Mathematical modeling of the acetabulum fracture (type 62-B1.3 by AO/ASIF) deformities and hip endoprosthetics in combination with osteosynthesis

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Secondary degenerative disabling changes in the hip joint often develop in the long term after surgical treatment of hip fractures. A well-founded differential approach to the selection of endoprosthesis components and additional means of stabilizing bone fragments is necessary. Objective. To investigate changes in relative deformation values in a hip joint model with a acetabulum fractures 62–B1.3 type by AO/ASIF classification under the conditions of its endoprosthesis using various osteosynthesis options. Methods. A basic finite-element model of the pelvic girdle of a person with a fracture of the bottom of the cruciate ligament type 62-B1.3 (AO/ASIF) was developed, on which 7 variants of endoprosthesis of the left hip joint were modeled: without fracture (1); without osteosynthesis of fragments (2); fixation of a fragment of the acetabulum back wall with two screws (3), two screws and a bone plate (4), two screws and a bone plate with a Jumbo cup implantation (5); 5 case, long screw in the front column (6); option 5, long screws in the front and rear columns (7). Results. When using a large-sized Jumbo cup, the relative deformations of the bone regenerate in the center of the bottom of the KZ were reduced to 1.0 %, regardless of the osteosynthesis option. Around the free fragment of the short circuit, the largest relative deformations (3.0 %) were found in version 5 of the model. The use of long rods in the columns led to decrease in the relative deformations of the bone regenerate around the free fragment of the KZ to 2.0 %. Conclusions. Mathematical models proved that an increase in the number of osteosynthesis tools under the conditions of the total hip endoprosthesis replacement, 62-B1.3 (AO/ASIF) type KZ fracture leads to a decrease in the relative deformations of the bone regenerate along the entire fracture line. The use of a large-sized Jumbo cup makes it possible to reduce the level of relative deformations of the bone regenerate in the central part of the KZ.

Після хірургічного лікування переломів кульшової западини (КЗ) у віддаленому періоді часто розвиваються вторинні дегенеративні інвалідизуючі зміни в кульшовому суглобі. Необхідний обґрунтований диференційний підхід до вибору компонентів ендопротеза та додаткових засобів стабілізації кісткових фрагментів. Мета. Дослідити зміни величин відносних деформацій у моделі кульшового суглоба з переломом КЗ типу 62-B1.3 за класифікацією AO/ASIF за умов його ендопротезування з використанням різних варіантів остеосинтезу. Методи. Розроблена базова скінченно-елементна модель тазового поясу людини з переломом дна КЗ типу 62-B1.3 (AO/ASIF), на якій моделювали 7 варіантів ендопротезування лівого кульшового суглоба: без перелому (1); без остеосинтезу відламків (2); фіксація фрагмента задньої стінки КЗ двома гвинтами (3), двома гвинтами та накістковою пластиною (4), двома гвинтами та накістковою пластиною зі встановленням чашки Jumbo cup (5); 5 випадок, довгий гвинт у передній колонні (6); варіант 5, довгі гвинти в передній і задній колоннах (7). Вивчали величину відносних деформацій кісткового регенерату в зоні перелому. Результати. За використання чашки великого розміру Jumbo cup зменшувалися відносні деформації кісткового регенерату в центрі дна КЗ до 1,0 % незалежно від варіанта остеосинтезу. Навколо вільного фрагмента КЗ найбільші відносні деформації (3,0 %) виявлено у варіанті 5 моделі. Застосування довгих стрижнів у колоннах привело до зниження величини відносних деформацій кісткового регенерату навколо вільного фрагмента КЗ до 2,0 %. Висновки. На математичних моделях доведено, що збільшення кількості засобів остеосинтезу за умов ендопротезування кульшового суглоба з переломом КЗ типу 62-B1.3 (AO/ASIF) приводить до зменшення величини відносних деформацій кісткового регенерату вздовж всій лінії зламу. Використання чашки великого розміру Jumbo cup дає можливість знизити рівень відносних деформацій кісткового регенерату в центральній частині КЗ. Ключові слова. Математичне моделювання, кульшова западина, перелом, ендопротезування, остеосинтез, деформація.

