DOI 10.18019/1028-4427-2018-24-2-252-257

Management of posttraumatic long bone defects in the national orthopedic practice (literature review)

A.L. Shastov, N.A. Kononovich, E.N. Gorbach

Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation

We present present-day trends in the compensation of post-traumatic defects of long bones according to the Russian literature sources. The relevance of the problem due to the growth in the number of injuries in general and in the severity of trauma is highlighted. The basic directions in the solution of the problem of compensation of bone defects are shown. The merits and shortcomings of the available techniques as well as modern implantation materials based on hydroxyapatite, bioceramics and titanium alloys are analyzed. It has been pointed out that interdisciplinary interaction with the involvement of experts in the field of tissue engineering technologies, physicians, biologists, physicists, industry specialists and a sufficient financial support is needed to create optimal implants.

Keywords: long bone, defect, implant, Ilizarov apparatus, osteoinduction, osteoconduction, hydroxyapatite, titanium, bioceramics, bone plasty

Bone defect management is one of the priority issues in the medical, social and economic spheres in the Russian Federation [1, 2, 3, 4]. The pathology can be caused by fractures, cystic formations, tumors, false joints, infectious lesions and other conditions associated with the need for bone resection [3].

But above all, the relevance of the issue is related to the growth of high-energy trauma in the recent years and a large number of affected individuals with the consequences of polytrauma [5, 6, 7, 8].

At present, there are four directions in the reconstructive surgery of long bone defects: free bone grafting, management of defects with osteosubstituting and osteoinductive materials, non-free bone transport according to G.A. Ilizarov and combined methods.

Orthopedic traumatologists prefer the Ilizarov non-free bone plasty and vascularized or free autologous grafting in the defect, as the most effective and alternative methods [4].

The idea of bone defect compensation, proposed by GA. Ilizarov, opened a new page in osteoplastic surgery [9, 10, 11]. The method is based on the creation of compression-distraction forces at the site of bone fragments contact and dosed transport of an autologous non-free graft into the defect. The defect fills in by formation of distraction regenerate, which undergoes complete and organotypic restructuring over time and the recovers limb segment anatomy [12, 13].

Despite the obvious merits, many specialists are ambivalent about using the Ilizarov method in their practice. This is explained by long duration and multi-stage inpatient treatment, complexity and difficulty of osteosynthesis performance. In addition, continuous monitoring is necessary throughout the period of treatment and rehabilitation, which is often quite difficult due to remoteness of patients' residences from specialized medical institutions.

There are also a number of local problems that arise during and after treatment (decrease in the quality of life of patients, to a certain extent, as a result of the need for dressings, inconvenience in performing hygiene procedures, etc.) [14, 15, 16].

To reduce the hardware treatment period, an option was proposed and tested experimentally to use a combination of methods of locked intramedullary and external osteosynthesis with the Ilizarov apparatus. This technology has proven to be very efficient in clinical practice [17].

It was shown in a number of studies that the index of transosseous osteosynthesis in long bone defect management with the technology of combined osteosynthesis was equal to the index of distraction, 10.2 ± 0.78 days / cm; however, according to other authors, in the same situation, the period of hardware

Shastov A.L., Kononovich N.A., Gorbach E.N. Management of posttraumatic long bone defects in the national and foreign orthopedic practice (literature review). *Genij Ortopedii*. 2018. T. 24. No 2. pp. 252-257. DOI 10.18019/1028-4427-2018-24-2-252-257. (In Russian)

fixation corresponded to 160 ± 29.8 days. Despite the fact that there is no acceleration of the process of organotypic rearrangement of distraction regenerate, there is a decrease in hospital stay and improvement of quality of life [17, 18].

In turn, the use of free autologous grafting with arteriovenous shunting is difficult to perform and requires high-tech equipment. The use of this technique is limited by the volume of the donor material. There is also a high risk of complications such as hematomas with further development of purulent-inflammatory process, damage to blood vessels and nerves, thrombosis of arteriovenous anastomosis, resorption of the graft, the risk of fracture in the donor zone, and cosmetic defect. Also, this type of plasty is associated with a high risk of nonunion and pathological fractures of the replants due to delayed osteo- and angiogenesis [15].

