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КОМП'ЮТЕРНІ Й ІНФОРМАЦІЙНІ МЕРЕЖІ І СИСТЕМИ. АВТОМАТИЗАЦІЯ ВИРОБНИЦТВА

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COMPUTER MODELING OF IMPLANT FOR FEMUR REINFORCEMENT

О.В. Савєльєва, І.В. Прокопович, А.В. Павлишко, А.Л. Матвєєв, Т.І. Старушкевич. **Комп'ютерне моделювання імплантату для армування стегнової кістки.** Пропонується рішення задачі тривимірного моделювання за розробленими кресленнями експериментальних імплантатів для армування стегнових кісток з можливістю варіації їх параметрів згідно з індивідуальними антропометричними особливостями кожного пацієнта. Побудовано тривимірні моделі імплантату, використовуючи 3D-скан стегнової кістки, проведено розрахунок міцності імплантату під впливом ваги людини, з використанням програм Autodesk 3DsMax 2015 та Inventor. Тривимірні моделі імплантатів дають можливість фахівцям медичних закладів підлаштовувати всі необхідні розміри деталі під індивідуальні антропометричні особливості кожного пацієнта. Побудова моделі дає наочне уявлення про те, як саме буде виглядати імплантат з урахуванням тих чи інших параметрів. Тривимірне моделювання може дати корисну інформацію про поведінку імплантату і взаємодіючих з ним структур організму в «нештатних» ситуаціях, обумовлених, наприклад навантаженням та деформацією, що веде до перелому. Ця інформація дозволяє сформулювати додаткове, до медичних, «технічне» обгрунтування правильного вибору та точної установки імплантату.
Ключові слова: тривимірне моделювання, проксимальний відділ стегнової кістки, профілактичне армування, імплантати, аналіз на міцність, розрахунок навантажень

O. Savelyeva, I. Prokopovich, A. Pavlyshko, A. Matveev, T. Starushkevitch. **Computer modeling of implant for femur reinforcement.** The decision of the problem of three-dimensional modeling according to the developed drawings of experimental implants for the reinforcement of femoral bones with the possibility of variation of their parameters according to individual anthropometric features of each patient is proposed. Three-dimensional models of the implant were constructed using a 3D scan of the femur. The calculation of the strength of the implant under the influence of human weight, using the programs Autodesk 3DsMax 2015 and Inventor was carried out. Three-dimensional implant models enable medical professionals to adjust all the required dimensions of the item to the individual anthropometric features of each patient. The construction of the model gives a clear idea of how the implant will look, taking into account those or other parameters. Three-dimensional modeling can provide useful information on the behavior of the implant and the interacting structures of the body in the "unusual" situations caused by the load and deformation leading to a fracture. This information allows us to formulate an additional medical "technical" justification for the correct choice and accurate installation of the implant.
Keywords: 3D-modeling, proximal femur, preventive reinforcement, implants, strength analysis, calculation of loads

Introduction. Today, computer technology is deeply integrated into various industries. For medicine, this implementation is extremely important and relevant, since it allows minimizing the risks in the course of operations to a particular patient, and as a consequence – allows you to save more lives.

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With the use of three-dimensional computer models for bone surgery preparation, the risk of complications (or lethal consequences) in the patient as a result of such complex surgical interventions is reduced. 3D simulation of the objects of reinforcement allows the surgeon to take into account all the smallest nuances of the physical state of a particular patient, and thereby prevent a fracture in a low-energy trauma [1, 2].

Automation of the process, in turn, allows physicians to quickly make the necessary parameters of the object of reinforcement. This is very important, since doctors do not have the skills of modeling, and even have difficulty in representing three-dimensional objects without special visualization tool [3].

Increased bone strength characteristics are solved in various ways, one of which is preventive reinforcing metal femoral implants to reduce stress concentration. [4] Potential perspectives of this approach are based on reducing the cost of treatment, reducing the likelihood of a fracture, simplicity of the operation compared with the operation for bone fracturing after the fracture, the short duration of post operative procedures, etc.

Certification of such methods requires a comprehensive approach from the side of medicine, as well as from bioengineers, mechanics and specialists in the field of information technology. However, there are currently no methods of three-dimensional simulation with the possibility of introducing precise parameters. As a consequence, there is no relevant information and software with a complete library of standard objects used in bone reinforcement operations, with the calculation of individual anthropometric data of patients [5].