Key words. Mathematical modeling, acetabulum, fracture, endoprosthesis, osteosynthesis, deformation

Introduction

Treatment of acetabular fractures in the remote postoperative period in most cases triggers the development of secondary degenerative, disabling changes in the hip joint [1].

Type B acetabular fractures are accompanied by a shift of the distal fragment to the medial side, the ilium, which forms the upper and partially posterior walls of the acetabulum, in the case of an intact sacroiliac joint, is displaced insignificantly. The instability of fragments that occurs during loading makes it impossible to press-fit fixation of the acetabular component of the endoprosthesis and in our opinion it is leveled by stabilizing the posterior column of the acetabulum with a plate or a long screw. Stabilization of the front column with polyaxial screws, through the cup, increases the strength of the fixation of the latter.

Primary endoprosthetic repair in an acetabular fracture is complex and non-trivial, requiring the use of additional methods and means of osteosynthesis for stable installation of the acetabular component, along with the Jumbo cup. Modern publications characterize the Jumbo cup as an acetabular component of a hip arthroplasty with a diameter of 66 mm or more for men and 62 mm for women [2]. According to an alternative definition, its size is determined by individual anatomical parameters, and is formed by adding 10 mm to the radiologically determined diameter of the opposite acetabulum [3].

Implantation of an acetabular component of increased size requires a wider treatment of the acetabulum, with the formation of a native bone bed of an increased area, which, in turn, forms a more reliable support for fixing the cup, with admissible proximalization of the center of rotation of the joint. Jumbo cup installation is carried out using standard equipment and tools, does not require additional augments or anti-protrusion rings. These cup fixation features are implemented during hip revision surgery.
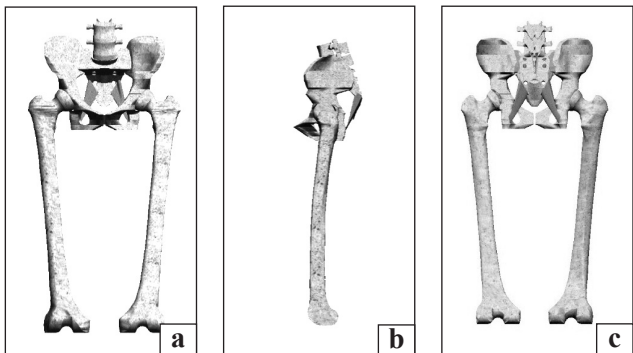
The use of the Jumbo cup is one of the most common techniques solving the problem of reliable installation of the acetabular component in extensive Paprosky IIIa–IIIb acetabular defects. In our judgments, we draw an analogy between defects of the acetabulum of non-traumatic origin and fractures and assume the feasibility of using the Jumbo cup. But the optimal choice of endoprosthesis components and osteosynthesis means has every opportunity to prevent such complications, restore patient activity and obtain positive socio-economic consequences, as well as significantly eliminates the need for complex, traumatic, staged surgical interventions with unpredictable functional consequences in the future.

A differential approach to the selection of endoprosthesis components and additional means of stabilizing bone fragments should be carried out not empirically, but on the basis of scientifically based theoretical principles [4].

The purpose of the study. To investigate the changes in relative deformation values in a model of a hip joint with a type 62-B1.3 fracture of the acetabulum according to the AO/ASIF classification in the case of its endoprosthetic repair using different options of osteosynthesis.

Material and methods

A basic finite element model of the human pelvic girdle with femurs was elaborated in the biomechanics laboratory of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine [7]. The appearance of the model is shown in Fig. 1.

A 62-B1.3 acetabulum floor fracture according to the AO/ASIF classification was simulated on the basic model. Modeling was performed by installing layers with mechanical properties of bone regenerate on the fracture lines (Fig. 2).

