ISSN 1814-6023 (Print)
ISSN 2524-2350 (Online)
УДК 616.718.42-001.5-089.844:612.76
https://doi.org/10.29235/1814-6023-2022-19-3-330-336

Поступила в редакцию 01.02.2022
Received 01.02.2022

Oleksandr O. Kostrub[1], Yurii V. Polyachenko[1], Mikhail A. Gerasimenko[2], Nazar S. Vadzyuk[1], Vladimir V. Kryvenyuk[3], Viktor V. Kotyuk[1]

[1]Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine, Kiev, Ukraine
[2]Republican Scientific and Practical Center of Traumatology and Orthopedics, Minsk, Republic of Belarus
[3]Institute for Problems of Strength by G. S. Pisarenko of the National Academy of Sciences of Ukraine, Kiev, Ukraine

BIOMECHANICAL EVALUATION OF FEMORAL NECK FRACTURE OSTEOSYNTHESIS

Abstract. Bone geometry, density, and thickness of the cortical layer of the femoral neck (FN) contribute to the mechanical strength in osteosythesis of femoral neck fractures (FNF) in young adults. The available techniques for fracture fixation of the FN are reviewed with respect to the biomechanical stability.

A biomechanical study of the osteosynthesis stability of the FNF with three cannulated screws was carried out using synthetic models of the proximal part of the femoral bone (FB). The experimental models were divided into 4 groups. Each group related to the configuration of screws in the FN. The vertical and horizontal FNF stability was assessed using two series of load. In series I, models were loaded with forces in the longitudinal axis to the FB and in series II, forces acted in the perpendicular direction to the FB axis. The loading forces were evaluated when the displacement of 2 mm fragments was achieved. The highest stability strengths were obtained in group I in the both series – 1898 N with a vertical load and 1046 N with a horizontal load. Further, in decreasing order, the results of stability were obtained in groups II, III and IV.

In this study, it was found that the consideration of the position of screws according to architectonics of the FN is crucial for fragment stability. The triangular position of screws with three points of contact with the compact bone ensures the maximum stability of the construct in osteosynthesis of the FN fractures, which is comparable to the normal walking load conditions.

We hypothesize that osteosynthesis of FN fractures with three screws in a triangular manner could provide a better stability when inserted into the dense tissues of the proximal FB with relation to bone architectonics. To ensure a maximum stability, each screw should have three points of contact with the compact bone – the lateral cortical wall of the subtrochanteric region of the FB, the inner wall of the FN, and the compact part of the FB head. New triangular configuration of screws' placement could have a better neutralization of share forces in FN fractures.

Keywords: femoral neck fracture, screw osteosynthesis, bone biomechanics

For citation: Kostrub O. O., Polyachenko Yu. V., Gerasimenko M. A., Vadzyuk N. S., Kryvenyuk V. V., Kotyuk V. V. Biomechanical evaluation of femoral neck fracture osteosynthesis. *Vestsi Natsyyanal'nai akademii navuk Belarusi. Seriya meditsinskikh navuk = Proceedings of the National Academy of Sciences of Belarus. Medical series*, 2022, vol. 19, no. 3, pp. 330–336. https://doi.org/10.29235/1814-6023-2022-19-3-330-336

А. А. Коструб[1], Ю. В. Поляченко[1], М. А. Герасименко[2], Н. С. Вадзюк[1], В. В. Кривенюк[3], В. В. Котюк[1]

[1]Институт травматологии и ортопедии НАМН Украины, Киев, Украина
[2]Республиканский научно-практический центр травматологии и ортопедии, Минск, Республика Беларусь
[3]Институт проблем прочности имени Г. С. Писаренко НАН Украины, Киев, Украина

БИОМЕХАНИЧЕСКОЕ ИССЛЕДОВАНИЕ ОСТЕОСИНТЕЗА ПЕРЕЛОМОВ ШЕЙКИ БЕДРЕННОЙ КОСТИ

Аннотация. Геометрия кости, плотность и толщина кортикального слоя шейки бедренной кости (ШБК) способствуют механической прочности при остеосинтезе переломов шейки бедренной кости (ПШБК) у молодых людей. Доступные методы фиксации ПШБК рассмотрены с точки зрения биомеханической стабильности.

