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INFLUENCE OF THE HIP JOINT SHAPE TO STRESS FIELD AFTER HEMIARTHROPLASTY

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Summary: *Migration of the implant head after hemiarthoplasty is a problem which appertain to nearly all patients. Article deals with development and utilization of parametrical FE model of the hip joint for numerical analysis of implant head migration. There are two main input parameters for the stress analysis. CE angle representing the shape of acetabulum and direction of the femoral replacement loading. To assess the influence of selected parameters on thr implant migration and to enable easy comparison to patients X-Ray scanning, the analysis was carried out as axially symmetric 2D and 3D contact problem. Ultimate values of first principal stress, third principal stress and sum of displacements were used as a reference magnitude.*

1. Introduction

Hip joint replacement is the only way for millions of patients to recover their mobility. 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.

There are two basic surgical methods for hip joint replacement. Total hip joint replacement, which consists of femoral component and acetabular cup or hemiarthroplasty, femoral component only, which article deals with. Hemiarthroplasty is usually used in case of femoral neck fracture of senior patients. In face of global population aging this problem is becoming world-wide important. Hemiarthroplasty is a surgical proccedure of femoral neck and head replacement. The replacement stem is fixed in the femur by special bone cement. Head of the replacement abut against intact acetabulum. Hemiarthroplasty apply to immobile patients or in case of less than five years living prediction.

The biggest problem of the hemiarthroplasty is migration of the replacement head which is observable after couple of month in all cases of after-surgery patients [Bartoníček J. 2005]. There are two dominant directions of the replacement head migration: median migration into

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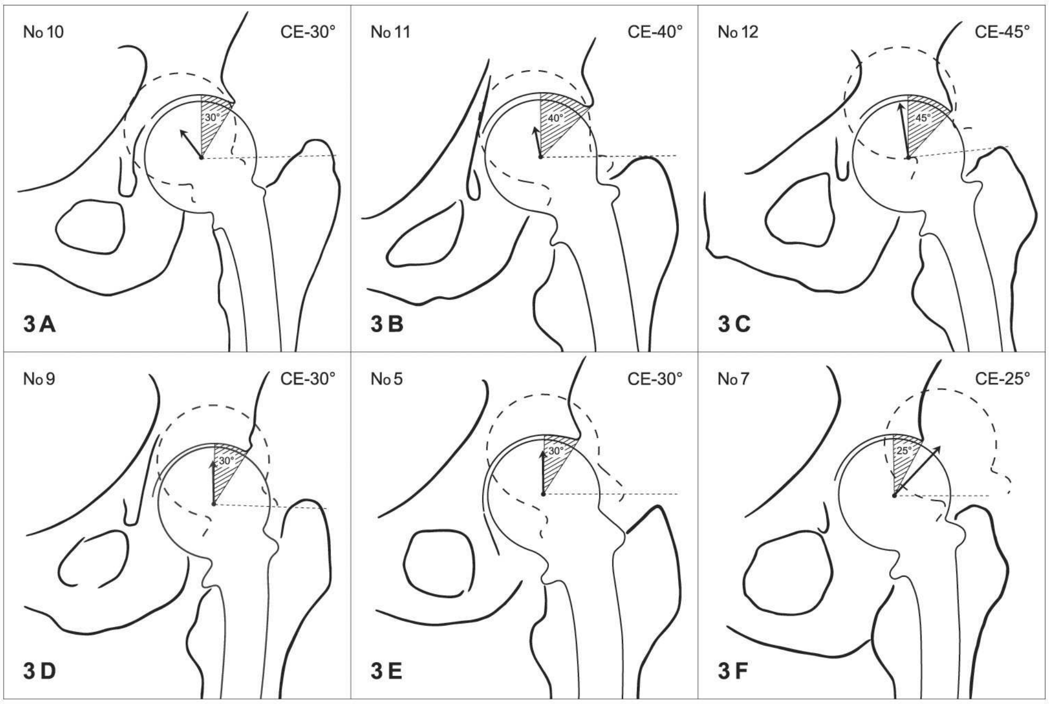

Figure 1: Type of clinically observed migration

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 and shapes of acetabulum.

