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Research Article

The Mathematical Study of Using Femoral Stems with Metaphyseal and Diaphyseal Fixation Types in Defects of the Femur at the Level of the Lesser Trochanter

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Abstract

Introduction: The relevance of this article is based on the amount of unsatisfactory results after total hip arthroplasty in patients with consequences of trauma of proximal femur.

Aim: To investigate the stress-strain state of proximal femur in total hip arthroplasty with defect of the femoral neck at the level of the lesser trochanter with inserted different fixation type stems.

Material and Methods: With the help of finite element method analysis, we performed a modeling of human pelvis and hip joints in different phases of gait after total hip arthroplasty in conditions of femoral neck defect at the level of the lesser trochanter with inserted metaphyseal fixed and diaphyseal fixed type stems.

Results: The study shows that the level of stress-strain state of proximal femur during total hip arthroplasty in conditions of femoral neck defect at the level of the lesser trochanter is different for models with metaphyseal fixed and diaphyseal fixed type stems. The stress state level for the model with metaphyseal fixed type stem is higher. The greatest difference is observed for the first and the third phases of movement in the upper third part of the medial femoral surface in contact with the endoprosthesis.

Conclusion: It is necessary to give priority to use of endoprosthesis with diaphyseal fixed type stem at total hip arthroplasty with the defect of the femoral neck at the level of the lesser trochanter.

Keywords: *Mathematical Modeling; Stress-Strain State; Total Hip Arthroplasty; Type of Stem Fixation*

Introduction

In recent years, in order to improve methods of surgical interventions in modern orthopedics and traumatology mathematical modeling is widely used. At the same time one of the most informative methods of studying stress-strain state of the bone tissue is the finite element method [1-3].

The advantages of this method are: the possibility of bone modeling with different materials, a good approximation of the curves, the possibility to refine results by grinding the discretization (finite element reticle), consideration of various boundary conditions.

The main areas of application of the finite element method in orthopedic biomechanics is the study of stress-strain state of bone structures and its changes in bone remodeling process; testing and optimization of artificial joints design and bone fixation devices; studying articular cartilage mechanical behavior, ligament apparatus and other soft tissue structures associated with the bone [4-7].

Therefore, we pay great attention to the study of changes in the stress-strain state of the acetabulum and the proximal femur in arthroplasty by modeling different types of defects and deformities as a result of traumas, as well as the opportunities of normalization of the stress-strain state.

Aim

The aim of this work is to study the stress-strain state of the proximal femur in terms of arthroplasty with defect of the femoral neck at the level of lesser trochanter with various fixation types of established stems.

Material and Methods

In biomechanical laboratory, we have created a complete model of human pelvis with a hip joint and a femur taking into account pelvic ligaments and pubic symphysis which allows for adequate reflection of the stress-strain state in the pelvis [8]. This model allows to estimate the load on the pelvis and hip joint in different phases of movement [9]. We considered three phases of step as loading peaks on the hip joint during walking account for 20% of the step cycle ("toe off" at the time of sock lifting the non-persistent leg, supporting leg - full contact of the foot), 30% of the step cycle ("stand alone" single bearing position), and 50% of the step cycle ("heel strike" heel kicking of non-persistent leg). The second half of the cycle repeats the previous step for the other leg [10,11].

Also, to set the endoprosthesis cementless fixation has been added to this model.

Using a selection of different prosthesis stems' design and type of fixation in terms of defects and proximal femur deformations is very important for hip arthroplasty in case of traumas. The selection of stems' design has a significant role by providing a long-term stable fixation of the implant.

In our model, we have constructed a cervical defect model at the level of the lesser trochanter. A comparison in this model between two types of stems: metaphyseal and diaphyseal has been performed.

The first option was a model with an established endoprosthesis by modeling the cervical defect at the level of trochanter minor with a diaphysial fixation stem.

The second option is a model with an established endoprosthesis by modeling the cervical defect at the level of trochanter minor with a metaphysial fixation stem.

The modeling was performed with in the left hip joint with a cervical defect at the level of trochanter minor by establishing Zimmer endoprosthesis with a polyethylene liner, stems with metaphyseal and diaphyseal fixation types (Figure 1).