The purpose of the research, the problem statement. The decision of the problem of three-dimensional modeling according to the developed drawings of experimental implants for the reinforcement of femoral bones with the possibility of variation of their parameters according to individual anthropometric features of each patient is proposed. To do this, it is necessary to construct a three-dimensional model of the implant using a 3D scan of the femur, to calculate the strength of the implant under the influence of human weight, using the Autodesk 3DsMax 2015 and Inventor 2017 programs.

Analysis of major achievements and literature (Materials and methods of research). Using different variants of implantation systems can help the surgeon in solving the problems of complicated fractures of the femur in the general arthroplasty of the hip joint, allowing the selection of implants depending on the proximal and distal dimensions [6].

The structure of bone tissue is extremely complex. It has the properties of composite material. It has several layers with clear separate boundaries (compact and spongy substance). But its main feature is the ability to “live”, that is, to change its geometry and content, depending on external loads by creating and destroying the osteons (structural units of bone tissue) [7, 8]. Some of the problems associated with bone tissue are solved in one way or another, and some are not solved and require a comprehensive study.

Thus, for example, fractures that occur in the background of osteoporosis (reduced bone density, disturbance of its microarchitecture and increased fragility), represent a global medical and social problem [9]. As the research has shown, at osteoporosis there are fractures of different localization, and especially in the neck of the femur, which led to recognition of this disease one of the most important health problems.

From various literary sources it is known that in the world every year in people of older age groups there are 1.5 million fractures. Of these, 19 % falls on the share of femur fractures. In addition, each year the number of people prone to a fracture increases. The International Osteoporosis Foundation predicts an increase by up to 2050 in the number of cervical fractures by 300 % [2, 10].

Unfortunately, this type of fracture is even the most dangerous. It has extremely serious medical and social consequences. Only 15 % of patients will be able to return to their normal lifestyle – to restore the ability to travel without additional support. Moreover, surgical intervention has a high risk for the elderly.

Such a small percentage of successful operation is due to the fact that existing implants for bone joining increase the dilution of bone tissue around them. In connection with the inability to restore the integrity of the thigh, lethality in the first two years after the fracture of the femoral neck is more than 30 % (and one in four in the first six months). Not to mention the decline in the quality of life, since a person is very limited in motion and even deprived of the opportunity to walk. According to the World Health Organization, fractures of the proximal femur give osteoporosis the 4-th place among all causes of disability and mortality [10, 11]. Such severe consequences of the fracture lead to the fact that only the fear of falling causes the elderly to self-limit their physical and social activity. Another economic reason that increases the severity of the neck fracture is the cost of treatment. According to various authors, 70 % of the bed fund are occupied by patients with this type of fracture, hospitalization lasts an average of 30 days. In Europe, the cost of treatment and rehabilitation is about 35 thousand dollars [12, 13]. Failures and complications during endoprosthetics of the femur with the use of modern foreign or domestic endoprostheses are determined not only by the weight and frequency of the pathology of the femur, but also by the absence of a clear system of planning the operation, that is, the implantation of the components of the endoprosthesis in each particular case.

Fig. 1. The main sections of the femur: 1 – head; 2 – a large spit; 3 – rectangular fossa; 4 – neck; 5 – small spit; 6 – proximal section (all above the intersection A–A); 7 – the body

Existing schemes show the general technique of possible planning of an operation without taking into account specific biomechanical conditions. This often causes simply the transfer of the template to the X-ray, rather than the decision pathological changes by implantation of the endoprosthesis [14].

The use of conservative methods of treatment does not allow to adequately dealing with the problem of femur fracture. Surgical intervention with implants enables to restore only 50 % of the strength of the bone from its initial strength to the fracture [15].

Consider the proposed method of preventive reinforcement of the femoral neck, prone to a fracture for the elderly [16].

The bone is a solid (bearing) component of the endosculpture of a living organism. The composition of bone tissue includes organic and inorganic substances [17]. The older the bone, there are more inorganic substances. When aging of bone tissue along with hardness there is brittleness. The simplified structure of the femur, sufficient for this study, is presented in Fig. 1.

The complex geometric structure of the femur requires precise measurements to build a computer model. For the study, it is necessary to use a laser scan of the human femoral surface, which accurately repeats the geometry of the real thigh, while bone geometry is available electronically [18].

Fig. 2 shows a three-dimensional model of the bone surface obtained by laser scanning, which consists of many triangles, that is, the triangulation of the surface of the femur bone is performed.