Проведено биомеханическое исследование стабильности остеосинтеза ПШБК тремя канюллированными спонгиозными винтами с применением синтетических моделей проксимального отдела БК. Экспериментальные модели были распределены на 4 группы. Каждая группа соответствовала определенной конфигурации взаимного расположения винтов в ШБК. Эксперимент проводился в двух сериях. В I серии модели подвергались вертикальной нагрузке, во II серии – горизонтальной нагрузке. Действие силы фиксировали при смещении отломков на 2 мм. Наилучшие показатели прочности фиксации получены в I группе в обеих сериях – 1898 Н при вертикальной нагрузке и 1046 Н при горизонтальной нагрузке. Далее в убывающем порядке получены результаты стабильности во II, III и IV группах.

В процессе эксперимента установлено, что триангулярное расположение винтов с учетом архитектоники ШБК, каждый из которых имеет три точки соприкосновения с компактной костной тканью, обеспечивает максимальную стабильность конструкции при остеосинтезе переломов ШБК, что сопоставимо с нагрузкой в обычных условиях ходьбы.

Мы полагаем, что при остеосинтезе ПШБК три винта могут создать лучшую стабильность, если они расположены в плотных тканях проксимального отдела бедренной кости с учетом особенностей архитектоники кости. Для обеспечения максимальной стабильности каждый винт должен иметь три точки контакта с компактной костью – латеральная кортикальная стенка подвертельной области БК, внутренняя стенка ШБК и компактная часть головки БК. Новая треугольная конфигурация установки винтов могла бы лучше нейтрализовать срезывающие силы при ПШБК.

Ключевые слова: перелом шейки бедренной кости, остеосинтез винтами, биомеханика кости

Для цитирования: Биомеханическое исследование остеосинтеза переломов шейки бедренной кости / А. А. Коструб [и др.] // Вес. Нац. акад. навук Беларусі. Сер. мед. навук. – 2022. – Т. 19, № 3. – С. 330–336 (на англ. яз.). https://doi.org/10.29235/1814-6023-2022-19-3-330-336

Introduction. The cornerstone of surgical treatment for FNF is anatomic reduction and stable internal fixation. A significant number of complications in the treatment of the FNF in young patients like nonunion, migration of fixation devices, secondary displacement of fragments reaches 40–50 % [1, 2]. It is known that share stress and vertical plane of fracture line increases failure rate. The success of treatment depends on reduction quality and biomechanical stability of the fragments that is crucial as well as viability of the femoral head [3, 4]. However, a number of clinical and biomechanical studies indicate that the localization and the angle of the FNF plane to the horizontal plane do not influence the results of osteosynthesis with screws [5, 6]. The direction of the external forces is mainly vertical to support the body in the gravitational field. Forces in the anterior–posterior direction are considerably lower compared to the vertical forces [7]. Most biomechanical studies would agree that 3 screws should be used with diameters of larger than 6 mm [8, 9]. Adding a fourth screw has not consistently shown to provide biomechanical benefits, most likely due to the weakening of the lateral wall by the screw insertion holes.

We believe that improvement of the osteosynthesis technique of the FNF could be beneficial. According to previous findings rational placement of cannulated screws should be taken into account with the anatomical and biomechanical features of the proximal FB [10]. It has been found out the shape, dimensions and thickness of the cortical layer of the FN. Crossectional size is wider in upper half than in lower half of FN. Placement of cannulated screws should be considered due to previous findings [11, 12].

The aim of this study was to investigate dependence of stability strength of screws osteosynthesis placed in various configurations in between FN.