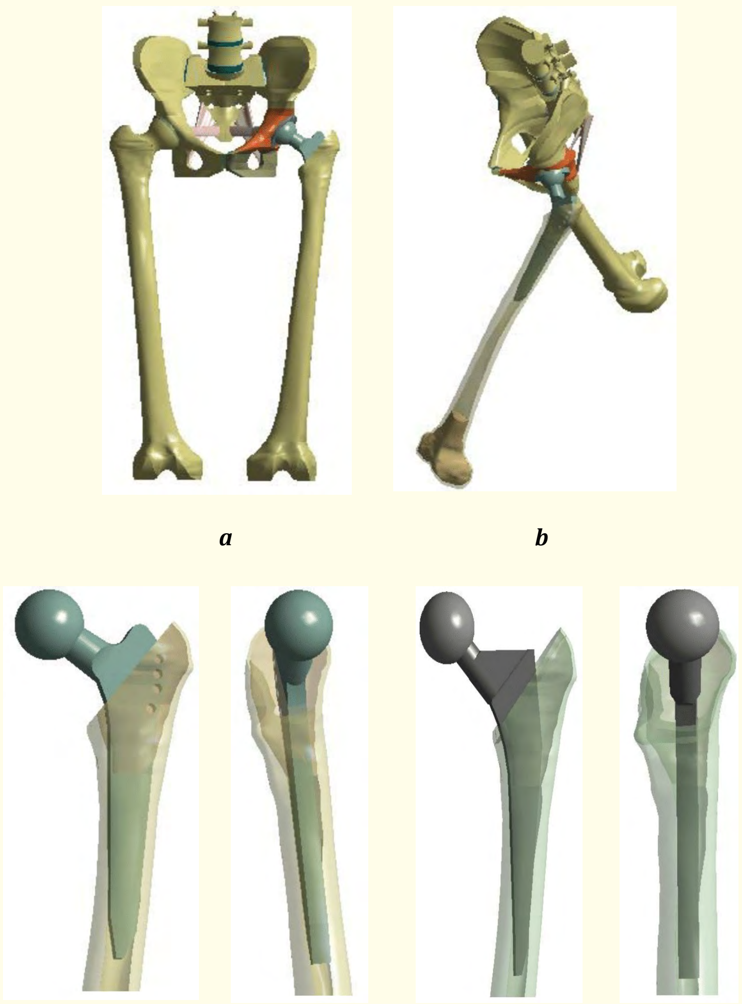


Figure 1: *Changes in the design model: endoprosthesis with a diaphysial (a-d) and with a metaphyseal fixation stem (e, f).*

For stress-strain analysis proximal femur with established stem was conditionally divided in height into three zones, which approximately coincide in the height distribution with Gruen classification [12] (Figure 2). In these zones, the maximum values of Mises stresses in the femur are located. These stress values were used to compare different design models with endoprostheses.

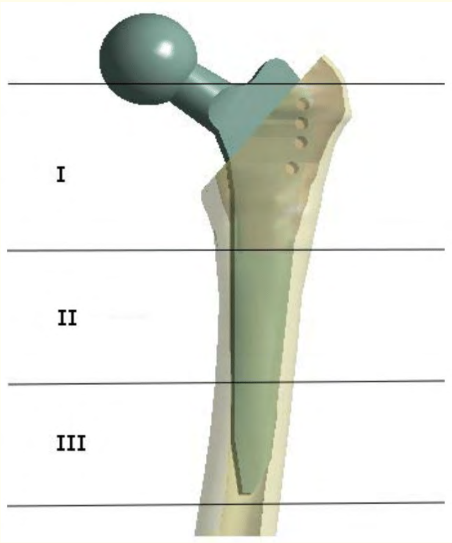
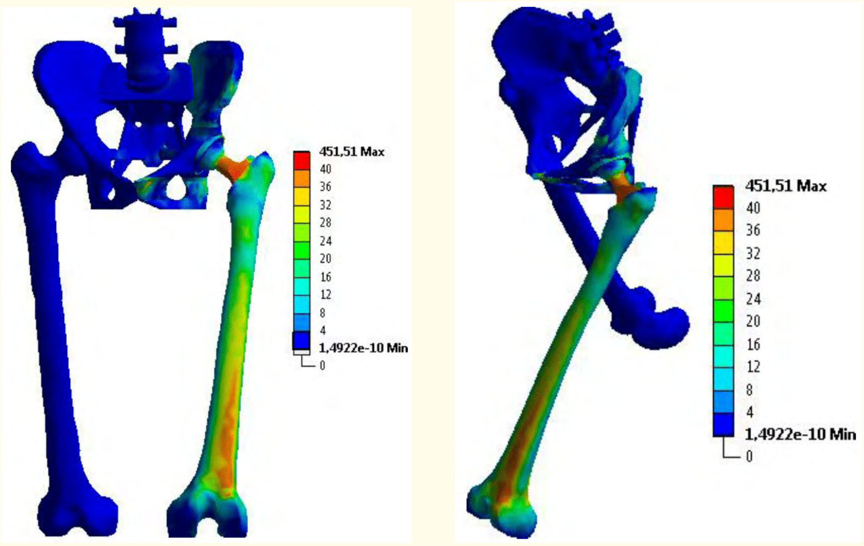


