Original article
https://doi.org/10.18019/1028-4427-2025-31-4-415-423

Results of surgical alloplasty for bone defects of various locations due to distal humerus fractures

A.P. Davydov✉, A.G.Chibrikov, V.Yu. Ulyanov, I.A. Norkin

Saratov State Medical University n.a. V. I. Razumovsky, Saratov, Russian Federation

Corresponding author: Alexey P. Davydov, alexeydawidow@gmail.com

Abstracts

Introduction Currently, up to 30 % of cases after surgical treatment in distal humerus fractures result in permanent disability. It is important to improve the surgical techniques to ensure the restoration of the anatomical integrity of this department.

The **aim** of the work was to perform a comparative analysis of the results of surgical plasty with donor block and cubic cadaver allografts for bone defects of various locations in the distal humerus fractures based on an assessment of bone density and vascularization of the grafted area.

Materials and methods The study involved 56 patients with distal humerus fractures, divided into three groups based on the defect location and two subgroups depending on the method of surgical plastic surgery. A comparative analysis of treatment outcomes was conducted based on the values of the vascularization index of the defect zone obtained by ultrasound study, as well as the Hounsfield index values obtained by computed tomography of the damaged segment. The allograft area was assessed in three zones of interest, the central, marginal and native bone structures.

Results The use of a block allograft provided increase in the values of the Hounsfield index 3 months after surgery in the central graft zone with a defect in the medial column to a value of 190HU (p = 0.01),with a lateral defect to 185HU (p = 0.01), with a central defect to 170HU (p = 0.03); increased the values of the Hounsfield index in the marginal zone 3 months after surgery, the graft area with a medial defect was 210HU (p = 0.01), a lateral defect was 200 HU (p = 0.01), and a central defect was 185 HU (p = 0.02). It provided the increase in the values of the vascularization index of the graft zone with a defect in the medial column by 1.2 times (p = 0.01), in the lateral column by 1.15 times (p = 0.01), in the central zone by 1.18 times (p = 0.02).

Discussion The results of the study indicate that the use of a block allograft increases the density of bone tissue in the marginal and central zones of defect grafting area 3 months after surgery, more expressed if it is localized in the medial and lateral columns, and increases the intensity of blood flow in the defect grafting area 2 months after surgery.

Conclusion Comparison of the results of plastic surgery for post-traumatic bone defects in comminuted fractures of the distal humerus showed the advantage of using native block allograft in defects of the lateral and medial columns due to the optimization of osteointegration processes in the defect zone in the medium-term postoperative period.

Keywords: humerus, comminuted fracture, surgical treatment, allograft, bone density, vascularization

For citation: Davydov AP, Chibrikov AG, Ulyanov VYu, Norkin IA. Results of surgical alloplasty for bone defects of various locations due to distal humerus fractures. *Genij Ortopedii*. 2025;31(4):415-423. doi: 10.18019/1028-4427-2025-31-4-415-423.

INTRODUCTION

Comminuted fractures of the distal humerus (DH) are a severe traumatic pathology. Their incidence is 5.7 cases per 100 thousand adults, accounting for up to 15% of all injuries to the humerus [1]. In young working age, such injuries are a consequence of a high-energy mechanism of trauma, in older people they happen due to a low-energy mechanism as a result of falls from one's own height onto the elbow joint. Given the bimodality of the distribution of this type of injury in the population, the relevance of this problem is beyond doubt due to the increase in life expectancy, as well as the growth in the absolute number of users of personal mobility devices, such as electric scooters, unicycles, and others.

Comminuted fractures in patients over 65 years of age and associated osteopenia, as well as small-fragment fractures in young patients may be accompanied by a post-traumatic bone defect. In this case, one of the types of treatment is total elbow arthroplasty. However, due to the high risk of postoperative complications and a significant proportion (70%) of poor treatment outcomes, this surgical treatment is indicated for older patients with a reduced activity index [2]. Open reduction and internal fixation with plates without restoration of the defect area can lead to the impossibility of strong intraoperative fixation of fragments or a reduction in the contact area of fragments in the fracture zone, forcing the surgeon to resort to additional external immobilization in the postoperative period, which contributes to the development of elbow joint contractures [3].