To simulate a tense deformed state of the neck of the thigh is enough to be used in calculations of the upper 2/3 of the femur. This fact greatly simplifies the geometric complexity of the femur and, accordingly, saves the processor time of the numerical experiment [19].

The internal structure of the bone is quite complicated. It contains cartilage and cortical plates, blood vessels, bone marrow, and others. In this connection, the bone needs to be idealized to simplify the resulting calculation model. Therefore, in bones most often distinguish compact (dense) and spongy (soft) bone matter.


Fig. 2. Geometric model of the femur, obtained by laser scanning

Compact fabric is homogeneous, hard and is an outer layer of bone. In bones it can occur in the form of a thin film, and maybe it is much

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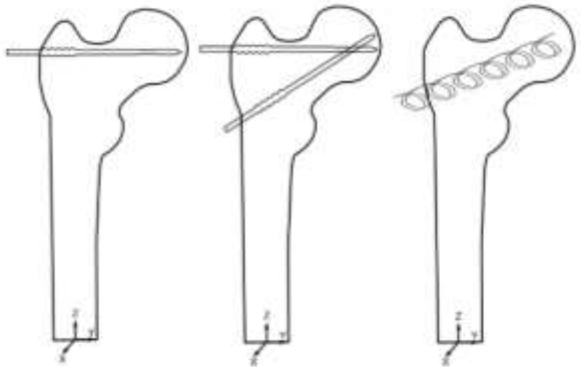

a b c

Fig. 3. Location of the implants in the bone: spin (a); a spin + a spin (b); a crew – corkscrew (c)

thickened. Spongy substance consists of interconnected plates that intersect in different directions. Such a connection forms a system of cavities and openings that are filled with other bone substances.

In particular, in the middle of long bones a large cavity is filled with bone marrow. In the process of aging of the body in the bones there is an increase in the proportion of mineral substances, which makes the bones become more fragile [17, 19].

Due to the complex geometry of the femur and the hip bone mathematical modeling can be done only on the basis of the numerical approach, eg based on finite element method (FEM). Therefore, apart from the geometry and internal structure for many experiments, it is important to choose the size of the finite element so that the main features of the structure of the bone tissue are not lost.

If in a metal material the finite element can be reduced to the sizes of a crystalline lattice, the size of which is very small (and the more precisely the finite element grid sets the volume of the element of construction, in the general case, we obtain a more precise solution from the point of view of mathematics), then the bone has no crystalline lattices Thus, it is necessary to find out the dimensions of the structural element of the bone tissue, which will be the justification for choosing the size of the finite element [16, 19].

Reinforcement of the femur. Three devices (spin, corkscrew, screw) [20, 21] were designed and patented for the reinforcement of biological composite material and prevention of femoral neck fractures in patients at risk, which can be implanted in the bone in various combinations.

Schematically, the location of some implants is shown in Fig. 3. In terms of medicine, it is important to minimize bone damage during implantation, as well as not touching the solid bone layer that is on the surface, so as not to destroy it.

When inserting an implant in the form of a spin, it is introduced “perpendicularly” to the axis of the femur (perpendicular to the axis *OZ*, see Fig. 3). When inserting two spins needles one of them is inserted perpendicular, and the second inserted at an angle of approximately 50°, and the spins inside the bone do not intersect. Implant in the form of a corkscrew is inserted at an angle of approximately 50°. The geometric orientation of the implants and the choice of the angles of their placement are due to the medical practice of implant research to merge the already demolished femur neck [20, 21].

This article discusses the device “screw – corkscrew”. Screw – corkscrew [21] is an implant consisting of a twisted spiral spoke (Fig. 4) having a head provided with a screwdriver slot. The key feature is that the spoke is twisted in the form of a spiral with an outer diameter of a circle of 8.0 mm and a pitch of 8.0 mm.

One of the positive qualities of a screw – corkscrew is that it possesses the property of damping, that is, the ability to reduce the amplitude of oscillatory movements.

As a material for implants it is supposed to use stainless steel, nickel or titanium alloys with the following mechanical characteristics: $E = 2 \cdot 10^{11}$ Pa, $v = 0.3$. Since the predicted values of stress in the implants do not go beyond the boundary of the elastic zone, the linear mechanical characteristics of the metal materials are sufficient for this study [21, 22].

We will design the implant model in the 3D modeling program Autodesk 3DsMax 2015. Construction begins with a screw part. Based on the drawing, the required Helix parameters are determined.