A worthy alternative to auto- and allografts are artificial substitutes of bone tissue. Their non-biological origin significantly reduces the risk of infection transmission, as well as the occurrence of undesirable immune responses.

Currently, the experts in the field of traumatology and orthopedics have been actively searching in this direction. Implantation materials applied up-to-date feature various properties.

Some of them have high mechanical strength, thus providing a reinforcing effect on the implant-bone site, and, as a rule, are non-biodegradable. Others, on the other hand, are biodegradable, sufficiently plastic and are designed to fill in bone cavities of complex shape and varying volume [19, 20]. Both should be biocompatible with bone and surrounding tissues, have osteoconductive and osteoinductive properties, be a matrix for vascular ingrowth or induce angiogenesis. Materials should not exert a toxic effect on the surrounding tissues, or on the body as a whole [21].

Implants with high strength characteristics, withstanding high mechanical loads, have been introduced in traumatology and orthopedics. As a rule, these are non-biodegradable materials: ceramics, metals, carbon-based and composite or polymeric materials [22, 23, 24, 25, 26].

Depending on their effect on the reparative ability of bone tissue, there are:

• Biotolerant materials: stainless steel, chrome-cobalt alloy. Such materials are separated from surrounding tissues in the body by a powerful fibrous capsule and do not have any effect on the term of consolidation [27];

• Bioinert materials: titanium, zirconium, gold, corundum ceramics, glassy carbon, titanium nickelide, tantalum, niobium, aluminum oxide, which do not affect the period of defect management. However, the reparative processes associated with the formation of bone tissue occurs on the surface of the implant material without the formation of a fibrous capsule [27, 28, 29];

• Bioactive materials: implants coated with hydroxyapatite (HA), tricalcium phosphate ceramics, and similar compounds. The stimulating substance ensures the interaction of the implant with surrounding tissues and accelerates the processes of bone formation. The substrate plays the role of a scaffold and determines the mechanical properties of the implant [26, 27, 29,30].

Titanium is currently the most bioinert material. Porous titanium, due to its high hardness, cavitation, corrosion and erosion resistance, non-magnetization, biochemical and biomechanical compatibility with the human body is often used as an endofixator and as a three-dimensional matrix for the formation of osteogenic tissue [31, 32, 33]. At the same time, low osseointegrative function requires covering the surface of implants made of such material with bioactive substances. Most often, hydroxyapatite is used for this purpose, which promotes the formation of collagen and elastin fibers, effects the differentiation of cell elements in the osteogenic direction [34, 35, 36].

The use of various composite materials containing hydroxyapatite showed efficacy in bone defect management under experimental conditions. The authors noted that restoration of bone integrity with the formation of a continuous cortical plate occurs, on average, at 90 days [37, 38, 39, 40, 41, 42].

However, other researchers who experimented on similar defects by the methods without the use of additional materials, managed to achieve bone restoration within the same period (92.7 days, fixation index 22.1 ± 0.8 days / cm) [43, 44].

The use of a matrix with multipotent mesenchymal cells [45], as well as three-dimensional grafts (osteogenic cells, hydroxyapatite, proteoglycan)

[46] can provide reduction in the timing of bone support area formation in the defect zone. However, the production of such materials requires complex expensive equipment.

Summarizing all of the above, it can be concluded that the existing technologies for bone defects management with the Ilizarov methods of non-free bone grafting is associated with a long (about a year) osteosynthesis in external apparatus, the complexity of the biomechanical process and a significant number of complications.

The shortcoming of composite and cell-based implants is their insufficient mechanical strength, despite good osteoinductive properties and the possibility of filling defects of a complex shape.

The use of implant materials based on bioinert metals and their alloys, carbon and bioceramics, allows achieving mechanical strength in the defect zone. But their widespread use is difficult due to the inability to cover the defects of complex configuration and the lack of sufficient induction properties. The latter is solved by covering the implantation materials with bioactive substances.

The novel technologies related to 3D prototyping and providing a personalized approach (additive technologies) which allow creating implants that possess all the necessary properties for defect filling have been under investigation recently. These technologies should be aimed in the future at ensuring fast and high-quality manufacturing of biologically active implants for a specific patient.