Seven options for endoprosthetic repair of the left hip joint for this type of hip fracture were created:

– 1 — without fracture (control);

– 2 — without means of osteosynthesis of fragments;

– 3 — with fixation of a fragment of the posterior wall of the acetabulum with two screws;

– 4 — with fixation of a fragment of the posterior wall of the acetabulum with two screws and a bony plate.

– 5 — using a Jumbo cup and fixing fragments of the posterior wall of the acetabulum with two screws and a bone plate;

– 6 — using a Jumbo cup and fixing fragments of the posterior wall of the acetabulum with two screws and a bone plate, a long screw in the front column;

Fig. 1. Basic finite element model: anterior view (a), in the sagittal plane (b), posterior view (c)

– 7 — installation of a Jumbo cup, fixation of a fragment of the posterior wall of the acetabulum with two screws, long screws in the front and posterior columns.

Differences in additional methods of fixation of bone fragments, as well as the difference in the size of acetabular components and the number of screws that fix them, clearly demonstrate a directly proportional reduction of deformations in the joint with an increase in the number of fixing elements. This analysis and awareness of iatrogenic traumatization allow us to select, from among all theoretically possible, precisely those combinations of osteosynthesis with endoprosthetic repair, which are most expedient to use in practice.

Fig. 3 shows options for installing a standard hip endoprosthesis cup and hip socket osteosynthesis elements.

Fig. 4 presents options for using a hip joint endoprosthesis with a large Jumbo cup and elements of hip socket osteosynthesis.

In our study, the material was treated as homogeneous and isotropic. A 10-node tetrahedron with a quadratic approximation is chosen as the final element.

The corresponding mechanical properties were determined for all materials from which the models were made, namely Young's modulus of elasticity and Poisson's ratio (Table 1). The mechanical properties of biological tissues were selected in accordance with the literature [6–9], and that of metal structures in accordance with the technical literature [10].

In the course of the study, one-support standing on the left limb was modeled. For this, the samples were loaded with a vertical distributed force of 540 N, which corresponds to the average weight of a person without taking into account the weight of the supporting limb. The action of the hip adductor muscles between the greater trochanter of the left femur and the wing of the iliac bone was simulated by introducing the appropriate forces: *m. gluteusmedius* (medial
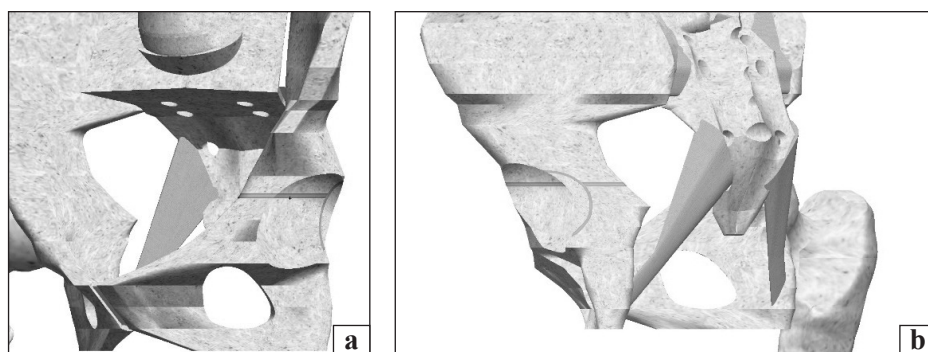

Fig. 2. Model of type 62-B1.3 according to AO/ASIF classification acetabular fracture: anterior (a) and posterior (b) views
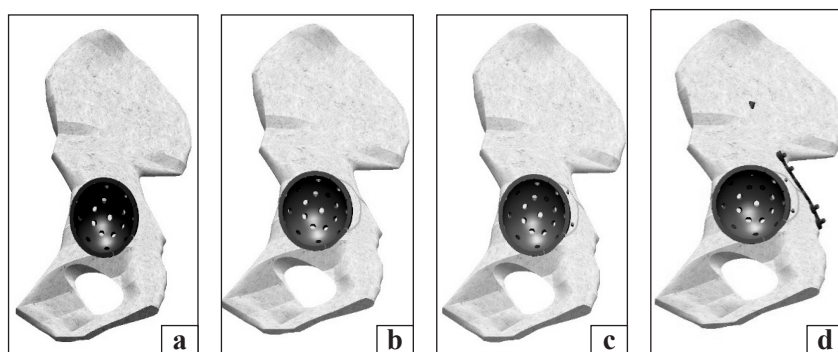