Currently, not only autogenous but also allogenous grafts, which exist in various forms, can be used as a defect-filling material [4]. Despite its high osteoinductive properties, autogenous grafts have disadvantages such as an expanded surgical field, increased likelihood of postoperative infectious complications, and increased surgical time [5]. The absence of such shortcomings in allografts, high conductive properties, variability of the graft shapes used, and unlimited material allow for filling defects of various geometric proportions [6]. However, if there are no restrictions on the shape of the graft used and the method of retaining it in the defective maternal bed due to the presence of cortical walls when filling a defective cavity, then in the presence of a defect in the axial cortical structures, this problem still exists, especially in cases where prolonged external immobilization is undesirable [7]. Therefore, at present, the development of methods of surgical treatment and plastic surgery of the defect zone aimed at DH reconstruction, which can provide reliable fixation and improve the results of surgical treatment, is relevant [8].

Purpose To conduct a comparative analysis of the results of surgical plastic surgery of bone defects using donor block and cubic cadaver allografts based on an assessment of bone tissue density and vascularization of the grafted zone following fractures of the distal humerus with defects of various locations.

MATERIALS AND METHODS

The study involved 56 patients diagnosed with closed comminuted fractures of the distal humerus of AO type 13C2 and 13C3 with a primary bone defect due to traumatic impact. The injured persons were comparable in age and time since the injury. Indications for surgery were determined according to clinical guidelines for the treatment of patients with distal humerus fractures (Clinical Guidelines "Distal Humerus Fractures", 2024, approved by the NPS of the Ministry of Health of the Russian Federation).

Based on the location of the post-traumatic defect, established by radiography in two standard views and computed tomography of the elbow joint, patients were divided into three groups (Table 1, Figures 1–3):

— Group 1: patients with concomitant post-traumatic defect in the medial column area;

— Group 2: patients with concomitant post-traumatic defect in the lateral column area;

— Group 3: patients with concomitant post-traumatic metaphyseal defect in the central zone.

In regard to defect size, each group was divided into 2 subgroups:

— Type A defect size up to 1.5 cm^2;

— Type B defect size in the range of 1.5–3 cm^2.

Table 1

Distribution of patients based on defect location and size

Parameters		Group 1 (n = 19)		Group 2 (n = 19)		Group 3 (n = 18)	
		1A	1Б	2A	2Б	3A	3Б
Number of patients		10	9	9	10	9	9
Females	number	6	6	5	6	5	6
	%	60	66	55	60	55	66
Age, years		42 (21–60)	37 (25–59)	39 (19–58)	46 (22–57)	44 (28–55)	39 (25–56)
AO fracture type		13C3	13C2	13C2	13C3	13C2	13C3
BMI, kg/m^2		28 (24–32)	30 (26–34)	34 (30–39)	30 (25–32)	31 (26–35)	35 (28–38)
Time since injury, days		4	2	3	5	3	4

Fig. 1 X-rays of a 43-year-old patient with a fracture of the distal humerus and associated bone defect of the lateral column (frontal and lateral views)

Fig. 2 X-rays of a 49-year-old patient with a fracture of the distal humerus and associated bone defect of the central metaphyseal zone (frontal and lateral views)

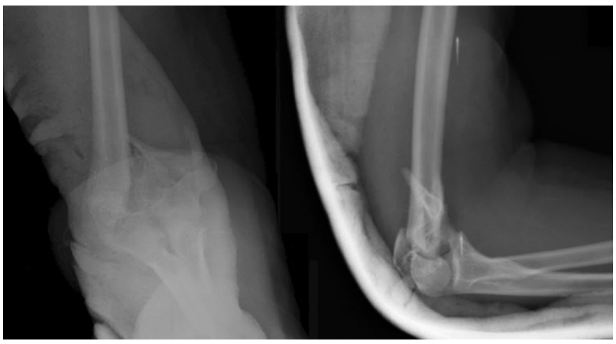

Fig. 3 X-rays of a 38-year-old patient with a fracture of the distal humerus and associated bone defect of the medial column (frontal and lateral views)

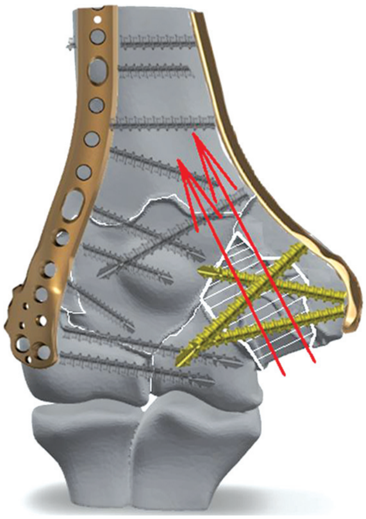

Fig. 4 Alloplasty with block allograft of post-traumatic bone defect in comminuted fractures of the distal humerus

Based on bone defect size and technical feasibility of its fixation, patients underwent two types of surgical reconstruction of the defect area.