Materials and research methods. To establish previously conducted biomechanical studies which indicate that the size and shape of the fixator are less important than the relative position of metal structures between themselves and the location of relatively more durable anatomical formations of the proximal femur [13]. A biomechanical study of four combinations of cannulated screws in FN osteosynthesis was carried out. The study was performed in the Institute for Problems of Strength by G. S. Pisarenko. Osteosynthesis of FNF was performed with 7.3 mm cannulated screws with short thread on synthetic models (SM) of the right proximal femur “Synbone”. According to the manufacturer’s instructions, the mechanical properties of SM corresponds to those of a healthy human bone. Identical dimensions and properties of the models reduces faults in the results of experimental studies. We used the SM of the right FB, in which parallel channels were drilled with a cannulated drill for the subsequent placement of screws. Further they were sawn in the plane 50º to the horizontal plane, simulating a transcervical unstable fracture. Cannulated screws were introduced to the subchondral layer of the FH head into the pre-drilled canals.

The experimental work consisted of loading the synthesized fragments in two mutually perpendicular planes – vertical (the diaphysis of the femur is set at an angle of 7º to the vertical corresponding to the position of the FB in the vertical position of the body) and horizontal (which simulates the load from the “sitting” position to the “standing” position) – to study the angular displacement between fragments.

The experimental models were divided into 4 groups depending on the insertion points and the relative position of the screws in the synthetic bone. Each group had 2 models. 2 series of loads carried out.

The insertion points and relation to anatomy of the proximal femur are described (Fig. 1).

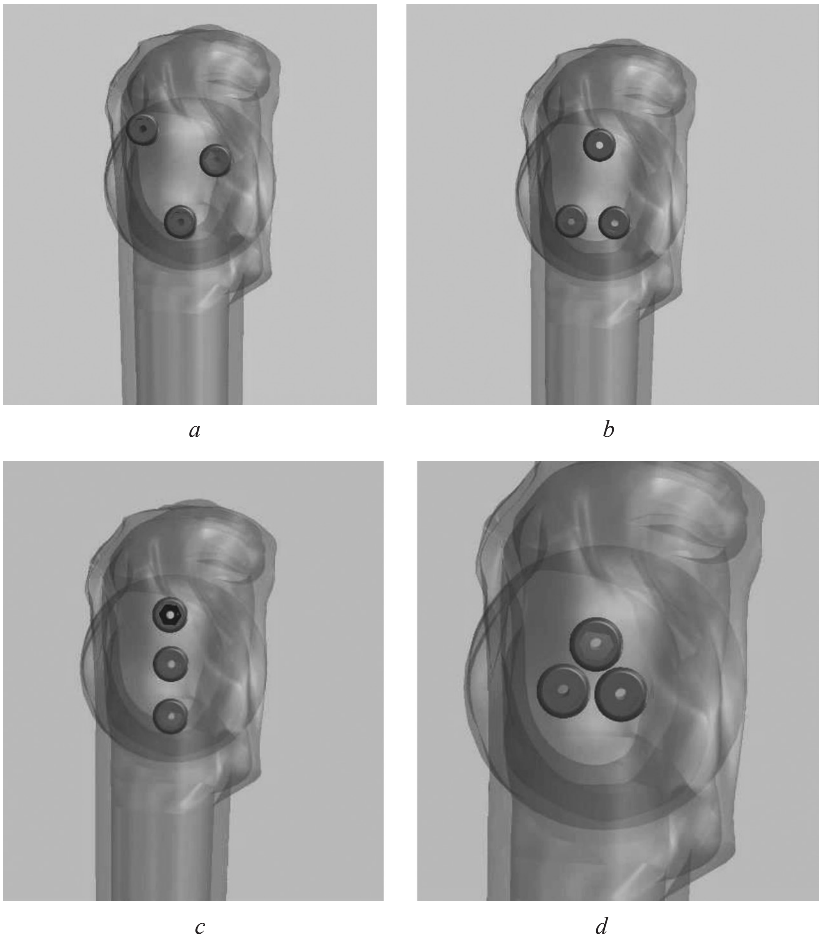

Fig. 1. Insertion points of the screws in 4 groups: I (*a*), II (*b*), III (*c*), IV (*d*)

Group I – the insertion points for screws of the subtrochanteric lateral cortex are placed in a triangle with the apex directed posteriorly. Screws are inserted subcortically and parallel to each other so that they appear in the FN at 1, 6 and 9 o'clock of the clock face, and the distal screw rests on the calcar.

