetabulum could be the unbalance very dangerous. Migration of the implant head after hemiarthoplasty is the problem which is observed to nearly at all patients. Muscle unbalance and shape of acetabulum are the two main problems solved by numerical analysis of hip joint FE model. The paper deals with numerical analysis of hip joint surgery that effects changes of acetabulum stress field and implant migration in acetabulum area. Pelvic bone geometry was obtained from computer tomography by semi-automatic generation. The numerical analysis compares shapes and peak values of stress field in acetabulum area. Ultimate values of first principal stress, third principal stress and total displacements were used as reference magnitudes and confront with after-surgery exploration.*

1. Introduction

In spite of the fact that new designs of replacements are developed every year, manufacturing technologies are advancing, new materials are emerging and surgical methods are improving as well, the optimal hip joint replacement has not been designed. Finite element (FE) models have now become the most widely used numerical tool for use in the field of computational biomechanics where the regions of interests represent very complicated structures, usually inner organs. The stress analysis of a new type of an implant is one of the most common problems solved in biomechanics is, particularly assessment of its influence on the stress state in the respective tissues. It is necessary to construct detailed mathematical models of selected part of human system. As convenient source of data for the model creation, Computer Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound (US) techniques are used.

Hip hemiarthroplasty or arthroplasty, is a surgical procedure in which the diseased parts of the hip joint are removed and replaced with new artificial parts. The goals of hip hemiarthroplasty surgery are to improve mobility by relieving pain and improve function of the hip joint. The hip is essentially a ball and socket joint, linking the "ball" at the head of the femur with the cup-shaped "socket" in the pelvic bone. If the surgery is a "hemiarthroplasty," the only bone replaced with a prosthetic device is the head of the femur. The most common reason why

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people have hip hemiarthroplasty operation is the wearing down of the hip joint that results from osteoarthritis. Other conditions, such as rheumatoid arthritis, necrosis, injury, and bone tumors also may lead to breakdown of the hip joint and the need for hip replacement operation.

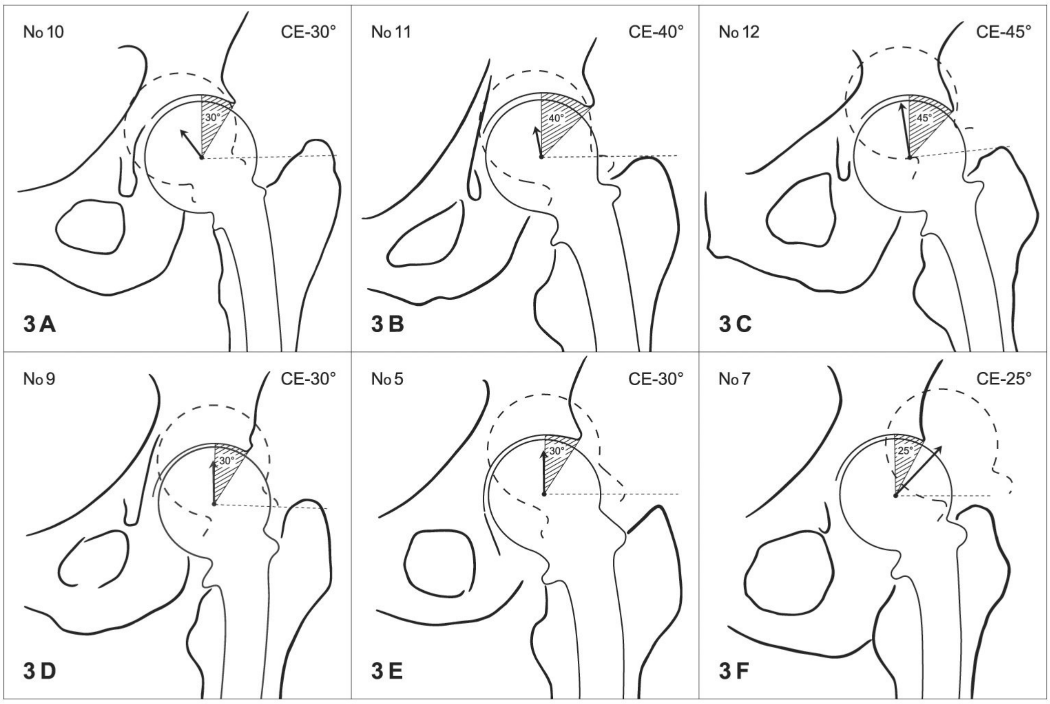

Fig. 1: Six different clinically observed migration

The greatest problem of the hemiarthroplasty is migration of the replacement head which is observable after couple of months in all cases of after-surgery patients (Bartoníček J. 2003) . There are two dominant directions of the replacement head migration: median migration into pelvis minor or migration in acetabular lumbrum direction. These migration directions are represented in [Fig. 1]. The aim of this work is to analyse the migration of the replacement head in pelvic bone under various types of loading.

2. Experiment

The bone material for the experiments was obtained from cadavers. We had several samples of cancellous bone from the pelvic bone of relatively old patients. Tensile test in combination with optical identification method were used to gain material properties of cancellous bone. Drill out testing samples with diameter three to five millimetres and length minimally eighteen millimetres, sized and gum in holders were tested by Instron 3382 loading machine. Second testing device was Nicon high resolution camera. It is required using holders not to crack the sample by jaws. Optical identification method is based on spot centers detection for strain. From measuring out data we were able to obtain stress-strain curve and modulus of elasticity. Technique of bone testing is described in detail in (Kytýř, D. 2006).