Generally, the creation of a new generation of implants that meet all the necessary requirements is possible only with a comprehensive interdisciplinary approach that would involve experts in the field of tissue engineering technologies, doctors, biologists, physicists, industry specialists and with a sufficient financial support.

REFERENCES

1. Barabash A.A., Barabash A.P., Barabash Iu.A. Formirovanie distraktsionnogo regenerata pri razlichnykh faktorakh komprometatsii osteogeneza [Formation of distraction regenerated bone for various factors of osteogenesis compromising]. *Sbornik tezisov IX s"ezda travmatologov-ortopedov Rossii* [Proceedings of IX Congress of traumatologists-orthopedists of Russia]. Saratov, 2010, vol. 1, pp. 84-85. (In Russian)
2. Borzunov D.Iu. Nesvobodnaia kostnaia plastika po G.A. Ilizarovu v probleme reabilitatsii bol'nykh s defektami i lozhnymi sustavami dlinnykh kostei [Non-free bone grafting according to G.A. Ilizarov in the problem of rehabilitation of patients with long bone defects and pseudoarthroses]. *Genij Ortopedii*, 2011, no. 2, pp. 21-26. (In Russian)
3. Netyl'ko G.I., Rumakin V.P., Konev V.A. Eksperimental'noe modelirovanie kostnogo defekta so sklerozirovannoi stenkoi [Experimental modeling of bone defect with a sclerosal wall]. *Genij Ortopedii*, 2014, no. 3, pp. 72-76. (In Russian)
4. Shevtsov V.I., Borzunov D.Iu. Reabilitatsiia patsientov s defektami i lozhnymi sustavami dlinnykh kostei, sovremennoe sostoianie problem [Rehabilitation of patients with long bone defects and pseudoarthroses, current state of the problem]. *Genij Ortopedii*, 2008, no. 4, pp. 48-54. (In Russian)
5. Agadzhanian V.V. Aktual'nye problemy intensivnoi pomoshchi pri politravme [Relevant problems of intensive medical care for polytrauma]. *Intensivnaia pomoshch': problemy i resheniia: materialy II Vseros. konf.* [Intensive medical care: problems and solutions: Materials of II All-Russian Conference]. Leninsk-Kuznetskii, 2004, pp. 3-5. (In Russian)
6. Alekperli A.U., Kurshakova I.V., Kartashkin V.L. Osobennosti diagnostiki i lecheniia sochetannykh povrezhdenii u lits pozhilogo i starcheskogo vozrasta [Special features of diagnosing and treating concomitant injuries in elderly and senile persons]. *Skoraia Med. Pomoshch'*, 2003, no. 4, pp. 52-54. (In Russian)
7. Vorontsova T.N., Tyuliayev N.V., Solomin L.N. Sotsial'no-gigienicheskaia i kliniko-diagnosticheskaia kharakteristiki patsientov, prolechennykh metodom vneochagovoi fiksatsii po povodu perelomov kostei skeleta [Socio-hygienic and clinical-and-diagnostic characteristics of patients treated by external fixation technique for skeletal bone fractures]. *Genij Ortopedii*, 2011, no. 4, pp. 39-43. (In Russian)
8. Implantaty s uglovoi stabil'nost'iu LCP. Khirurgicheskaia tekhnika, komplektatsiia naborov Mathys Medical Ltd. [Implants with LCP angular stability. Surgical technique, Mathys Medical Ltd. set building up]. M., 2003, 27 p. (In Russian)
9. Ilizarov G.A. Znachenie kompleksa optimal'nykh mekhanicheskikh faktorov v regenerativnom protsesse pri chreskostnom osteosinteze [Value of the complex of optimal mechanical factors in the regenerative process during transosseous osteosynthesis]. *Eksperimental'no-teoreticheskie i klinicheskie aspekty chreskostnogo osteosinteza, razrabatannogo v KNIIEKOT: materialy Vsesoiuz. simpoziuma s uchastiem inostrannykh spetsialistov* [Experimental-theoretical and Clinical Aspects of the Transosseous Osteosynthesis developed in Kurgan Scientific Research Institute of Experimental and Clinical Orthopaedics and Traumatology: Materials of All-Union Symposium with participation of foreign specialists]. Kurgan, 1984, pp. 8-49. (In Russian)