Group II – the insertion points of the screws on the surface of the subtrochanteric region are placed in a triangle with a base directed distally, and two distal screws rest on the calcar, and the third – into the upper part of the head.

Group III – screw insertion points on the surface of the subtrochanteric region are placed linearly in the frontal plane, with the distal screw inserted over the calcar, the middle screw through the center of the neck, and the proximal screw parallel to the previous, into the upper part of the head.

Group IV – the insertion points of the screws on the surface of the subtrochanteric region are placed in a triangle around the FN axis, and are inserted close to each.

The study of the rigidity of osteosynthesis of the "implants – SM" model under the action of force in the vertical and horizontal directions was carried out on a testing machine AIMA-5-2 with the following characteristics:

measurement accuracy of the applied load: ±0.1 N;

accuracy of measuring the movement of the movable gripper: $\pm 10^{-5}$ m;

movement speed of the active gripper $8.3 \cdot 10^{-6}$–$3.3 \cdot 10^{-5}$ m/s.

The proximal end of the model was placed between the support sites of the setup.

The specimen was fixed to the testing machine in diaphyseal part. Force P was transmitted through a special adapter to the FH, thus simulating the transfer of a concentric load from the acetabulum.

In series I of the study, force P_1 was applied to the proximal fragment in the cranio-caudal direction, that corresponds force on the hip joint during single-standing phase, which causes deformation of the bending of the joints of the corresponding fragments of the upper third of the FH (Fig. 2, *a*).

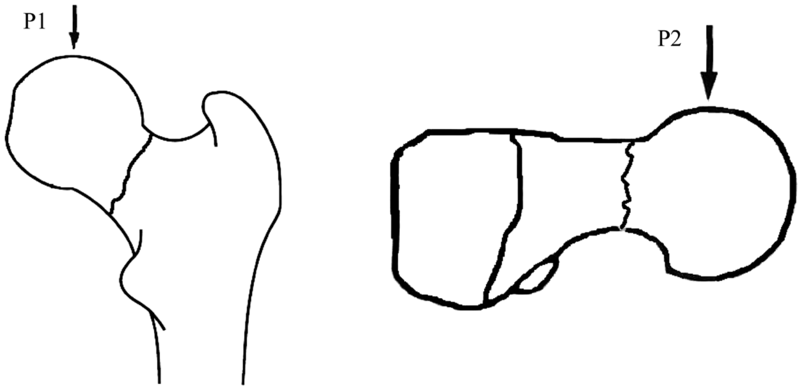

Fig. 2. Direction of force to the femoral head: vertical (P_1), horizontal (P_2)

In the second series of studies, the force P_2 was applied perpendicular to the longitudinal axis of the FH to its head in the ventro-dorsal direction, which caused deformation of the bending and torsion of the synthesized fragments of the upper third of the FH. A bending moment was simulated in the ventro-dorsal direction, which corresponds to the direction of force action when a person climbs a stairs and ascends from a sitting position (Fig. 2, *b*).

The magnitude of the displacement between the fragments in the direction of the force action was determined using a dial indicator. Thus, the consequences of nonloading, which was necessary to achieve a diastasis between the fragments of the FN equal to 2 mm were experimentally evaluated. The appropriate forces were chosen to simulate the load corresponding to the conditions of clinical practice when moving in the hip joint.

The amount of displacement of the fragments relative to each other was recorded after each increase in the load by 50 N with static holding at each increase of $t = 60$ s. The displacement value was determined at the end of the exposure. The final value of the load force was $P_{max} = 2000$ N, corresponding to the action of the force with a single-support step period with an average human body weight.

The data obtained were obtained statistically. Parametric statistical methods were used to characterize the accuracy of the data [14].

Results and its discussion. The use of the CM helped to reduce research errors due to the identity of the sizes and mechanical characteristics of the samples. This made it possible to level the properties inherent in human bone, namely, age-related changes in bone tissue, osteopenia and osteoporosis, the difference in size and thickness. Two series of studies were obtained.