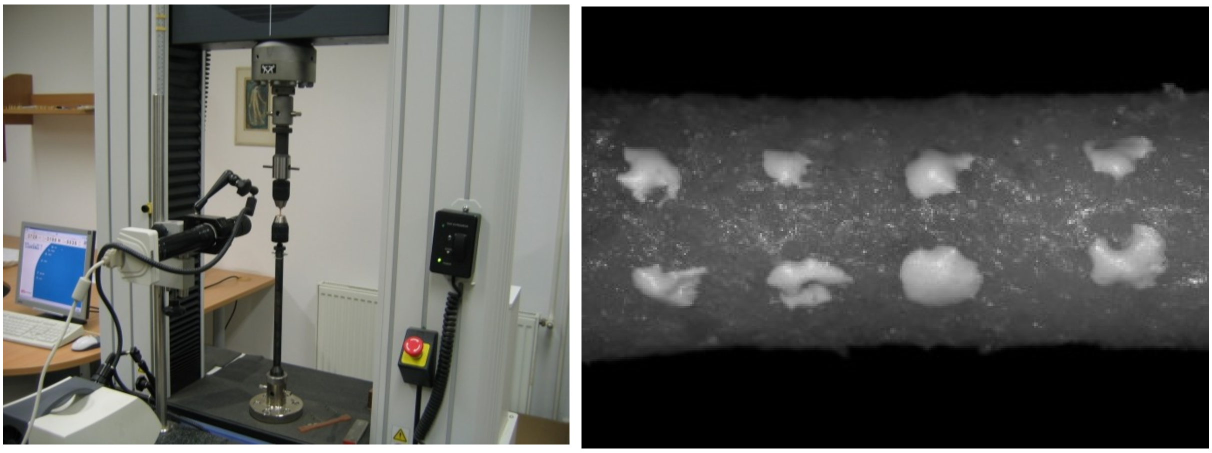

Fig. 2. Experimental set up & detail of testing sample

3. Materials

There are two materials in this simplified model. Steel inplant head was defined using rigid material, pelvic bone using nonlinear foam material model with crushable elements. Loading curve [Fig 3], which was used to define material properties of the cancellous bone, were taken from literature (An, Y.H., 2000) and validated by experiments. Range of material characteristics is wide, material with lower value of Young modulus was chosen for the model to get the most unsfavourable situation.

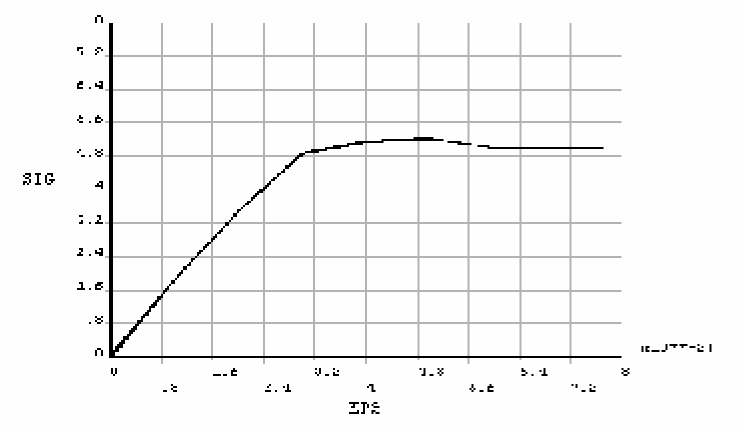

Fig 3: Stress-strain curve of cancellous bone

4. Models

There are volumetric models used for analysis. Pelvic bone geometry was obtained from computer tomography by semi-automatic generation in two basic steps. The first step was tissue segmentation by thresholding in each scan. The second step was surface mesh definition. Factors, which could have influence to the migration are considered as parametrical inputs. The main factors which may influence the migration of the implant is the direction of loading force. Boundary conditions were represented by fixation of all surface within the area close to acetabulum. The loading of the acetabulum is modelled by assigning acceleration to the mass steel replacement head. Loading resultant intersect the centre of gravity of the replacement head. The plane of interest of the model is 19° inclined from the frontal plane. Model was solved in various loading direction. This loading range is slightly larger than the range of physiological loading.

5. Method

Modelling and all simulations are carried out using LS-DYNA, part of ANSYS FE package for an explicit dynamic analysis. The problem was solved as a contact analysis with surface to surface contact. The FE model of the pelvis is symmetrical in the median plane; therefore it is not necessary to model both parts, only right part is used. Elements representing cancellous bone are created using quadratic tetrahedral elements. For simplification were the acetabulum created with the help of Boolean operations in the shape of a regular sphere.

6. Conclusion

The stress and displacement fields showed that primary migration of the replacement head follows the direction of loading. Results showed importance of well-developed acetabulum reducing extreme values of cancellous bone stresses. The way of the artificial femoral implant fitting influences the direction of loading force. When the prosthesis is fitted higher in comparison with the intact head the muscles on lateral side are prestressed and the resultant force is deflected from vertical direction laterally. On the other hand when the replacement head is fixed lower the result is opposite. The head of the hip joint replacement is fixed correctly, when its centre is 1-3 mm under the greater trochanter. Result of this numerical analysis corresponds well with real migration observed clinically.

7. Acknowledgement

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