Fig. 3. Options for installing a standard hip endoprosthesis cup: a) endoprosthesis without a fracture (option 1); b) cup without elements of osteosynthesis (option 2); c) osteosynthesis of a fragment of the posterior wall of the acetabulum with two screws (option 3); d) osteosynthesis of a fragment of the posterior wall of the acetabulum with two screws and a bone plate (option 4)
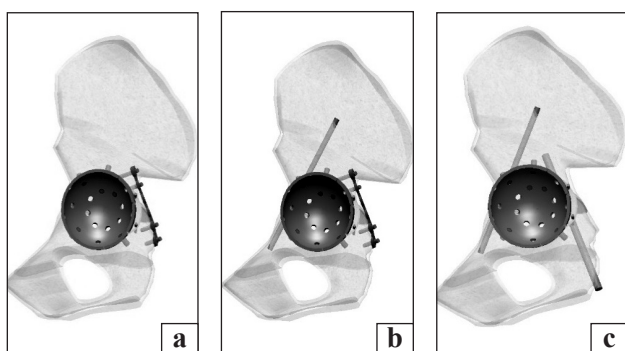

Fig. 4. Options for installing a hip joint endoprosthesis with a Jumbo cup, osteosynthesis, fixation of a fragment of the posterior wall of the acetabulum: a) with two screws and a bone plate (option 5); b) two screws and a bone plate, a long screw in the anterior column (option 6); c) two screws, long screws in the anterior and posterior columns (option 7)

gluteal muscle) — 1,150 N and *m. gluteusminimus* (small gluteal muscle) — 50 N [11, 12]. In the area of the knee joint at the level of the condyles of the left femur, all models had rigid fixation. The loading scheme of the models is shown in Fig. 5.

To compare the changes in the stress-strain state of different models, we studied the relative deformations of the bone regenerate in the fracture zone, which is the element most prone to deformation due to the lowest value of the modulus of elasticity.

The stress-strain state of the models was studied using the finite element method. The value of the relative deformation was used as a criterion for evaluating the stress state of the models [10].

Modeling was performed using the SolidWorks automated design system. Calculations of the stress-strain state of the models were carried out using the CosmosM software complex [13].

Results and their discussion

At the first stage of the study, the relative deformations of the bone regenerate in models with a standard cup were assessed. The distribution of deformations in the models is shown in Fig. 6.

It was determined that during endoprosthetic repair of a hip joint with a type 62-B1.3 fracture of the acetabulum floor according to the AO/ASIF classification using a standard endoprosthesis cup, the largest relative deformations of the bone regenerate

Table 1

Mechanical characteristics of materials used for modeling

Material	Young's modulus (E), MPa	Poisson's ratio, ν
Cortical bone	18350	0.29
Spongy bone	330	0.30
Cartilaginous tissue	10.05	0.49
Bone regenerate	1.00	0.45
Titanium BT-16	$1.1 \cdot 10^5$	0.20

Fig. 5. Model loading scheme

occurred in the model without additional means of osteosynthesis. Therefore, the amount of relative deformation of the regenerate around the free fragment reached 5.0 %, with 3.0 % at the bottom of the acetabulum.

Reproduction on the model of the use of osteosynthesis tools made it possible to reduce deformations of the bone regenerate along the entire fracture line. In particular, fixation of a free fragment of the acetabulum made it possible to reduce the relative deformation of the bone regenerate around it to 3.0 %, and in the center of the acetabulum to 2.0 %.