Patients with a defect size of up to 1.5 cm^3 underwent plastic surgery with a lyophilized, ultrasound-treated allogeneic cadaveric grafts of cubic shape impacted into the bone bed.

Patients with a defect size of 1.5-3 cm^3 underwent plastic surgery with the technique that comprised (Fig. 4) [9]:

— formation of a tenon-shaped groove in the area of the maternal bed and a tenon-shaped protrusion on the surface of the graft;

— formation of bone canals connecting the allograft block with the bone marrow cavity;

— insertion of blocking screws through the plate and the bone block of the allogeneic graft in intersecting planes.

To control the consolidation processes, an X-ray study was performed using the universal OPERA SWING system manufactured by General Medical Merate SpA (Italy). Direct and lateral X-ray views of the distal humerus were taken. To objectify the bone tissue mineralization processes and quantitatively assess the rigidity of bone structures, multispiral computed tomography (MSCT) was performed on a Phillips device and the Hounsfield index was calculated (densitometric index scale, HU). An assessment was made of the attenuation of X-ray radiation passing through the examined bone tissue in relation to distilled water. In the case of bone defect filling and the use of an allogeneic graft, a change in this indicator over time during dynamic observation indicates the activity of the reparation and mineralization processes of the bone graft. The Misch classification was used as an evaluation scale, according to which it is possible to compare the absolute indicators in HU units.

To conduct MSCT scanning of the distal humerus, three areas of interest were defined, corresponding to the area of alloplastic material and the adjacent bone:

— zone R1 sized 0.5–1 cm^2 corresponded to the marginal part of the graft that bordered the recipient bone;

— zone R2 sized 0.5–1 cm^2 corresponded to the central portion of the allograft;

— zone R3 sized 0.5–1 cm^2 was portion of the metaphyseal bone that bordered with the graft.

The Hounsfield index was calculated based on the size of the alloplastic material used [10–14].

To establish the activity of metabolic processes in the bone callus formation zone in patients of different groups, the method of ultrasound (US) Dopplerography with the calculation of the vascularization index (VI) was used, which involves counting newly formed vessels in the fracture zone. They appear on the 7-10th day after the injury. The number of vessels increases proportionally to the growth of soft bone callus; by the time of mature callus formation, the activity of this process decreases. The intensity of metabolic processes was calculated by counting the area of visualized vessels in the bone callus zone. The study area was 2 × 2 cm, including the periosteal and intermediary zones proximal and distal to the fracture line (Fig. 5). The calculation was carried out using the formula:

$$VI = S\ vessels\ /\ S\ bone\ callus$$ [15–18].

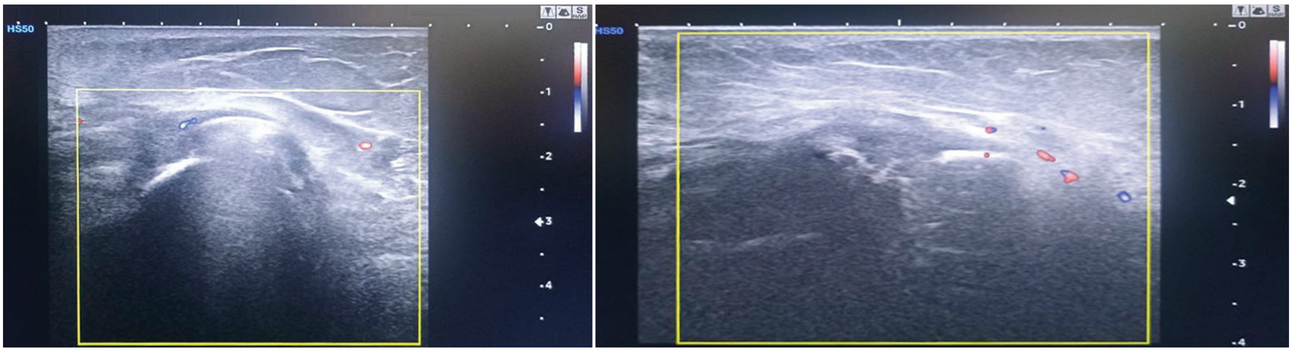

Fig. 5 Ultrasound Dopplerography of the distal humerus fracture zone in a 42-year-old patient: 14 days and 2 months after surgical treatment