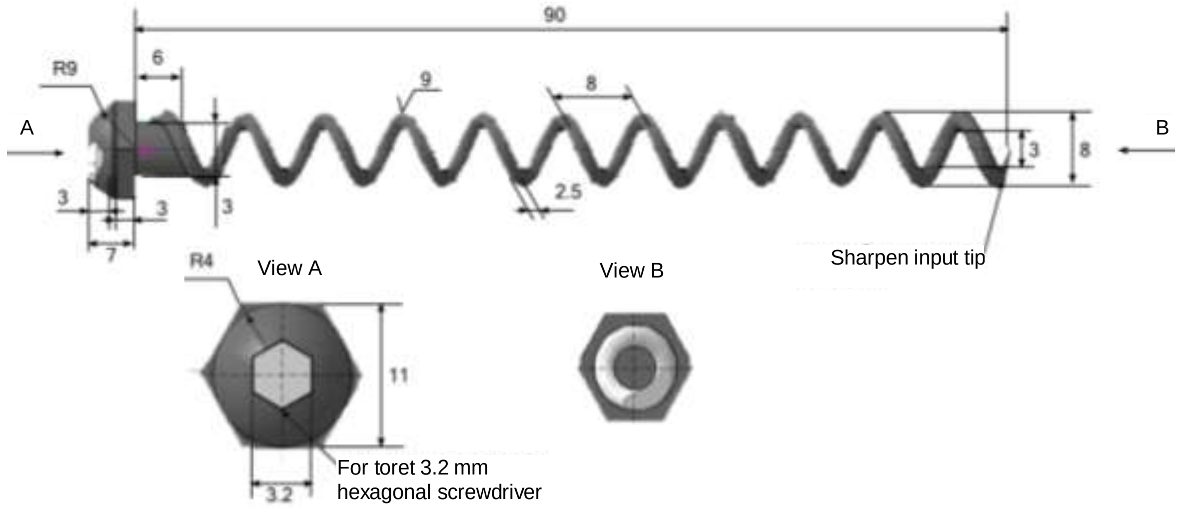

Fig. 4. Implant in the form of a screw-corkscrew

Now, in order to give the thickness of the resulting spiral, it is necessary to create a circle that will be the intersection of the part. The diameter of this circle should be 2.5 mm. To implement this manipulation, the Loft tool (Fig. 5) is used.

After that, the user begins to model the implant head. A hexagonal prism is created. Its width should be 11 mm and height 3 mm (Fig. 6).

Now you need to add a spherical part of the head. To do this, a half of the intersection of this part is created and using the Lattice tool, it is rotated around the given axis (Fig. 7).

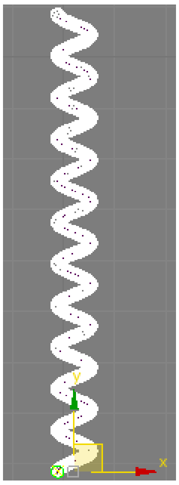

Fig. 5. Screw obtained using the Loft tool

Fig. 6. Hexagonal prism with screw

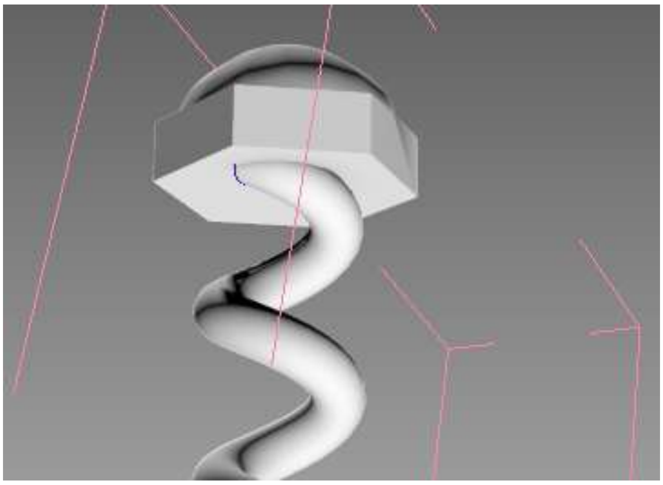

Fig. 7. Annex spherical part of the implant head

It remains only to cut a hole in the head, which also has the form of a hexagonal prism. The hole must have a depth of 3 mm and a width of 3.5 mm, according to the measurement drawing. The hole is cut out using the Subtraction Boolean operation.