Additional installation of the periosteal plate resulted in an even greater decrease in the relative deformation of the bone regenerate, both around the free fragment — up to 2.0 %, and in the center of the acetabulum — up to 1.5 %.

We considered how the relative deformations of the bone regenerate changed in a model with a fracture of the acetabulum after the use of endoprostheses with a Jumbo cup. Fig. 7 shows the distribution of relative deformations of the bone regenerate in the models.

The results of the simulation allow us to state that the use of a large Jumbo cup leads to a decrease in the relative deformations of the bone regenerate in the center of the bottom of the acetabulum to 1.0 %, regardless of the osteosynthesis option. Around the free fragment of the acetabulum, the largest relative deformations at the level of 3.0 % were found in the model with osteosynthesis as per option 5: fixation of the fragment of the posterior wall of the acetabulum with two screws and a bone plate.

The use of long rods in the rear or in the posterior and anterior columns made it possible to reduce the relative deformations of the bone regenerate around the free fragment of the acetabulum to 2.0 %.

The indicators of relative deformations of the bone regenerate in models of the hip joint during its endoprosthetic repair in the conditions of a fracture of the bottom of the acetabulum are given in Table 2.

A diagram was constructed for a visual comparison of the values of relative deformations at control points on the bone elements of the hip joint models in the case of its endoprosthetic repair under the conditions of a type 62-B1.3 acetabular fracture according to the AO/ASIF classification, shown in Fig. 8.

It has been proven that the addition of osteosynthesis, as well as the use of a cup with an increased diameter, makes it possible to reduce the level of relative deformations of the bone regenerate along the entire fracture line. To a greater extent, this applies to the central part of the bottom of the acetabulum, to a lesser extent to the free fragment. This can be
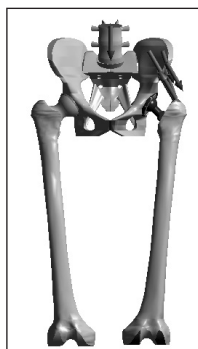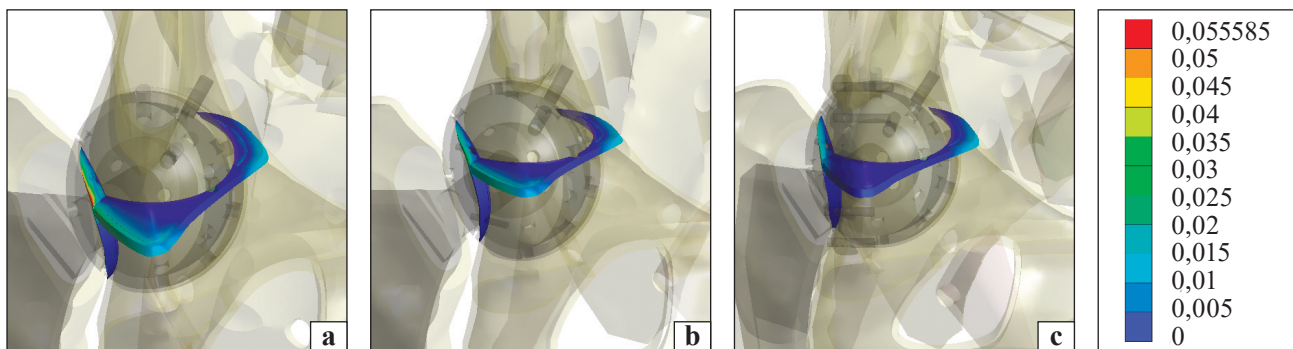
Fig. 6. Distribution of relative deformations of bone regenerate in models with a standard cup: a) without osteosynthesis (option 2); b) osteosynthesis of a fragment of the posterior wall of the acetabulum with two screws (option 3); c) osteosynthesis of a fragment of the posterior wall of the acetabulum with two screws and a bone plate (option 4)
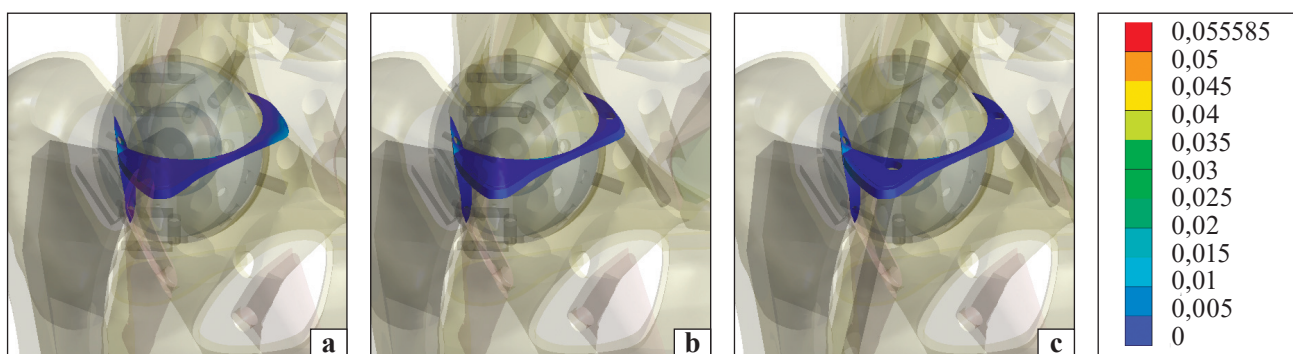