2. Models

To assess the influenfe of selected parameters on the implant migration a planar model of pelvic bone was developed. To enable easy comparison between patient's X-ray images it is modeled as frontal projection of pelvic bone. The shape of the bone was obtained from X-ray scan. Factors, which could influence the migration are considered as paremetrical inputs. The main geometrical factors which may influence the migration of the implantat are the CE angle and the direction of loading force. The second model is volumetric which is created from computer tomography data. The development of the model is described in detail in [Vyčichl J. and Jiroušek O. 2005]. In this case the geometry is invariant, there is only one input parameter the direction of the load. Parametrization of the geometry seems to be useful to accelerate generation of the model. Pelvic is symmetrical in the median plane, therefore it is not necessary to model both parts, only right part is used. Nonparametrical part of the planar model is iliac and pubic bone. Diameter of the replacement head and the shape of acetabular area is given as parametes.

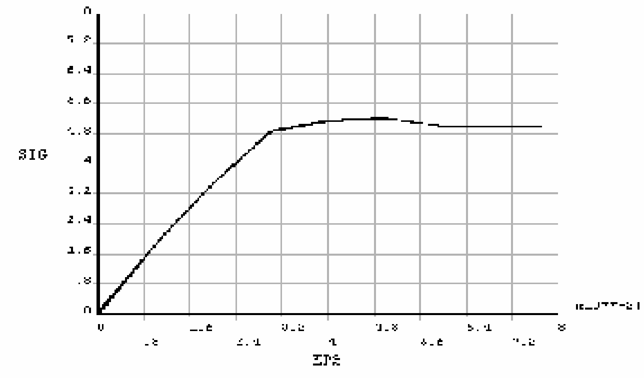

Figure 2: Stress-strain curve of cancellous bone

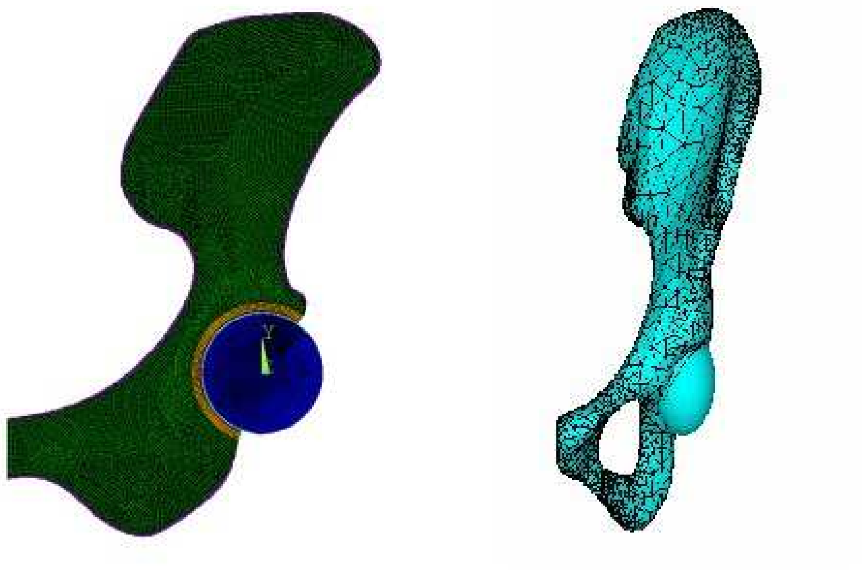

Figure 3: Planar and volumetric model of pelvis

3. Materials

There are five diferent materials used in the planar FE model: steel replacement head, chondral and subchondral bone in the acetabular fossa, cortical bone on the surface and cancellous bone inside the pelvis. There are two materials in the volumetric model: cancellous bone of the pelvic and steel of replacement. All materials except the cancellous tissue are considered by homogeneous, linear and isotropic. Material properties of the cancellous bone (Fig. 2) are taken from litarature as well as from experiments conducted at our institute in recent years. Range of material characteristics is wide, material with lower value of Young modulus was chosen for the model to get the most disfavourable situation.