The volumetric model of the screw implant built in the Autodesk 3DsMax 2015 system, taking into account all the necessary parameters, is presented in Fig. 8.

Due to the construction of the implant model, it is possible to place it in the proximal femur obtained by 3D scanning (Fig. 9).

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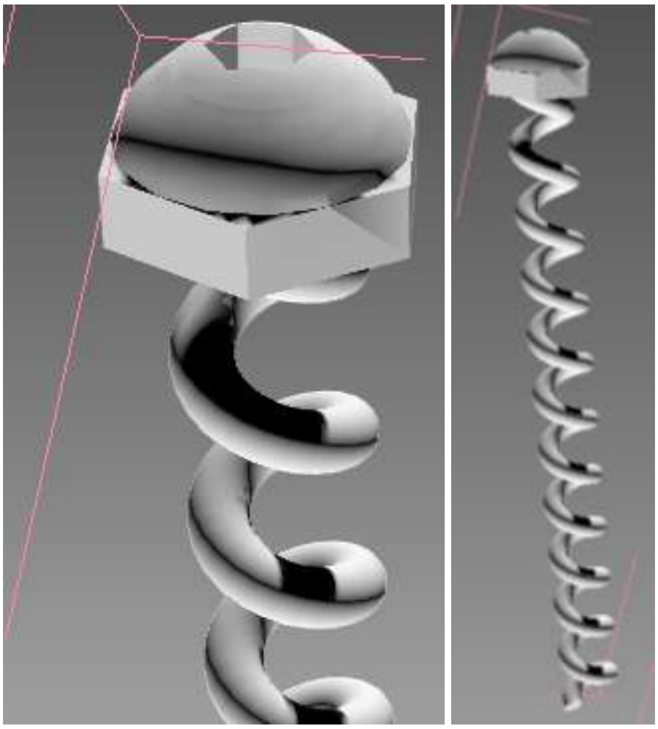

Fig.8. A three-dimensional model of the screw implant is ready

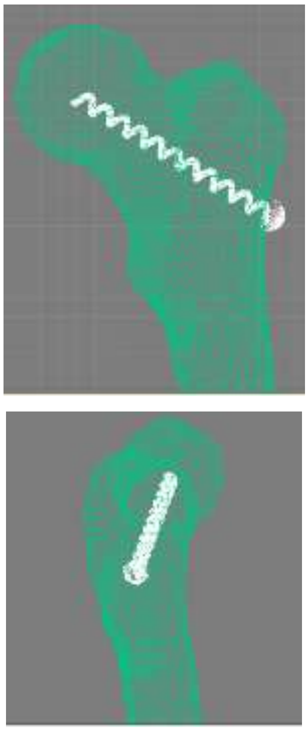

Fig. 9. Screw implant, located in the femoral bone

Calculation of the implant model for durability. The calculation of the implant model for durability was carried out in the Autodesk Inventor 2017 program [23].

To start a static analysis, a startup window is launched, which specifies the type of study and the state of the model.

In order to calculate the load, it is necessary to begin to correctly assign the materials of objects to begin. To do this, go back to the implant file and assign a material, for example: Stainless steel (Fig. 10).

