Prediction of Remodeling Changes after Short Stem Total Hip Arthroplasty

Jan Vodička[1,*], Jan Heřt[2], Lukáš Horný[3], Matěj Daniel[4]

[1] *ČVUT v Praze, Fakulta strojní, Ústav mechaniky, biomechaniky a mechatroniky , Technická 4, 166 07 Praha 6, Česká republika*

[2] *FN Motol, Ortopedická klinika 1. LF a FN Motol, V Úvalu 84, 150 06 Praha 5, Česká republika*

[3] *ČVUT v Praze, Fakulta strojní, Ústav mechaniky, biomechaniky a mechatroniky , Technická 4, 166 07 Praha 6, Česká republika*

[4] *ČVUT v Praze, Fakulta strojní, Ústav mechaniky, biomechaniky a mechatroniky , Technická 4, 166 07 Praha 6, Česká republika*

Abstract

In this study, we deal with a description and evaluation of remodeling changes after implantation of the short stems. First postoperative image was used to create 2D model of the proximal femur with the implant. It serves as a geometry in a boundary value problem describing mechanical interaction between bone tissue and stem of the implant. The problem was formulated by means of finite element method (FEM). To evaluate remodeling changes, FEM results were compared to two-years postoperative image. The comparison was based on changes in stress field and changes in principal stress directions. The results suggest, that short stem Proxima helps to restore the orientation of the main groups of trabeculae in the proximal femoral area and reduces the stress shielding effect after THA.

Key words: Bone Remodeling, Functional adaptation, Short stem, Stress shielding

1. Introduction

Our body is exposed to randomly changing external mechanical conditions during its whole life. For the bone tissue it is typical that it changes its internal structure to maintain internal integrity, stability, strength, and mineral homeostasis. The way how the bone adapts to changes in these conditions is referred to as *functional adaptation* or *strain adaptation* [2].

Predicting the remodeling processes and understanding the adaptation properties of living bone are essential prerequisite for designing successful prosthetic devices that are connected with bone tissue after the surgery.

Total hip arthroplasty (THA) is one of the most common type of surgery that is offered to patients with chronic hip disease where conservative therapy is no longer effective. Unfortunately, prosthetic devices may significantly change stress fields in adjacent bone tissue. However, such conditions are significantly different to their physiological states. This deviation will trigger the strain-controlled adaptation process and the bone will remodel to accomplish the homeostatic state. When this process is manifested mainly by bone density reduction, it is referred to as *stress shielding*. One way how to reduce the stress shielding effect in patient's femur after total hip replacement is the implantation of so-called short stems [3].

Short stems of the total hip replacement have been developed to improve load transfer in the proximal femoral area, as well as to reduce an amount of resected bone tissue. Other benefits include: reducing the convalescence of the patient, possibility of using mini-invasive surgical procedures or reduction in overall postoperative pain.

1.1 Background

1.1.1. X-ray set

This study is based on series of X-ray images taken in patients who have been implanted with a short hip stem *Proxima*. The series include preoperative images as well as postoperative images. To evaluate remodeling changes after implantation, two X-ray images were compared – first postoperative and two-years postoperative.

* Author contact: Jan.Vodicka@fs.cvut.cz

Fig. 1. *First postoperative X-ray image*

Fig. 2. *Two-years postoperative X-ray image*

1.1.2. Wollf's Law

The description and evaluation of remodeling changes is based on the concept of Wolff's law stating, that the main groups of trabeculae are oriented parallel to the principal stress directions [2], [4].

2. Finite Element Methods

2.1. Input geometry and material parameters

The first postoperative image was used to create 2D model of proximal femur with the implant. It serves as a geometry for a boundary value problem describing mechanical interaction between bone tissue and stem of the implant. The problem was formulated by means of finite element method. To evaluate remodeling changes, FEM results were compared to two-years postoperative image.

Both materials (hip implant and bone tissue) were considered as homogenous, isotropic and linearly elastic.

2.2. Boundary and loading conditions

Displacements in nodes of the distal end of the femur were assigned to be zero which expresses a fact that the bone is fixed at this place.

With regard to the loading condition, it was assumed that the action force, which acts in the center of the head of the hip joint, is approximately 2,5x higher than body weight and its magnitude is determined according to eq. (1).

$$F = 2{,}5 \cdot \frac{m \cdot g}{D} \tag{1}$$

Here F is the force in hip joint, m is the body weight of the patient, g is the gravitational acceleration and D is the diameter of femoral head.

Equality of displacements was assigned at the border between bone tissue and stem which expresses an assumption of the osseointegration of the implant to the bone. The whole model was meshed using 6-node elements CPS6M [1].