In the first series of studies in four groups of people (4 in each), displacement of fragments within 2 mm occurred when exposed to force: 1898 ± 44.38 N – in group I; 1682 ± 31.14 N – in group II; 1404 ± 40.37 N – in group III; 1182 ± 61.81 N – in group IV.

Moreover, the differences between groups II–IV are statistically significant relative to group I.

Tab. 1 shows that the triangular arrangement of the cannulated screws with the apex directed distally (group I) provides the greatest resistance to force in the cranio-caudal direction.

In the second series of studies of four groups, displacement of fragments within 2 mm occurred when exposed to forces: 1046 ± 65.42 N – in group I (Tab. 2); 806 ± 62.29 N – in group II; 400 ± 25.5 N – in group III; 648 ± 49.19 N – in group IV.

Table 1. **Vertical loading results after osteosynthesis of the FNF with cannulated screws in four groups**

Index	Group			
	I	II	III	IV
Average value, N	898	682*	404*	182*
Standart deviation	4,38	1,14	0,37	1,81
Standart error of mean	9,85	9,85	8,06	7,64

Note. Here and in Tab. 2: * – reliably to group I ($p \leq 0.0005$).

Table 2. **Horizontal loading results after osteosynthesis of the FNF with cannulated screws of four configurations**

Index	Group			
	I	II	III	IV
Average value, N	1046	806*	400*	648*
Standart deviation	65,42	62,29	25,5	49,19
Standart error of mean	29,26	27,86	11,4	22

Moreover, the differences between groups II–IV are statistically significant relative to group I.

As seen in Tab. 2, it can be seen that the triangular arrangement of the cannulated screws with the apex directed distally (group I) provides the greatest resistance to the action of force in the ventro-dorsal direction.

Analysis of variance showed the statistical significance of the differences between groups in both study series at $p \leq 0.0001$: in series I: $F = 234.37$; $v_{inter} = 1.47$; $v_{intra} = 3.35$; in series II: $F = 131.29$; $v_{inter} = 1.11$; $v_{intra} = 4.49$, where v_{inter} – is the intergroup number of degrees of freedom, v_{intra} – is the intragroup number of degrees of freedom.

The following pairwise comparison of the reference group with all control groups showed the static reliability of the data obtained according to Student's test with Bonferroni correction ($p \leq 0.05$).

In group I, the screws are located subcortically, which provides three-point fixation of each screw in the dense compact tissue of the lateral cortical wall of the subtrochanteric region of the FB, the inner wall of the cervical cortical layer and the head. In our opinion, it is the support on the cortical layer of the cervix that provides the necessary stability of fixation and prevents displacement of fragments. A displacement of 2 mm was noted under the force of 1898 N. The dynamics of the relationship between displacement and force action is shown on the Fig. 3.

In group II, there was no significant difference in results, since two screws located over the Adams' arch, with a third subcortical screw located in the upper pole, provide good vertical stability. Displacement of fragments by 2 mm was noted under the action of a force of 1682 N.

In the III group, indicators were obtained that were close to the previous ones. In our opinion, this result was obtained due to the fact that all three screws are located in the frontal plane, two of which – the upper and lower ones – are also located subcortically. Therefore, a displacement of 2 mm was noted at 1404 N.

The least stability of the cervical fragments of the SC in group IV was noted – a displacement of 2 mm occurred under the action of a force of 1182 N. This is due to the fact that the screws have only two fixation points – the sub-suction section and the SC head. In the middle of the cervix, the screws pass into the cancellous layer, which has low strength values.

In the first series of the study, results were obtained that characterize the strength of fixation of fragments when force is applied in the ventro-dorsal direction. A displacement of 2 mm was recorded under the action of a force of 1046 and 806 N for groups I and II, respectively (Fig. 4).

