Application of the method of finite element analysis in studying the reliability of various options of fixation of models of human pelvic bones

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Abstract. Modern society is already unthinkable without computer-aided design systems, which are systems that implement information technology for performing design functions. These technologies are actively used in all branches of human activity, including in medicine [5]. It is known that the use of an external fixation device makes it possible to cure complex cases of fractures of human pelvic bones [4,6]. To simplify the design, secure fastening, reduce trauma, various types of external and internal fixation devices are applied. Nowadays, treatment of complex fractures of human pelvic bones with the help of the fixing Ilizarov apparatus takes place on the basis of the facts of analyzing the patient’s condition, that is, by an empirical method. Eliminating modeling from the design calculation may aggravate the patient’s condition due to such factors as excess load on the frame or its insufficient rigidity.

1. Introduction
The application of the method of finite element analysis in the study of the loading process of the “fixing device - bone” system makes it possible to calculate a large number of design layouts and select the most rational one. In addition, debugging the technology with the use of modern engineering calculation systems (CAE) allows you to avoid material and time costs, and in some cases to abandon the use of erroneous or inefficient solutions.

The goal of this project is to calculate the state of movements in the zone of fracture of human pelvic bones by varying the static compressive loads on the three-dimensional bone model, using the developed models in the finite element complex SolidWorks Simulation. Geometric models of bone and fixing devices were imported into the finite element modeling system, where the state of the system movements was calculated. In the course of this study, an algorithm was developed for determining the most optimal method for fixing injuries using the finite element analysis method of the “fixing device - bone” system. The reason for choosing this algorithm was the need to determine a more efficient method of fixing injuries used in medicine for treating victims with a similar injury [7,8].

2. Materials and methods
Titanium (Ti-R50400) is used as the material of the fixing structures, and plastic (ABS) is more suitable for the pelvic bone model. Taking into account the anisotropic properties of the bone material, the
solution of the contact problem of the elasticity theory allows us to see the picture of stress distribution in the elements of the “bone - fixing structure” postoperative system with a high degree of reliability [2, 3].

In the first model, the device is equipped with 4 locking screw rods with a diameter of 6 mm, inserted horizontally. Of these, 2 rods are inserted into the model of pelvic bones in the anterior-posterior dimension, and 2 others are inserted vertically at an angle of 90° to the first ones. The screw rod are interconnected by metal plates with "half-arc" holes. Half-arc connection is carried out by an anterior fixing device in the form of a straight rack support with holes and brackets fixed to the “half-arcs” and the support itself with threaded adjusting rods, which is the “anterior pelvic support” as shown in Figure 1. The posterior sections of the pelvic bone model are fixed with a Ø 6-mm screw with partial threading.

![Figure 1. The result of modeling the first version of the structure](image1)

In the second model, the external fixation device is placed on pelvic bones on 6 screw rods crossing at different levels, inserted both in the anterior and posterior parts of the pelvic bone model. Four half-arcs with the anterior and posterior rack supports of the apparatus are connected by two threaded rods and four brackets, forming a closed structure (Figure 2). This structure is more complex in terms of modeling.

![Figure 2. The result of modeling the second version of the structure](image2)
The third design is the most simplified and contains one plate with holes adjoining directly to the anterior section of the pelvic bone model, fixing the anterior section of the pelvic model by screwing it and the Ø6 mm inner screw with partial threading connecting its posterior sections, Figure 3.

![Figure 3. The result of modeling the third version of the structure](image)

Using the SolidWorks Simulation program, we conducted a virtual analysis of three variants of fixing structures under the action of the load range from 500 N to 2500 N, which was applied to the right (unstable) half of the pelvis and the fixed left (stable) half of the pelvis.

3. Results and discussions

The finite element analysis of the first fixation variant is shown in Figure 4. The analysis of loading of the first version of the structure shows the displacement of only the anterior section of the pelvic bone model, under the action of a load of 500 N. The maximum load imposed on the bone is 2500. The increment of the load values is 100 N.

![Figure 4. Analysis of the displacement of the first version of the structure](image)

The finite element analysis of the second fixation variant is presented in Figure 5. These calculations were also carried out with loads from 500 N to 2500 N, in increments of 100 N. The resulting displacements indicate that this structure has the maximum displacement both in the anterior and
posterior part of the pelvic bone model relative to its original position, which says about the relatively low stability of the system "fixing device - bone".

![Figure 5](image)

**Figure 5.** Analysis of the displacement of the second version of the structure

The finite element analysis of the third fixation variant, shown in Figure 6, as well as in the previous calculations, used loads in the range from 500 N to 2500 N, with an increment of 100 N. The calculation of displacements of the third fixation variant showed the smallest displacements since the layout perceives loads well, in case of rigid fixation. But this method is unfeasible since to achieve rigid fixation in practice is a more difficult task. If the fixation of the anterior section is not sufficiently rigid, then at critical load the screws will break off from the fixing plate and this will lead to undesirable results.

![Figure 6](image)

**Figure 6.** Analysis of the displacement of the third version of the structure

The displacements in the anterior of the bone model (Figure 7.A) and in the posterior (Figure 7.B) were counted equally in all three devices. The results of the displacements of the three structures after each load were recorded in a table, and subsequently linearly interpolated, forming three different graphs.
Figure 7. Reference displacement points: A – in the anterior, B – in the posterior

Figure 8 shows the graph in which the lines show the dependence of the displacements of the anterior part of the structure on the loads set on the three-dimensional bone model while fixing the left half of the pelvis.

Figure 8. Comparative indicators of the displacements of part A of the three models.

Figure 9 shows the results of displacements of part B of the pelvic bone model with the same load increment of 100 N.

Figure 9. Comparative indicators of the displacements of part B of the three models
Analysis of the results of the displacements of the three variants of the layout of the apparatus in question showed that under the action of the load range, the first version of the structure of fixing the model of the pelvic bones is more stable. We also note its simplicity and the ability to produce dosage reposition in all directions.

4. Conclusion
The main difficulty was in modeling the bones themselves, and in a large range of vectors of forces acting on the structure. At present, thanks to the integration of computer-aided design systems, the finite element method and a series of tomograms, it is possible to create three-dimensional geometric models of fixing devices like the current prototype. In addition, thanks to the simulation, it is now possible to calculate such design of the apparatus, which, given the minimum required load, would be stable and durable with a small size and quantity of material per unit. These reasons are an incentive for the transition to 3D design and research by the finite element method.

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