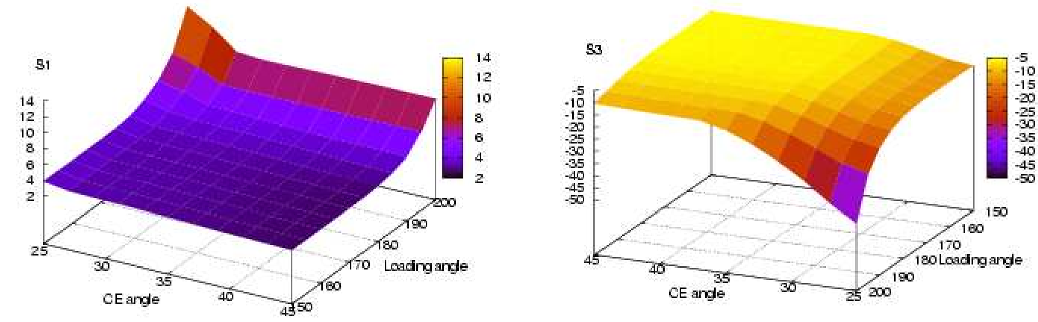

Figure 4: Peak values of 1^{rd} and 3^{rd} principal stress of planar model

4. Methods

For stress analysis in the pelvic bone the finite element method was used. Boundary conditions were represented by fixation of all surface within the area close to acetabulum. The loading of the acetabulum is modeled by assigning acceleration to the mass steel replacement head. Loading resultant intersect the center of the replacement head. In the volumetric model the plane of interest is $19°$ inclined from the frontal plane.

The planar model was solved in 120 loading steps with different value of acetabular lumbrum CE angle and loading direction. CE angle was varied from $25°$ to $45°$ with step set to $2°$. This range corresponds with major part of acetabular lumbrum in population. Loading direction was varied from $-30°$ to $20°$ with step set to $5°$. This range is a little bit lager than the range of physiological loading. The volumetric model was solved in 4 loading steps with loading direction $-45°$, $-10°$, $0°$ and $10°$.

5. Results

Extreme values of first principal stress, third principal stress and the sum of displacements were used as a reference magnitude. Depence of maximal values of principal stresses originating in cancellous bone on the CE angle and loading direction is given in Fig. 4. Results show the importance of well-developed acetabular lumbrum reducing extreme values of cancellous bone stresses. Maximal values of stresees increase corresponding to positive loading direction.

6. Conclusion

The stress and displacement fields show that primary migration of the replacement head follows the direction of loading. Decrease of CE angle and increaase of the loading direction angle concentrates the stress to acetabular lumbrum area. This very disfavourable situation probably follows the migration, therefore the natal predispositions of acetabular lumbrum have high influence on the migration. Analogically, in the case of median loading the consequence of the mechanical load is migration of the implant to pelvis minor region. Nevertheless, the peak value of the displacement does not correspond well with real migration observed clinically. One of possible causes of this difference is given by changes in the cancellous bone properties and muscle activity and balance before and after surgery.