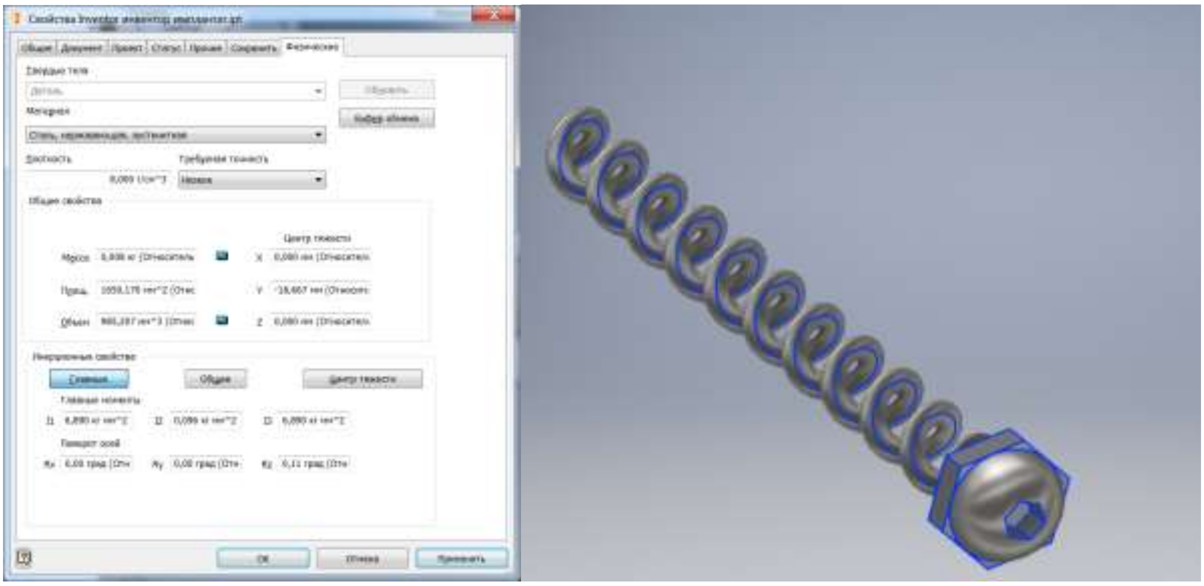

Fig. 10. The window of material designation

After this you need to fix the fixation. The surface of the implant head, which adjoins the bone directly (Fig. 11), is indicated.

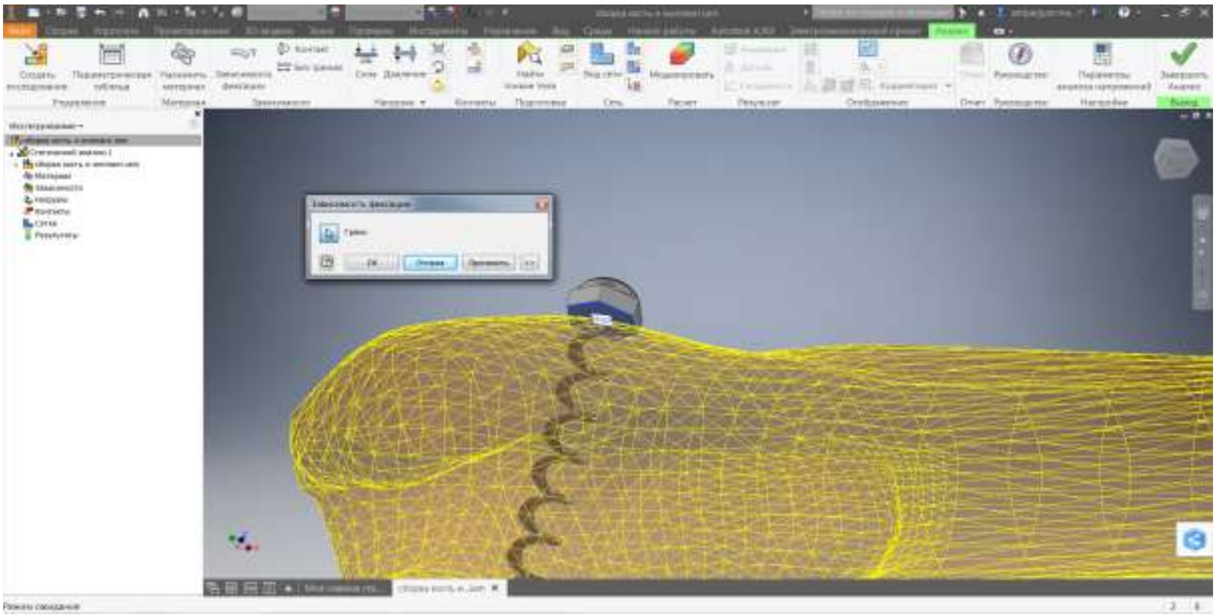

Fig. 11. The function of establishing dependencies of implant fixation from the femur bone

It is also necessary to deploy the bone with the implant as it should be located in the human skeleton (i.e., the bone is vertically) and indicate the forces that affect the implant. The first arrow is the usual gravity (Fig. 12).