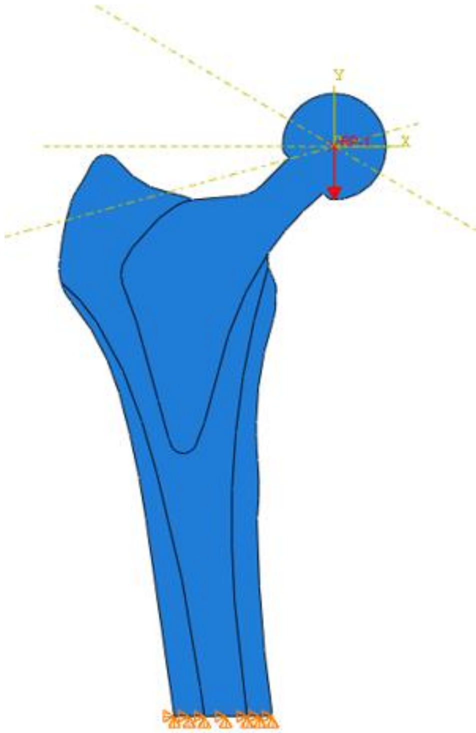

Fig. 3. *Boundary and loading conditions*

2.2. Point of interest

As has been said, prosthetic devices may significantly change stress field in adjacent bone tissue. The main idea of this study is an evaluation of the FEM results and comparison with long-term postoperative image. The comparison was based on changes in stress field and changes in principal stress directions.

3. Results

In this contribution, results obtained in two FEM models are presented. Each model corresponds to another patient. One with desirable and one with undesirable position and size of an implant.

For qualitative evaluation of the results, an attention was focused on the distribution of equivalent stress (von Mises) as well as on the distribution of maximum modulus of principal stresses. Furthermore, components of the stress tensor computed in each node were used to calculate the principal stress directions (the eigenvector problem). Examples are shown in Figures 4, 5, 6.

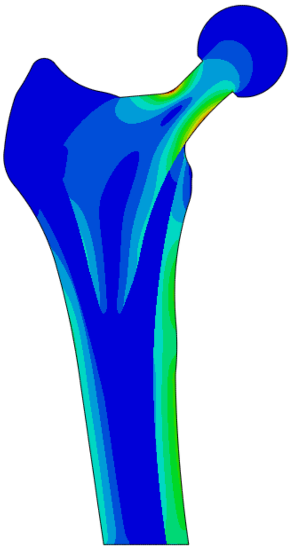

Fig. 4. *Distribution of equivalent stress (von Mises) – desirable size and position*

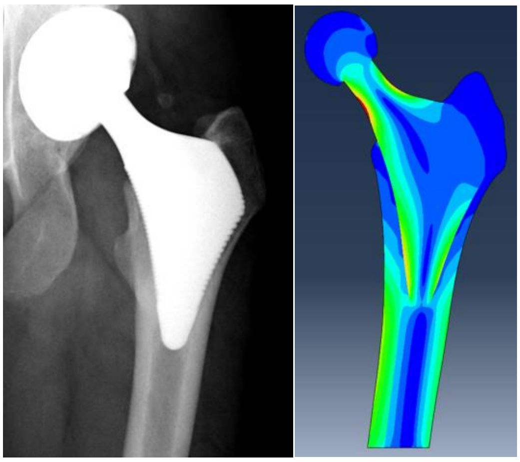

Fig. 5. *Distribution of equivalent stress (von Mises) – undesirable size and position*

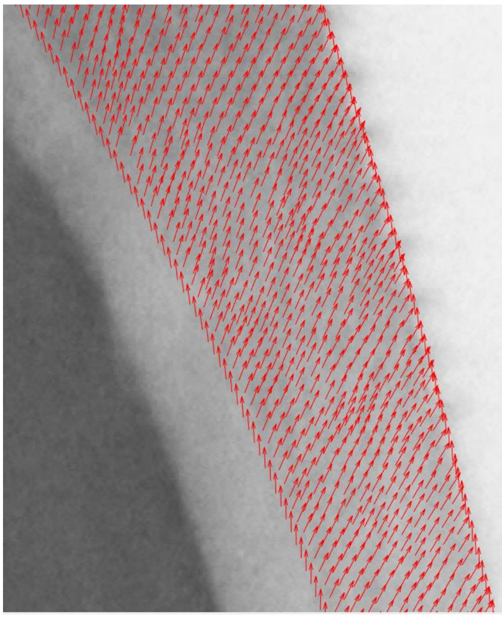

Fig. 6. *Orientation of principal stress*

4. Conclusion

The results suggest, that short stem *Proxima* helps to restore the orientation of the main groups of trabeculae in the proximal femoral area and reduces the stress shielding effect after THA assuming appropriate implant size and position. On the other hand, by inappropriate implantation unfavorable conditions associated with *stress shielding* (such as hypertrophy) may occur due to higher concentration of the stress.

Acknowledgment

This study has been supported by the Technology Agency of the Czech Republic in the project Gradient functionally structured hip implant with a long-life span with id. TH03010354.

List of symbols

F applied force in the center of the femoral head
g gravitational acceleration
D diameter of femoral head
m patients body weight

References

[1] *ABAQUS/Abaqus Analysis User´s Guide, Ver. 6.14 Documentation. Dassault Systémes Simulia Corporation, 2014.*

[2] *COWIN, Stephen C.; DOTY, Stephen B. Tissue mechanics. Springer Science & Business Media, 2007*

[3] GRONEWOLD, Jens, et al. Changes in strain patterns after implantation of a short stem with metaphyseal anchorage compared to a standard stem: an experimental study in synthetic bone. Orthopedic reviews, 2014, 6.1

[3] *Hart, R. T., 2001 Bone modelling and remodelling: Theories and computations, In S. C. Cowin (ed.) Bone Mechanics Handbook, CRC Press.*