The follow-up period of patients in the study groups was 6 months. X-ray study was performed 1.5 months after surgery with dynamic control at 3–3.5 months after surgery to visualize the process of bone callus formation; the final X-ray study at 6 months after the surgery recorded the final signs of fracture consolidation or complications, if any. Computed tomography was performed after 1.5, 3.5, and 6 months to calculate the Hounsfield index, which allowed for an objective comparison of the stiffness of bone tissue and the graft integration, osteoclastic, and initial osteoblastic regeneration stages 6 months after surgery. Doppler ultrasound with VI counting was performed 14 days, 1.5, and 3.5 months after the surgery. The timing is due to the staging of the process of vessel formation in the bone callus that begin to form in the fracture zone 7–10 days after injury, reach the highest density per unit of bone tissue by 1.5–2 months after injury and decrease to the initial value after 3.5 months.

Statistical processing of the obtained data was performed using the IBMSPSS 20 Statistics software package. Due to the discrepancy between most of the obtained data and the normal distribution law, the nonparametric Mann-Whitney U-test, the Wilcoxon test, and the probability index (p) were used to compare the values.

The study was approved by the Ethics Committee of the Saratov Razumovsky State Medical University and was carried out in accordance with the Helsinki Convention. All patients were informed in advance about the conditions of the study and gave written consent to participate.

RESULTS

Evaluating the dynamic changes in the VI indices in the defect zone, an increase in the values was revealed in all subgroups at two months after the operation. The value increased more significantly in subgroups 1B, 2B, 3B — by (7.9 ± 1.27) times ($p = 0.01$), in subgroups 1A, 2A, 3A it increased by (6.9 ± 1.13) times ($p = 0.02$). A decrease in the VI values was noted at 3.5 months after the operation compared to the data obtained 14 days after the operation. Moreover, the average values of VI in subgroups 1A, 2A, 3A were lower by (1.65 ± 1.13) times ($p = 0.001$), and in subgroups 1B, 2B, 3B — by 1.03 times ($p = 0.002$) (Table 2).

The comparison of the indicators showed that the method of bone defect plastic surgery with a block allograft had a positive effect on the value of bone tissue stiffness in the border zone R1 and the central zone R2 at 3 months after the surgery for all defect locations ($p < 0.05$).

The dynamic analysis of the indicators of the central zone of the filled defect noted that the values obtained three months after surgery were lower than the values after 1.5 months for all defect locations ($p < 0.05$).

Table 2

Dynamics of changes in the VI values

Groups	Average values of VI after surgery, %					
	14 days	2 months	p	4 months	p_1	p_2
1A	3.46 ± 0.14	24.02 ± 0.55	0.001	3.60 ± 0.09	0.017	> 0.05
2A	3.32 ± 0.10	25.80 ± 0.68	0.001	3.61 ± 0.12	0.003	0.047
3A	3.65 ± 0.15	23.17 ± 0.83	0.002	3.80 ± 0.10	0.002	0.048
1B	3.57 ± 0.25	28.44 ± 0.46	0.012	5.42 ± 0.18	0.003	0.040
2B	3.48 ± 0.18	29.51 ± 0.29	0.019	6.18 ± 0.25	0.005	0.045
3B	3.54 ± 0.12	27.12 ± 0.72	0.022	5.90 ± 0.16	0.007	0.039

Notes: p — significance of difference compared with 2-week data; p_1 — significance of difference compared with data after 2 months; p_2 —через significance of difference compared with 2-weeks data

The comparison of graft stiffness in the central zone established that in comminuted fractures with a defect in the central metaphyseal zone, the values (170 HU, $p = 0.032$) were 1.12 times lower than in medial defects (190 HU, $p = 0.001$), and 1.1 times lower than in lateral defects (185 HU, $p = 0.002$) (Table 3).

Table 3

Values of the Hounsfield index according to CT data during dynamic monitoring

	Hounsfield index (HU) values																	
	1A			2A			3A			1B			2B			3B		
	1,5 mon	3 mon	6 mon	1,5 mon	3 mon	6 mon	1,5 mon	3 mon	6 mon	170	210	250	170	200	260	160	185	270
R1	100	130	200	105	140	205	110	140	200	0.031	0.003	0.046	0.03	0.009	0.02	0.001	0.026	> 0.05
p_1	0.027	0.005	0.039	0.031	0.012	0.008	0.033	0.04	0.037	> 0.05	0.015	> 0.05	> 0.05	0.006	> 0.05	> 0.05	0.002	> 0.05
p_3		0.009			0.01			0.011			0.012			0.013			0.015	
p_4			0.02			0.001			0.021			0.03			0.02			0.01
R2	140	120	190	130	120	200	130	110	190	210	190	250	205	185	240	190	170	250
p_2	0.011	0.01	0.029	0.025	0.002	0.031	0.026	0.001	0.031	0.025	0.001	0.04	0.008	0.007	0.003	0.03	0.032	> 0.05
p_3		0.038			0.012			0.003		0.021	0.003	0.026	0.023	0.009	0.025	0.02	0.01	0.028
p_4			0.021			0.001			0.001		0.014			0.015			0.012	
R3	220	280	330	210	270	310	230	260	300			0.041			0.01			0.022
p_3		0.015			0.012			0.019		240	280	320	240	285	305	220	255	300
p_4			0.01			0.002			0.021	> 0.05	0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	0.033	> 0.05