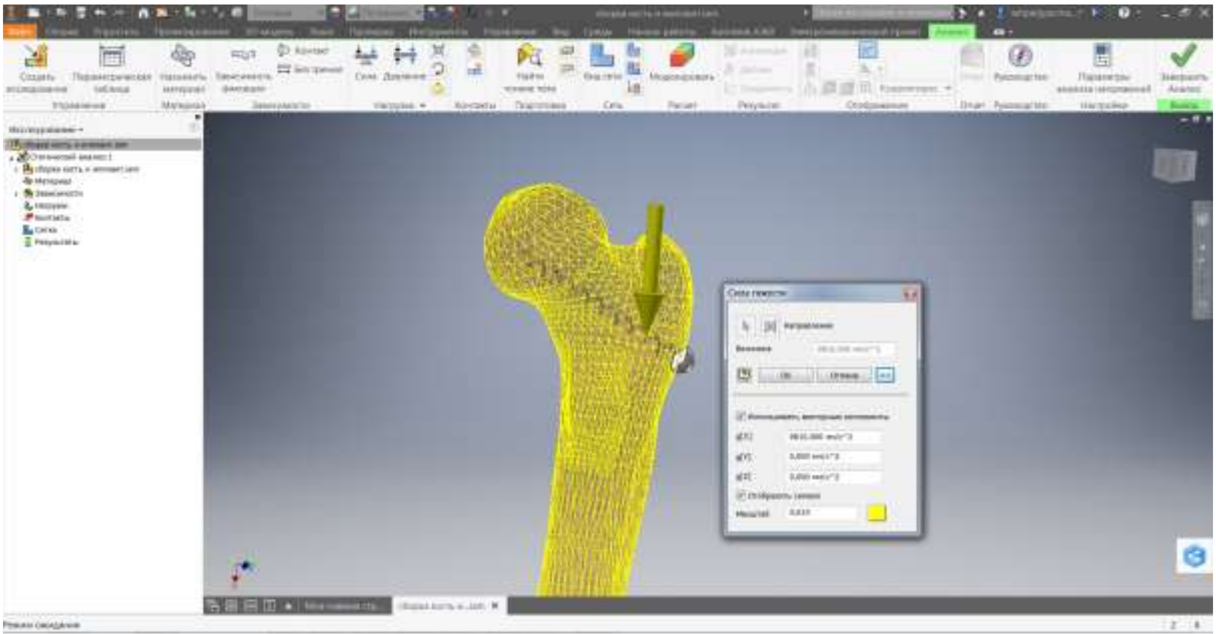

Fig. 12. Establish gravity that affects the implant

And another force – the second arrow, it's already a mass of a person that affects the bone with the implant. For example, we set a mass of 60 kg, which is approximately equal to 600 N (Fig. 13).

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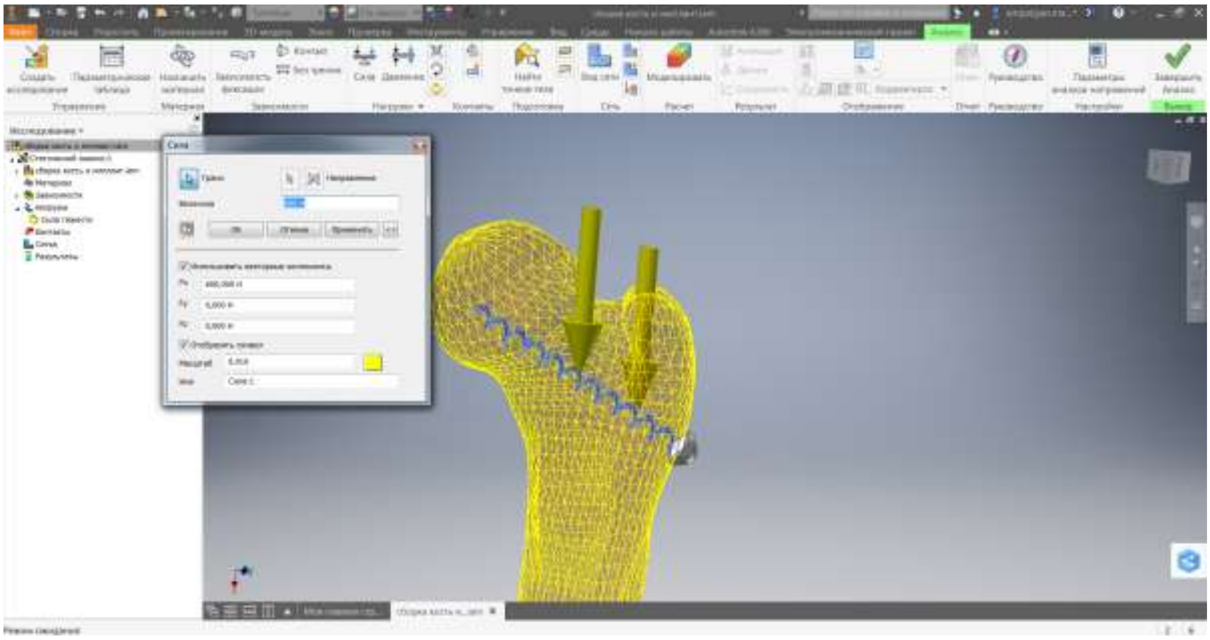

Fig.13. Establishing the weight of the person who affects the implant

As shown in Fig. 14, under the greatest pressure was the area of the screw element adjacent to the implant head (95071 MRa).