10. Ilizarov G.A. Nekotorye teoreticheskie i klinicheskie aspekty chreskostnogo osteosinteza s pozitsii otkrytykh nami obshche-biologicheskikh zakonomernostei [Some theoretical and clinical aspects of transosseous osteosynthesis from the standpoint of the general biological regularities discovered by us]. *Eksperimental'no-teoreticheskie i klinicheskie aspekty chreskostnogo osteosinteza, razrabatannogo v KNIIEKOT: tez. dokl. Mezhdunar. konf.* [Experimental-theoretical and Clinical Aspects of the Transosseous Osteosynthesis developed in Kurgan Scientific Research Institute of Experimental and Clinical Orthopaedics and Traumatology: Abstracts of International Conference]. Kurgan, 1986, pp. 7-12. (In Russian)
11. Shevtsov V.I. K 90-letiiu so dnia rozhdeniia G.A. Ilizarova. Vklad Ilizarova i sozdannoi im shkoly razvitii metoda chreskostnogo osteosinteza [To the 90the anniversary of G.A. Ilizarov. The contribution of G.A. Ilizarov and the school created by him into the development of transosseous osteosynthesis method]. *Genij Ortopedii*, 2011, no. 2, pp. 7-14. (In Russian)
12. Gubin A.V., Borzunov D.Y., Malkova T.A. The Ilizarov paradigm: thirty years with the Ilizarov method, current concerns and future research. *Int. Orthop.*, 2013, vol. 37, no. 8, pp. 1533-1539. doi: 10.1007/s00264-013-1935-0.
13. Solomin L.N. The basic principles of external skeletal fixation using the Ilizarov and other devices. Milan, Springer-Verlag, 2012.
14. Tikhilov R.M., Kochish A.Iu., Radomanova L.A., Kutianov D.I., Afanas'ev A.O. Vozmozhnosti sovremennykh metodov rekonstruktivno-plasticheskoi khirurgii v lechenii bol'nykh s obshirnymi posttravmaticheskimi defektami tkanei konechnostei (obzor literatury) [Possibilities of modern methods of reconstructive-plastic surgery in the treatment of patients with extensive posttraumatic defects of limb tissue defects (Review of the literature)]. *Travmatologiia i Ortopediia Rossii*, 2011, no. 2, pp. 164-170. (In Russian)
15. Barabash A.P., Kesov L.A., Barabash Iu.A., Shpiniak S.P. Zameshchenie obshirnykh diafizarnykh defektov dlinnykh kostei [Filling extensive long bone shaft defects]. *Travmatologiia i Ortopediia Rossii*, 2014, no. 2 (72), pp. 93-99. (In Russian)
16. Solomin L.N., Sabirov F.K. Oslozhneniia, sviazannye s primeneniem ekstrakortikal'nykh fiksatorov pri kombinirovannom i posledovatel'nom ispol'zovanii chreskostnogo osteosinteza i vnutrennei fiksatsii bedrennoi kosti [The complications related to the use of extra-cortical fixators when combined and consecutive using transosseous osteosynthesis and internal fixation of the femur]. *Travmatologi i Ortopediia Rossii*, 2015, no. 4 (78), pp. 103-110. (In Russian)
17. Emanov A.A., Mitrofanov A.I., Borzunov D.Iu. Zameshchenie defekt-psevdoartrozov dlinnykh kostei v usloviiakh kombinirovannogo osteosinteza (eksperimental'noe issledovanie) [Filling long bone defect-pseudoarthroses under combined osteosynthesis conditions (An experimental study)]. *Genij Ortopedii*, 2013, no. 3, pp. 43-47. (In Russian)
18. Mitrofanov A.I., Chevardin A.Iu. Tekhnologiia kombinirovannogo osteosinteza pri lechenii bol'nykh s posledstviiami travm dlinnykh trubchatykh kostei (tekhnologiia osteosinteza) [Combined osteosynthesis technology in treatment of patients with the consequences of long tubular bone injuries (osteosynthesis technology)]. *Genij Ortopedii*, 2014, no. 3, pp. 13-15. (In Russian)
19. Pichugin Iu.V., Sapozhnikov A.V., Ermolaev V.A., Zolotukhin S.N. Eksperimental'noe primeneniie biokompozitnykh materialov v veterinarnoi travmatologii [Experimental use of biocomposite materials in veterinary traumatology]. *Vestn. Ul'ianov. Gos. S.-kh. Akademii*, 2011, no. 3, pp. 78-80. (In Russian)
20. Polianskii R.K., Kozlov N.A. Otsenka effektivnosti ispol'zovaniia mezhpozvonkovykh implantatov iz uglesitalla u sobak v sheinom otdele pozvonochnogo stolba [Evaluation of the efficiency of using intervertebral implants of carbositall in the canine cervical spine]. *Ros. Veterinar. Zhurnal. Melkie domashnie i dikie zhivotnye*, 2013, no. 4, pp. 11-13. (In Russian)
21. Barabash A.P. Chreskostnyi osteosintez pri zameshchenii defektov dlinnykh kostei [Transosseous osteosynthesis for long bone defect filling]. Irkutsk, 1995. 208 s. (In Russian)
22. Aronov A.M., Bol'basov E.N., Guzeev V.V., Dvornichenko M.V., Tverdokhlebov S.I., Khlusov I.A. Biokompozity na osnove ftorpolimerov s gidroksiappatitom dlia intrameduliarnykh implantov [Biocomposites on the basis of fluoropolymers with hydroxyapatite for intramedullary implants]. *Med. Tekhnika*, 2010, no. 3, pp. 35-41. (In Russian)
23. Kirilova I.A. Kostnaia tkan' kak osnova osteoplasticheskikh materialov dlia vosstanovleniia kostnoi struktury [Bone tissue as the basis of osteoplastic materials for bone structure restoration]. *Khirurgiia Pozvonochnika*, 2011, no. 1, pp. 68-74. (In Russian)
24. Mironov S.P., Shevtsov V.I., Kononovich N.A., Stepanov M.A., Gorbach E.N., Golubev G.Sh., Sergeev K.S., Arkhipenko V.I., Grin' A.A.. Skriabin V.L., Reznik L.B., Shatokhin V.D., Baimuratov A.A. Uglerodnye nanostrukturnye implantaty - innovatsionnyi produkt dlia travmatologii i ortopedii. Chast' 1. Rezul'taty eksperimental'nykh issledovanii [Carbon nanostructured implants – an innovative product for traumatology and orthopaedics. Part 1. Results of experimental research]. *Vestn. Travmatologii i Ortopedii im. N. N. Priorova*, 2015, no. 3, pp. 46-53. (In Russian)
25. Kononovich N.A., Shevtsov V.I., Gorbach E.N., Medik V.A., Stogov M.V., Borzunov D.Y., Stepanov M.A. Experimental Study of Nanostructured Carbon Implants for Management of Circular Diaphyseal Long Bone Defects. *J. Bone Reports and Recommendations*, 2015, vol. 1, no. 1:7. doi: 10.4172/2469-6684.10007. Available at: iMedPub Journals. http://www.imedpub.com.