Fig. 7. Distribution of relative deformations of bone regenerate in models with an acetabular fracture in endoprosthetic repair with a Jumbo cup; osteosynthesis with fixation of a fragment of the posterior wall of the acetabulum: a) two screws and a bone plate (option 5); b) two screws and a bone plate, a long screw in the front column (option 6); c) two screws, long screws in the anterior and posterior columns (option 7)
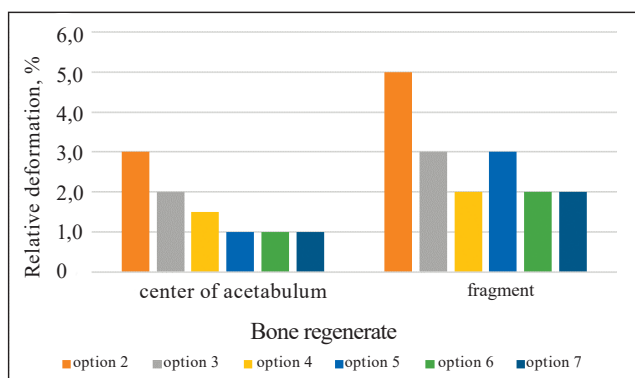

Fig. 8. Diagram of the values of the relative deformations of the bone regenerate in the models of the hip joint in its endoprosthetic repair in type 62-B1.3 acetabular fracture according to the AO/ASIF classification

Table 2

The magnitudes of the relative deformations of the bone regenerate in models of the hip joint with type 62-B1.3 acetabular fracture according t o the AO/ASIF classification in endoprosthetic repair

Osteosynthesis		Relative deformation, %	
cup	osteosynthesis	center of acetabulum	fragment
standard	option 2	3.0	5.0
	option 3	2.0	3.0
	option 4	1.5	2.0
Jumbo cup	option 5	1.0	3.0
	option 6	1.0	2.0
	option 7	1.0	2.0

explained by the fact that the additional means of osteosynthesis used together with the Jumbo cup are aimed at increasing the strength of the anterior and posterior supporting columns of the pelvis, and not at fixing the free fragment.

Conclusions

Mathematical models proved that increasing the number of osteosynthesis tools in endoprosthetic repair of the hip joint with type 62-B1.3 acetabular fracture according to the AO/ASIF classification leads to a decrease in the relative deformations of the bone regenerate along the entire fracture line.

The use of a large-sized Jumbo cup makes it possible to reduce the level of relative deformations of the bone regenerate in the central part of the acetabulum, but around the free fragment it does not differ from models with a standard cup.

Conflict of interest. The authors declare no conflict of interest.

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