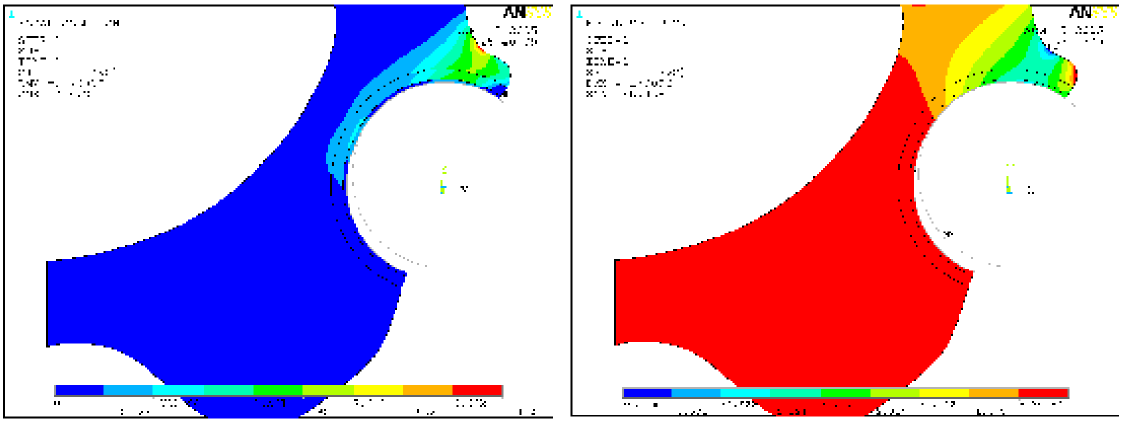

Figure 5: Field of 1^{rd} and 3^{rd} principal stress of planar model

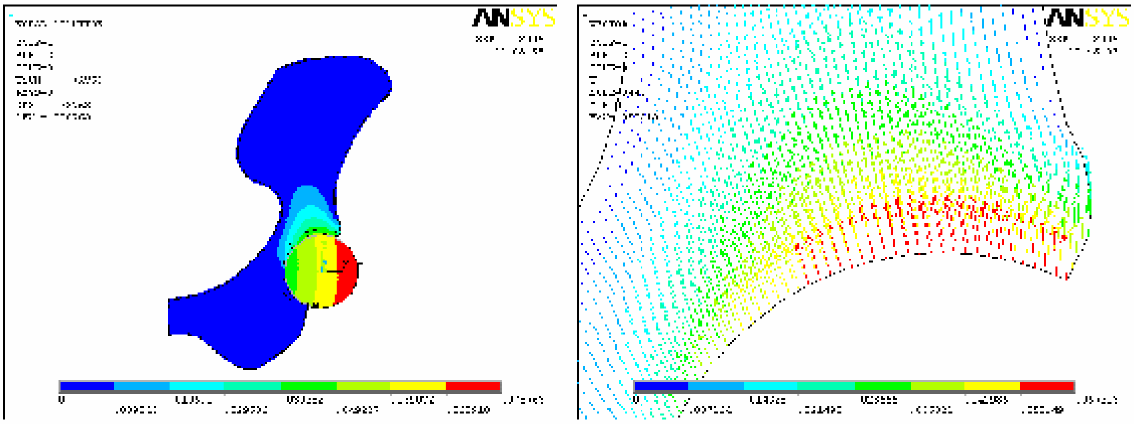

Figure 6: Sum and vector of displacement of planar model

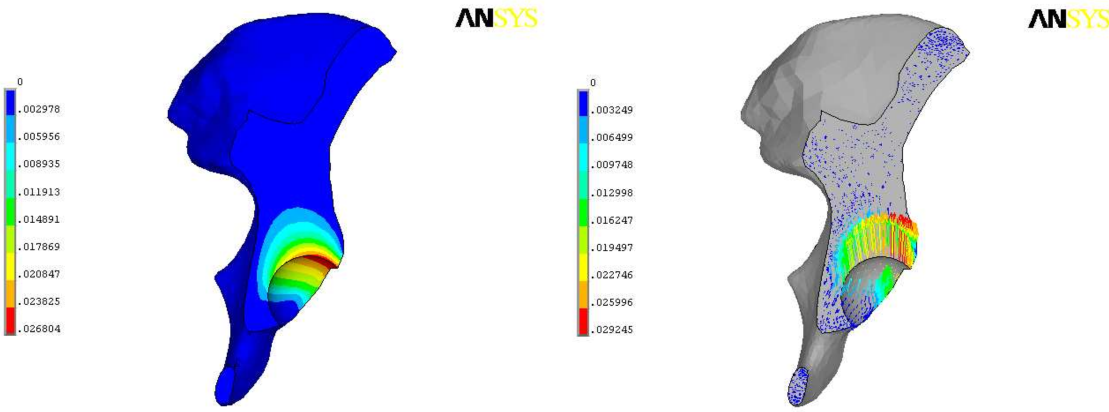

Figure 7: Sum and vector of displacement of volumetric model

7. Acknowledgment

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