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Application of the Finite Element Method in Modeling Biological Systems in Traumatology and Orthopedics

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Abstract. Surgical treatment of fractures of the proximal femur is a problem due to the lack of a uniform treatment strategy. Of particular importance is the analysis of the processes occurring in bone tissue during the healing of fractures under dynamic conditions, especially the analysis of mechanical stresses. The finite element method is an effective method for mathematical modeling of complex objects and describing the stress-strain states of these objects. In order to improve the results of treatment of fractures of the proximal femur and pelvic bones, mathematical modeling was carried out using the finite element method of a pertrochanteric femur fracture under conditions of fixation with a dynamic pin and a pelvic fracture under various conditions of its submersible fixation.
Keywords: finite element method, femur, fractures of the proximal femur, pelvic bones, pelvic fractures.

Introduction

Surgical treatment of fractures of the proximal femur is currently a problem due to the lack of a unified treatment strategy [5]. In connection with the development of dynamic osteosynthesis, which, unlike static osteosynthesis, thanks to the telescopic type of metal fixator, ensures constant contact of bone fragments at all stages of repair, the analysis of the processes occurring in bone tissue during the healing of fractures in conditions of constant movements of the system elements is of particular importance bone is an implant. No less important, from a practical point of view, is the study of mechanical stresses that arise in bone tissue under load during the healing (fusion) of a fracture. Experiments on humans in vivo in traumatology and orthopedics are impossible, and therefore the possibilities of mathematical modeling become very relevant [4].

Materials And Methods

By the beginning of the 21st century. In connection with the rapid development of computer technology and the increase in the power of electronic computers, the finite element method has found effective application for solving practical problems in various fields of human activity, primarily in structural mechanics, fluid mechanics and heat engineering [4]. Mathematical modeling of biomechanical processes (for example, the stress-strain state of dental implants, endoprostheses of large joints and metal fixators, taking into account the real physical properties of bone tissue [1]) is carried out using a software package, one of which is ANSYS [2]. For example, in the work of P. Ausiello [3], using the finite element method, an analysis of the dissipative ability of cement fixing dental ceramic implants in the bone was carried out, and in the work of F. Amirouche et al. [2] – analysis of the kinematics of the elements of the hip joint endoprosthesis depending on the stability of the installation of the acetabular component.

Results And Discussion

In order to improve the results of treatment of injuries to the proximal femur and pelvic bones, due to the need to assess the effect of metal fixation implants on the healing process, the biomechanics of the damage zone and the impossibility of full-scale experiments on the basis of the Department of General and Specialized Surgery, Faculty of Fundamental Medicine, Moscow State University, together with the society Hexa Limited Liability Company carried out mathematical modeling using the finite element method of a pertrochanteric femur fracture under conditions of fixation with a dynamic cephalomedullary pin and a pelvic fracture in various variants of its submersible fixation.

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A load with a human body weight of 80 kg was applied to the created models, and the stress-strain state of the bone-implant system was assessed.
The study clearly demonstrated the advantages of dynamic osteosynthesis in fixing fractures of the proximal femur, and also made it possible to calculate the optimal fixation of a pelvic ring fracture from the point of view of strength characteristics.
Based on computed tomography data, an anatomical three-dimensional finite element model of the pelvis was constructed, consisting of two pelvic bones and the sacrum, highlighting the cortical layer and cancellous bone (Fig. 1).