Figure 2: *Test points for measuring the stress-strain state.*

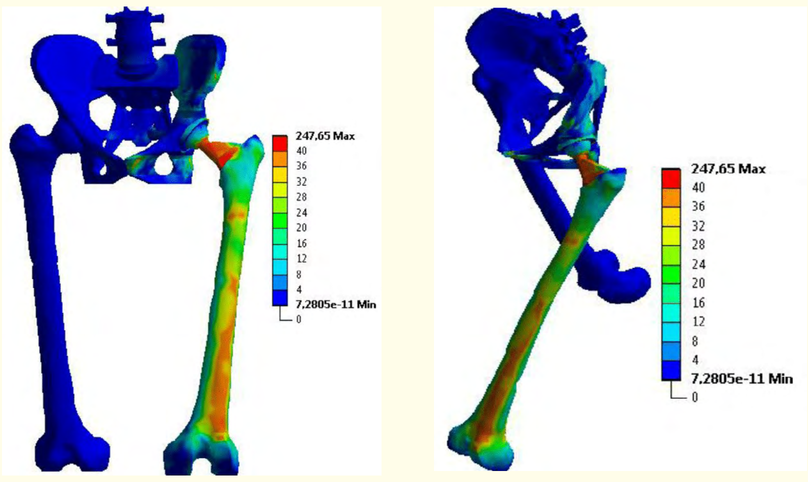
The main charge of the model is the body weight. The body weight was assumed to be 700 N. The work considers only the static charge, since during the rehabilitation the patients remain prudent in different periods of movement. Three phases of motion were considered: the moment of detachment of the toe of the foot of the non-supporting leg, the complete single-support position and the moment of contact with the heel surface of the non-supporting leg. In mathematical calculations, the ANSYS 14.0 program was used.

Results

Comparative analysis of the results of the first phase of movement has shown (Figure 3) that the general nature of the distribution of the stress-strain state of both versions is the same, but the level of stress is different. The most intense area is the lower part of the femur, where the level of stress state for the model with the type of diaphyseal fixation stem reaches 66.3 MPa, and for the model with the stalk-type metaphyseal fixation - 71.5 MPa. The stress level of the lower proximal femur was 27.6 MPa for models with endoprosthesis with a diaphyseal fixation stem type, and 40.7 MPa - for models with a metaphyseal fixation stem.



a ***b***



c ***d***

Figure 3: *Stress-strain state distribution values of Mises stresses in a model for first phase of step: with a diaphyseal fixation stem type (a, b) a metaphyseal fixation stem type (c, d).*

Comparative analysis of the studied results of the second phase of the movement has shown that the general nature of the stress-strain state distribution of both versions is the same, but the level of stress is different. The most intense area is the diaphysis of the femur in the lateral and medial sides, where the level of stress for the model with the endoprosthesis with a diaphyseal fixation stem type reaches a value of 18.2 MPa, and for the model with endoprosthesis with a stem type metaphyseal fixation - 21.9 MPa. At the top of proximal femur in the lateral side the level of stress reaches values of 20.1 MPa for models with endoprosthesis with diaphyseal fixation stem type, and 25.3 MPa - for the model with the endoprosthesis with a metaphyseal fixation stem-type.

A comparative analysis of the research results for the third phase of the movement has shown that the general nature of the stress-strain state distribution of both versions is the same, but the level of stress is different. The most intense area is the lower part of the thigh bone in front and back sides, where the level of stress state for the model with diaphyseal fixation stem type reaches 43.2 MPa, and for the model with the stalk-type metaphyseal fixation - 42.5 MPa. At the top of the proximal femur from the lateral side the level of stress reaches values of 18.1 MPa for models with diaphyseal fixation stem type, and 23 MPa - for models with metaphyseal fixation stem type.

Discussion

Today metaphyseal fixation type stems are widely used in primary hip arthroplasty due to satisfying long-term results of their use, with a stable fixation of 96% cases in term of follow up in 20 years [13] and the possibility of maintaining the diaphyseal femur for potential revisions, which is especially important in patients of young age. However, when the defect of bone tissue extends distally till the lesser trochanter, as a result of trauma, with the destruction of the Adams' arc, the achievement of a stable fixation of the stem in metaphyseal part of the femur can become a problem, that needs the use of stems with distal type of fixation [14].

In the research of Podgayskaya., *et al*. [15] the analysis of bone tissue tensions, that appear after total cementless hip arthroplasty, was carried out. They designed the models of femur with different shapes of femoral canal (champagne fluted and stovepipe). In each of models stem with proximal, metaphyseal and distal type of fixation were implanted. However, the obtained results showed distribution of tensions after total hip arthroplasty in intact anatomy of proximal femur; our study shows different levels of stress-strain state of proximal femur during total hip arthroplasty in conditions of femoral neck defect at the level of the lesser trochanter for models with metaphyseal and diaphyseal fixed type stems.

Conclusion

By analyzing all three phases of the movement, we can conclude that the stress-strain state of proximal femur in hip arthroplasty with femoral neck defect at trochanter minor's level is different for models with diaphyseal and metaphyseal fixation stem types.

Almost in all cases the stress level for the model with metaphyseal fixation stem type is important. The greatest difference (in several times) was observed in the first and third phases of movement in the upper third of the medial femoral surface where it contacted with the endoprothesis.

Conflict of Interest

The authors declare that there is no conflict of interest connected with this study.

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