26. Yoshikawa H., Tamai N., Murase T., Myoui A. Interconnected porous hydroxyapatite ceramics for bone tissue engineering. *J. R. Soc. Interface*, 2009, vol. 6, suppl. 3, pp. S341-S348. doi: 10.1098/rsif.2008.0425.focus.
27. Bondareva N.E. Otsenka gotovnosti sovremennogo stomatologicheskogo rynka k poiavleniiu novogo materiala dlia dental'noi i kostnoi implantatsii [Assessement of modern stomatologic market readiness to the emergence of new material for dental and bone imlpantation]. *Prioritetnye Nauchnye Napravleniia: ot teorii k praktike*, 2014, no. 11, pp. 156-161. (In Russian)
28. Itin V.I., Pribytkov G.A., Khlusov I.A., Zagrebin L.V., Shestov S.S. Implant – nositel' kletochnogo materiala iz poristogo pronitsaemogo titana [Implant is a carrier of cellular material of porous permeable titanium]. *Kletochnaia Transplantologiia i Tkanevaia Inzheneriia*, 2006, no. 3 (5), pp. 59-63. (In Russian)
29. Kazanin K.S., Basov A.V., Shpakovskii M.S., Gribnov N.I. Sravnitel'noe issledovanie kostnogo regenerata posle osteosinteza perelomov sheiki bedrennoi kosti bioinertnymi i bioaktivnymi implantami s kal'tsii fosfatnym pokrytiem (eksperimental'noe issledovanie) [Comparative investigation of a regenerated bone after osteosynthesis of femoral neck fractures using bioinert and bioactive implants with calcium phosphate coating (An experimental study)]. *Travmatologiia i Ortopediia Rossii*, 2015, no. 3 (77), pp. 51-60. (In Russian)
30. Surmeneva M.A., Surmenev R.A., Khlusov I.A., Pichugin V.F., Konishchev M.E., Epple M. Kal'tsiifosfatnye pokrytiia, sozdannye metodom VCh-magnetronnogo raspyleniia gidroksiappatita: osteogennyi potentsial in vitro i in vivo [Calcium-phosphate coatings created by the technique of high-frequency magnetron sputtering of hydroxyapatite: osteogenic potential in vitro and in vivo]. *Izvestiia Tomsk. Politekhnolog. un-ta*, 2010, no. 317 (2), pp. 101-106. (In Russian)
31. Plotkin G.L., Domashenko A.A., Sukhovol'skii O.K., Plotkina K.G., Oleinik A.V., Rassoshanskii A.N. Mesto konstruktsii iz nikelida titana v lechenii travm i zabolevanii oporno-dvigatel'noi sistemy (obzor literatury) [Place of the structures of titanium nickelide in the treatment of the locomotorium injuries and diseases]. *Travmatologiia i Ortopediia Rossii*, 2005, no. 2 (3), pp. 60-64. (In Russian)
32. Zhao C.Y., Zhu X.D., Yuan T., Fan H.S., Zhang X.D. Fabrication of biomimetic apatite coating on porous titanium and their osteointegration in femurs of dogs. *Materials Science and Engineering. C. Biomimetic and supramolecular systems*, 2010, vol. 30, no. 1, pp. 98-104.
33. Ryan G., Pandit A., Apatsidis D.P. Fabrication methods of porous metals for use in orthopaedic applications. *Biomaterials*, 2006, vol. 27, no. 13, pp. 2651-2670.
34. Makarova E.B., Zakharov Yu.M., Rubshtein A.P., Isaikin A.I. Integratsiia kostnoi tkani v poristye titanovye implanty s almazopodobnym nanopokrytiiami [Integration of bone tissue to porous titanium implants with diamond-like nanocoatings]. *Genij Ortopedii*, 2011, no. 4, pp. 111-116. (In Russian)