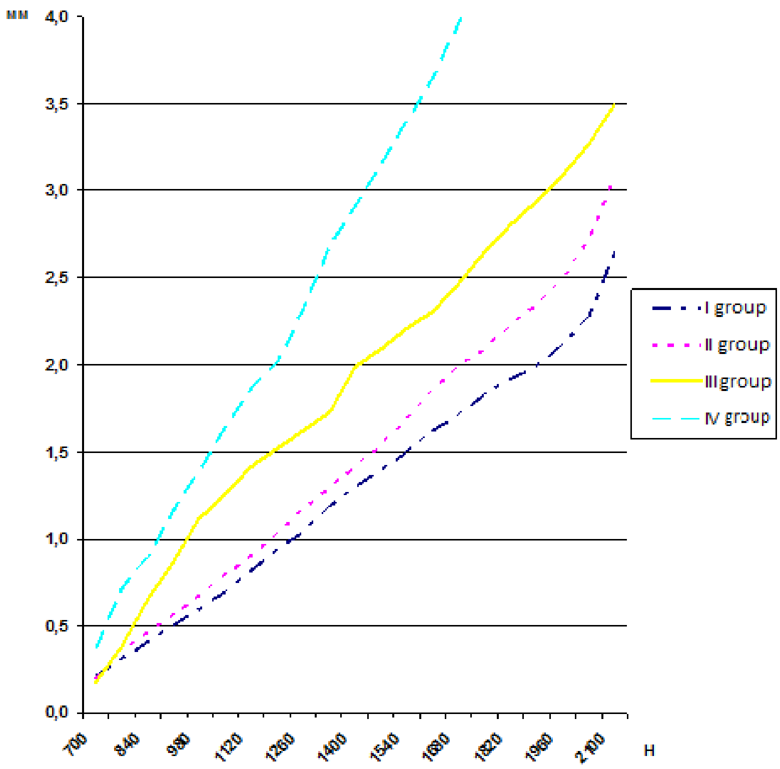

Fig. 3. Average value of displacement of fragments under vertical load

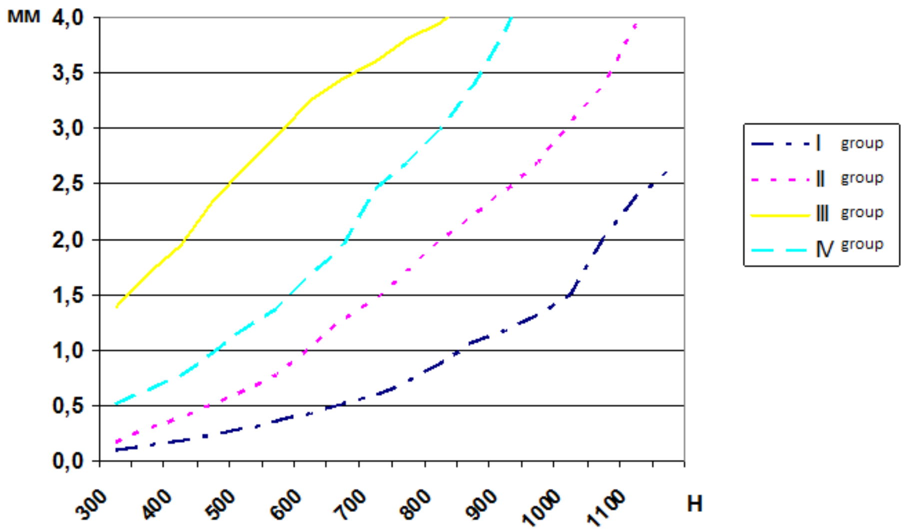

Fig. 4. Average value of displacement of fragments under horizontal load

Of particular note is the fact that in group III there was a displacement of 1.38 mm under the action of a force of only 300 N due to the fact that the screws located in one plane perpendicular to the direction of action of the force are not able to provide sufficient angular stability, fragility.

It is important to note that in the II series of the study, the destructive force was almost half that in the I series. This is due to the anatomical and biomechanical features of the proximal part of the FB.

An essential role for better vertical stability is played by:

1) the thickness of the cortical layer, which is large in the area of the Adams arch;

2) the larger size of the FN in the cranial-caudal direction compared to the anteroposterior one.

Factors that reduce the strength of the stability include:

1) a relatively thin upper posterior wall of the cervical cortical layer;

2) weak spongious tissue of the FN.