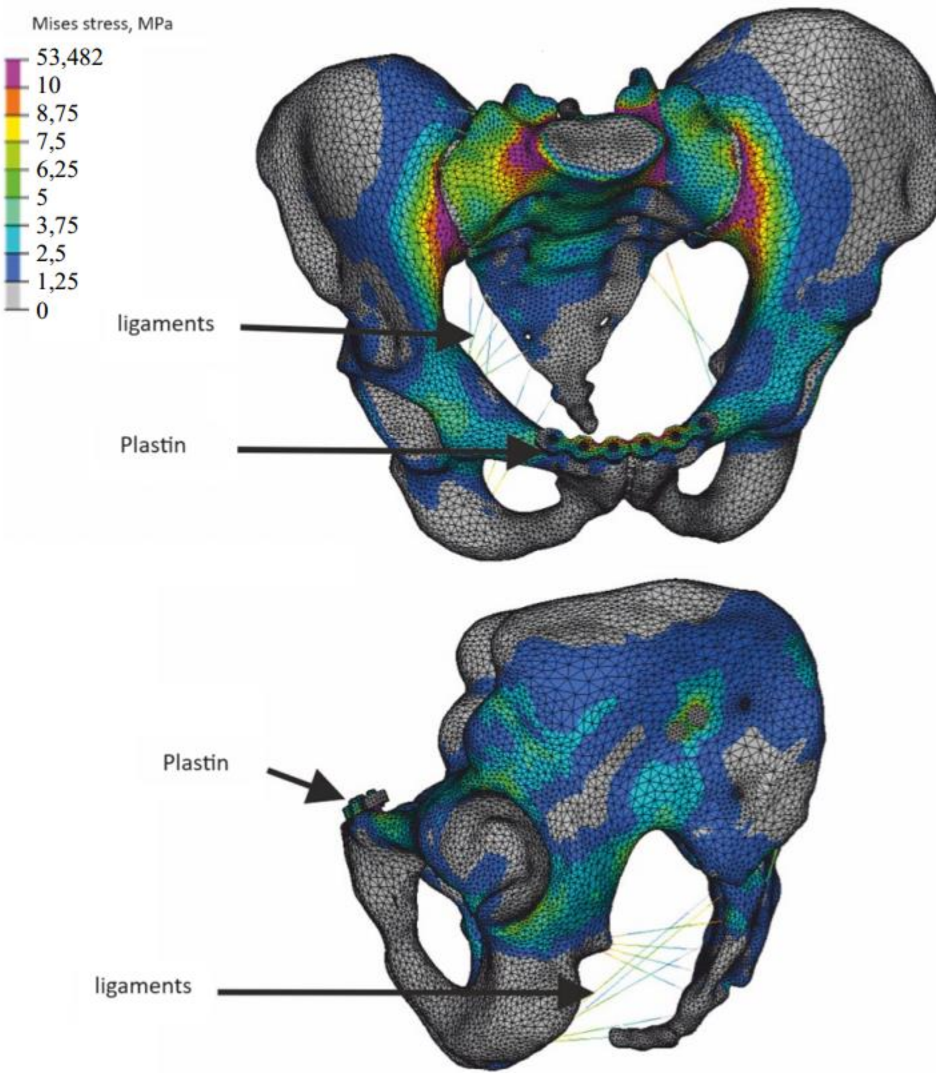

Fig. 1. Calculation of the stress-strain state of the finite element model of a pelvic fracture under conditions of fixation with a plate (the color of the scale reflects the stress-strain state of the system under an applied load in the sacral area)

Based on literature data [2], the end elements of the cancellous bone were defined as tetrahedrons with an edge length of 2 mm, the cortical bone layer was defined as shell triangular end elements with a side of 2 mm (Fig. 1). The sacroiliac joint and interpubic disc were regarded as isotropic solid structures built from hexahedrons. The model included the sacrotuberous (lig. sacrotuberous); sacrospinous (lig. sacrospinous) and sacroiliac (lig. sacroiliac) ligaments, which have a significant impact on the stress-strain state of the pelvis, represented in the model by elastic springs with a constant tightening force of 10 N [2]. Between the sacrum and the iliac bones, as well as between the pubic bones, a friction coefficient of 0.6 was determined [2]. The choice of the number of design points and the shape of the finite elements was determined by the optimal ratio of sufficient accuracy of the result and the time required to calculate the system using the ANSYS software package. The magnitude of the tensile forces and the coefficient of friction was

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determined by extrapolating the morphological and biomechanical data obtained by L.E. Kuznetsov to the characteristics of an adult organism. when studying the pelvic bones of children [6].
Mathematical modeling of pelvic bone fractures and damage to its joints was carried out under a virtual load on the sacral region of a distributed vertically oriented force of 800 N (body weight 80 kg).
The pelvis was virtually fixed in the area of the hip joints; the right ilium in the center of the hip joint is rigid in six degrees of freedom (three movements and three rotations), the left ilium is hinged with possible movement along the x axis (Fig. 2).

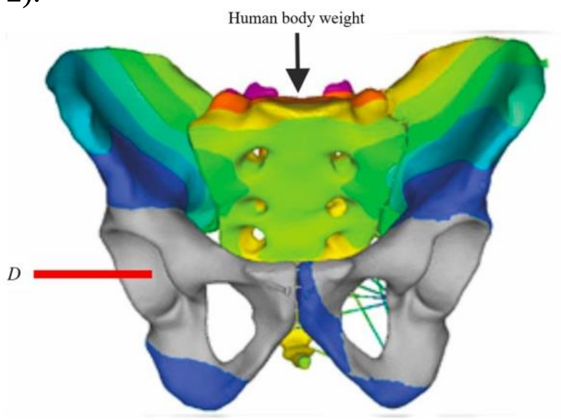

Fig. 2. Scheme of applying load to a model of a pelvic bone fracture. Region D – fixing the model with three degrees of freedom

Conclusion

1. Mathematical modeling using the finite element method allows us to evaluate the biomechanical state of the “bone-implant” system under dynamic conditions as closely as possible to reality.
2. Mathematical modeling of the behavior of the bone-implant system using the finite element method makes it possible to select the type of fixation of the pelvic ring for various injuries.
3. Dynamic cephalomedullary fixation eliminates the occurrence of critical stresses in the structural units and sharp stress gradients between the bone and the implant. When using this dynamic fixator, significant stresses are not formed in the bone tissue, which allows for full dosed compression of the fracture line and does not create prerequisites for complications when installing a telescopic screw along the axis of the femoral neck.

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