35. Kuznetsov S.L., Mushkambarov N.N. Gistologiia, tsitologiia i embriologiia: uchebnik dlia med. vuzov [Histology, cytology and embryology: textbook for medical high schools]. M., 2007, 600 p. (In Russian)
36. Popkov A.V. Biosovmestimye implanty v travmatologii i ortopedii (obzor literatury) [Biocompatible implants in traumatology and orthopaedics (A review of literature)]. *Genij Ortopedii*, 2014, no. 3, pp. 94-99. (In Russian)
37. Gorbach E.N., Silant'eva T.A. Morfologicheskaia kharakteristika zazhivleniia polutsirkuliarnykh defektov dlinnykh trubchatykh kostei v usloviiakh chreskostnogo osteosinteza s primeneniem preparata «Litar» [Morphological characterization of healing semicircular defects of long tubular bones under transosseous osteosynthesis using “Litar” preparation]. *Uspekhi Sovremennogo Estestvoznaniia*, 2015, no. 5, pp. 66-70. (In Russian)
38. Shaikhaliev A.I., Stretskii G.M., Krasnov M.S., Rybakova E.Iu., Tikhonov V.E., Iamskova V.P., Iamskov I.A. Deistvie novykh kompozitsii na vosstanovlenie kostnykh defektov u krys v eksperimente [The effect of new compositions on experimental filling of bone defects in rats]. *Fundament. Issled.*, 2013, no. 9, pp. 271-276. (In Russian)
39. Pavlova T.V., Mezentsev Iu.A., Pavlova L.A., Krivetskii V.V., Pavlov I.A., Panachev S.V. Morfofunktsional'noe sostoianie kostnoi tkani pri vvedenii kollagenovo-gidroksiappatinykh nanokompozitov [Bone tissue morphofunctional condition when nanocomposites of collagen-hydroxyapatite insertion]. *Nauch. Vedomosti Belgorod. Gos. un-ta. Seriia: Meditsina. Farmatsiia*, 2009, vol. 59, no. 7, pp. 28-33. (In Russian)
40. Pavlova T.V., Nesterov A.V., Pavlova L.A. Osobennosti primenenie nanomaterialov v meditsine [Special characteristics of nanomaterial use in medicine]. *Mezhdunar. Zhurn. Prikladnykh i Fundamenta. Issled.*, 2012, no. 2, pp. 139-140. (In Russian)
41. Stepanov M.A., Stogov M.V. Ispol'zovanie materiala «Litar» pri zazhivlenii polutsirkuliarnykh defektov dlinnykh trubchatykh kostei u sobak (eksperimental'noe issledovanie) [“Litar” material use when healing semicircular defects of canine long tubular bones (An experimental study)]. *Veterinar. Patologiia*, 2007, no. 3, pp. 167-170. (In Russian)
42. Ivanov P.V., Bulkina N.V., Karpova G.A,, Ziul'kina L.A., Vediaeva A.P. Eksperimental'noe obosnovanie primeneniia ksenokardial'noi plastiny «Kardioplant» v kachestve rezorbiruemoi membrany pri napravlennoi regeneratsii kostnoi tkani [Experimental substantiation of using “Cardioplant” xenocardial plate as a resorbable membrane when guided bone tissue regeneration]. *Fundament. Issled.*, 2013, no. 3-1, pp. 67-69. (In Russian)
43. Shastov A.L., Emanov A.A., Borzunov D.Iu., Stepanov R.V., Diuriagina O.V. Vliianie elektromagnitnykh voln teragertsovogo diapazona na distraktsionnyi osteogenez pri zameshchenii defekta goleni v usloviiakh chreskostnogo osteosinteza (eksperimental'noe issledovanie) [Effect of electromagnetic teraherz-range waves on distraction osteogenesis when filling leg defects using transosseous osteosynthesis (An experimental study)]. *Mezhdunar. Zhurn. Priklad. i Fundam. Issled.*, 2015, no. 8-2, pp. 281-286. (In Russian)