The use of SM instead of native preparations opens up additional opportunities for experimental studies – an increase in the accuracy of the results and the leveling of human bone polymorphism, such as the size, neck-shaft angle, thickness and density of individual anatomical structures. To the well-known fact that the Adams arch plays an important role in the stability of the FN, we propose to add the cortical layer of the FN.

Conclusion. The optimal indicators of the strength for fixation of the FN fragments were established in the first group, the characteristic feature of which was the following principles: subcortical position and three-point fixation of each screw in dense compact tissue of the lateral cortical wall of the subtrochanteric part of the FB, the inner wall of the cortical layer of the neck and the head.

With the developed method of osteosynthesis of the FNF, the stability of the fragments is maintained under a vertical load with a force of up to 1898 N, close to a single-support step phase. Under a horizontal load, fixation with the original osteosynthesis method withstands the action of force up to 1046 N.

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

References

1. Loskutov A. E., Oleinik A. E., Bredikhin A. V. Total hip arthroplasty for medial fractures of the femoral neck. *Zbirnik naukovikh prats' spivrobitnikiv NMAPO imeni P. L. Shupika. Tom 9, kniga 1* [Collection of scientific works of NMAPE named after P. L. Shupik. Vol. 9, book 1]. Kiev, 2000, pp. 51–54 (in Russian).

2. Klimovitskii V. G., Kanzyuba M. A., Kanzyuba A. I. Analysis of changes in the stress-strain state of the femoral neck during its osteosynthesis with screws. *Ukraïns'kii medichnii al'manakh* [Ukrainian medical almanac], 2005, suppl. 2, pp. 77–80 (in Russian).

3. Parker M. J., Blundell C. Choice of implant for internal fixation of femoral neck fractures. Meta-analysis of 25 randomised trials including 4,925 patients. *Acta Orthopaedica Scandinavica*, 1998, vol. 69, no. 2, pp. 138–143. https://doi.org/10.3109/17453679809117614

4. Spangler L., Cummings P., Tencer A. F., Mueller B. A., Mock C. Biomechanical factors and failure of transcervical hip fracture repair. *Injury*, 2001, vol. 32, no. 3, pp. 223–228 https://doi.org/10.1016/s0020-1383(00)00186-8

5. Lindequist S., Wredmark T., Eriksson S. A., Samnegård E. Screw positions in femoral neck fractures. Comparison of two different screw positions in cadavers. *Acta Orthopaedica Scandinavica*, 1993, vol. 64, no. 1, pp. 67–70. https://doi.org/10.3109/17453679308994532

6. Parker M. J., Dynan Y. Is Pauwels classification still valid? *Injury*, 1998, vol. 29, no. 7, pp. 521–523. https://doi.org/10.1016/s0020-1383(98)00118-1

7. Augat P., Bliven E., Hackl S. Biomechanics of femoral neck fractures and implications for fixation. *Journal of Orthopaedic Trauma*, 2019, vol. 33, suppl. 1, pp. S27–S32. https://doi.org/10.1097/BOT.0000000000001365

8. Bonnaire F. A., Weber A. T. Analysis of fracture gap changes, dynamic and static stability of different osteosynthetic procedures in the femoral neck. *Injury*, 2002, vol. 33, suppl. 3, pp. 24–32. https://doi.org/10.1016/s0020-1383(02)00328-5

9. Mayhew P. M., Thomas C. D., Clement J. G., Loveridge N., Beck T. J., Bonfield W., Burgoyne Ch. J., Reeve J. Relation between age, femoral neck cortical stability, and hip fracture risk. *Lancet*, 2005, vol. 366, no. 9480, pp. 129–135. https://doi.org/10.1016/S0140-6736(05)66870-5

10. Samsami S., Augat P., Rouhi G. Stability of femoral neck fracture fixation: a finite element analysis. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 2019, vol. 233, no. 9, pp. 892–900. https://doi.org/10.1177/0954411919856138

11. Popov V. A., Vadzyuk N. S., Ivanchenko O. O. X-ray anthropometric examination of the femoral neck in minimally invasive osteosynesis planning. *Ukraïns'kii zhurnal telemeditsini ta medichnoï telematiki* [Ukrainian journal of telemedicine and medical telematics], 2009, vol. 7, no. 2, pp. 219–223 (in Ukrainian).