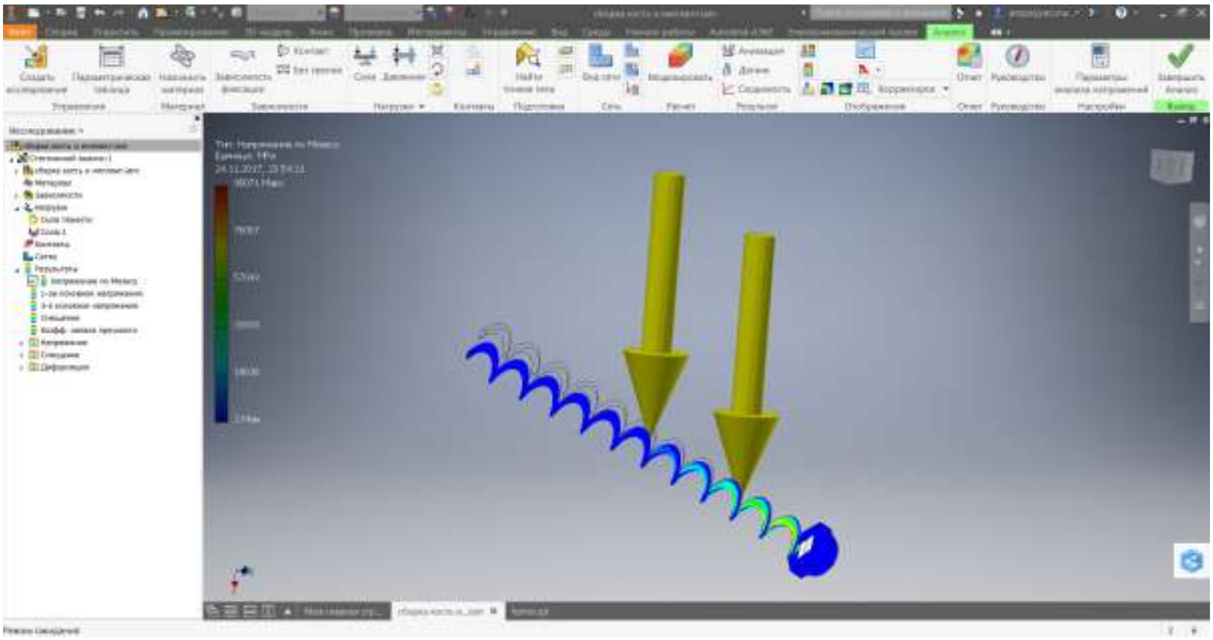

Fig. 14. Calculate the load of the implant

Conclusions. The main purpose of the study was to create a three-dimensional implant model for reinforcing the proximal segment of the femur.

For this purpose, literary sources on the structure of the bone were used and individual cases subject to the reinforcement operation. Modern methods of bone reinforcement using different metal structures were considered.

In the course of the study, a three-dimensional implant model was constructed and a 3D scan of the femur was used to calculate the implant strength under the influence of human weight using Autodesk 3DsMax 2015 and Inventor 2017 programs.

Three-dimensional design of the implant allows the introduction of various parameters of its constituent parts. Due to this, it was possible to adjust all necessary parts dimensions for individual anthropometric features of each patient. Such design gives a clear idea of how the implant will look, taking into account those or other parameters.

It will allow doctors to quickly establish the necessary parameters of the reinforcement object, which is extremely important, since physicians have no more modeling skills and even experience difficulties in representing three-dimensional objects without a special visualization tool.

Conducting a static analysis of strength helps to find the best options for designing three-dimensional models. Yes, you can ensure that the implant will function satisfactorily in the foreseeable conditions without defects, deformations and damage to the patient's health.

Thus, the use of three-dimensional computer models for preparing for bone operations reduces the risk of complications (or lethal consequences) of a patient as a result of such complex surgical interventions.

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