44. D'iachkov A.N., Emanov A.A. Rentgenologicheskaia dinamika zameshcheniia posttravmatichsekikh defektov kostei goleni u sobak metodom distraktsionnogo osteosinteza po Ilizarovu [X-ray dynamics of filling canine leg bone defects by the method of distraction osteosynthesis according to Ilizarov]. *Veterinariia*, 2015, no. 5, pp. 43-47. (In Russian)
45. Tepliashin A.S., Sharifullina S.Z., Chupikova N.I., Sepiashvili R.I. Perspektivy ispol'zovaniia mul'tipotentnykh mezenkhimal'nykh stromal'nykh kletok kostnogo mozga i zhirovoi tkani v reguliatsii regeneratsii opornykh tkanei [Prospects of using multipotent mesenchymal mesenchymal stromal cells of bone marrow and adipose tissue in regulation of support tissue regeneration]. *Allergologiia i Immunologiia*, 2015, vol. 16, no. 1, pp. 138-148. (In Russian)
46. Zaidman A.M., Ivanov N.A., Komareva O.S., Sukhikh A.V., Korel' A.V. Regeneratsiia kostnoi tkani nizhnei cheliusti metodom tkanevoi inzhenerii [Regeneration of mandibular bone tissue by the technique of tissue engineering]. *Sovremennye Problemy Nauki i Obrazovaniia*, 2015, no. 6, pp. 119. (In Russian)

Received: 23.11.2016

Information about the authors:

1. Alexander L. Shastov, M.D.,
Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation,
Email: alshastov@yandex.ru
2. Natalia A. Kononovich, Ph.D. of Veterinary Sciences,
Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation,
Email: n.a.kononovich@mail.ru
3. Elena N. Gorbach, Ph.D. of Biological Sciences,
Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation,
Email: gorbach.e@mail.ru