12. Popov V. A., Vadzyuk N. S. Structural features of the femoral neck according to computed tomography. *Litopis travmatologiï ta ortopediï* [Chronicle of traumatology and orthopedics], 2010, no. 1–2, pp. 65–69 (in Ukrainian).

13. Popov V. A., Vadzyuk N. S., Krishchuk N. G., Eshchenko V. O. Analysis of stressedly-deformed condition in modelling of nailing of femoral neck fracture fragments. *Visnik ortopediï, travmatologiï ta protezuvannya* [Journal of orthopedics, traumatology and prosthetics], 2011, no. 1, pp. 59–64 (in Ukrainian).

14. Glants S. *Medical-biological statistics*. Moscow, Praktika Publ., 1998. 459 p.

Information about the authors

Oleksandr O. Kostrub – D. Sc. (Med.), Professor, Head of the Department. Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine (27, Bulvarno-Kudryavska Str., 01601, Kiev, Ukraine). E-mail: akostrub@ukr.net. https://orcid.org/0000-0001-7925-9362

Yurii V. Polyachenko – D. Sc. (Med.), Professor, Acting Director. Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine (27, Bulvarno-Kudryavska Str., 01601, Kiev, Ukraine). E-mail: poliach.yv@gmail.com. https://orcid.org/0000-0003-1814-4240

Mikhail A. Gerasimenko – D. Sc. (Med.), Professor, Director. Republican Scientific-Practical Centre of Traumatology and Orthopedics (60/4, Kizhevatov Str., 220024, Minsk, Republic of Belarus). E-mail: vbo@ortoped.by

Nazar S. Vadzyuk – Ph. D. (Med.), Senior Researcher. Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine (27, Bulvarno-Kudryavska Str., 01601, Kiev, Ukraine). E-mail: ortopedika@ukr.net

Vladimir V. Kryvenyuk – D. Sc. (Med.), Professor. Institute for Problems of Strength by G. S. Pisarenko of the National Academy of Sciences of Ukraine (2, Timiryazevskaya Str., 01014, Kiev, Ukraine).

Viktor V. Kotyuk – Ph. D. (Med.), Senior Researcher. Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine (27, Bulvarno-Kudryavska Str., 01601, Kiev, Ukraine). E-mail: kotyuk_v@ukr.net. https://orcid.org/0000-0001-8837-8603

Информация об авторах

Коструб Александр Алексеевич – д-р мед. наук, профессор, заведующий отделом. Институт травматологии и ортопедии НАМН Украины (ул. Бульварно-Кудрявская, 27, 01601, г. Киев, Украина). E-mail: akostrub@ukr.net. https://orcid.org/0000-0001-7925-9362

Поляченко Юрий Володимирович – д-р мед. наук, профессор, и. о. директора. Институт травматологии и ортопедии НАМН Украины (ул. Бульварно-Кудрявская, 27, 01601, г. Киев, Украина). E-mail: poliach.yv@gmail.com. https://orcid.org/0000-0003-1814-4240

Герасименко Михаил Александрович – д-р мед. наук, профессор, директор. Республиканский научно-практический центр травматологии и ортопедии (ул. Кижеватова, 60/4, 220024, г. Минск, Республика Беларусь). E-mail: vbo@ortoped.by

Вадзюк Назар Степанович – канд. мед. наук, ст. науч. сотрудник. Институт травматологии и ортопедии НАМН Украины (ул. Бульварно-Кудрявская, 27, 01601, г. Киев, Украина). E-mail: ortopedika@ukr.net

Кривенюк Владимир Владимирович – д-р мед. наук, профессор. Институт проблем прочности имени Г. С. Писаренко НАН Украины (ул. Тимирязевская, 2, 01014, г. Киев, Украина).

Котюк Виктор Владимирович – канд. мед. наук, ст. науч. сотрудник. Институт травматологии и ортопедии НАМН Украины (ул. Бульварно-Кудрявская, 27, 01601, г. Киев, Украина). E-mail: kotyuk_v@ukr.net. https://orcid.org/0000-0001-8837-8603