Note: p — significance of difference in intergroup comparison; p_1 — significance of probability of R1 value relative to R3; p_2 — significance of difference of R2 relative to R3; p_3 — the correlation coefficient within a group by comparing indicators after 3 and 1.5 months; p_4 — probability value within a group by comparing indicators after 6 months and after 1.5 months

During the observation, 14 cases of treatment complications (25 %) were noted, the majority of which (six cases, 9 %) occurred among patients with a defect in the central metaphyseal zone (Table 4).

Table 4

Complications of surgical reconstruction in distal humerus factures

Type of complication		Number of complications					
		1A	2A	3A	1B	2B	3B
Osteoresoption	n	0	1	1	0	1	0
	%		1.8	1.8		1.8	
	p		0.002	0.002		0.002	
Delayed consolidation	n	2	2	3	1	1	2
	%	3.6	3.6	5.3	1.8	1.8	3.6
	p	0.02	0.007	0.01	0.02	0.03	0.07

DISCUSSION

Allogenic grafting for filling post-traumatic bone tissue defects of the distal humerus is used for anatomical reconstruction of the segment and enables recovery of the physiological biomechanics of elbow joint movements, for which early training of movements is critical. At the same time, insufficient fixation of the graft in the defect zone or compromised stability of bone fragments in the fracture zone may force the surgeon to resort to prolong immobilization. In turn, rigid fixation of fragments and graft due to reduced micromobility of the latter, promotes fracture consolidation and active reparative processes occurring at the "bone — graft" boundary [2, 3, 19–21]. However, analysis of the activity of these processes is almost impossible in in vitro material due to inability of recreating many cells with which the graft interacts during osteoreparation. At the same time, the activity of the cellular reactions themselves, successively replacing each other, is influenced not only by the osteoinductive but also by the osteoconductive properties of the graft, such as the architecture and size of the pores. Therefore, the native structure plays an important role in the process of adaptation of the bone graft in the bone bed [22, 23]. Having the roentgenological method in the arsenal, and namely the MSCT of the damaged segment, the area of the defect being filled can be directly studied.

This method allows for quantitative assessment. Since the integration of the bone graft goes through the stage of lysis and subsequent neoosteogenesis in the peripheral zone of the latter in the direction from the periphery to the center, the zone of the graft is divided into three areas of the same radius — R1, R2, R3 [13, 24, 25]. According to the CT data, several patterns can be established in the zones of the examined graft. In R1 zone, a gradual increase in the absolute HU values was noted in all groups, which indicates an increase in the rigidity of the allograft. This phenomenon can be explained by the process of mineralization of the bone graft which begins 1–1.5 months after surgical placement of the allograft into the defect. In this case, the deposition of mineral salts in the substrate of the bone substance accompanies the process of neoangiogenesis in the bone tissue segment that has already passed the lysis stage. Within one zone, the processes of lysis and mineralization of newly formed bone tissue may undergo in parallel in different directions. This phenomenon of simultaneous heterogeneity of the graft may explain the spread of quantitative values of the Hounsfield index [13, 19, 22]. However, the values of the border zone R1 of the graft was, in our opinion, the most important due to the quantitative characteristic of the strength of the contact between the graft and the bone bed. The border zone of contact of the fibrous-bone block type, corresponding to 201–300 HU in patients of subgroups 1A, 2A, 3A, was achieved 6 months after implantation, while in patients of subgroups 1B, 2B, 3B already 3 months after surgery (Table 3). At the same time, the value of 300 HU, corresponding to the bony block, was not achieved in any subgroup [26–28].

In patients of subgroups 1A, 2A, 3A with cadaveric allografts in the form of cubes as a defect filling material, lower initial HU values were noted in the border zone in all study zones R1–R3, which is similar to the data on bone tissue stiffness without defect filling [22, 30]. Given the type and shape of the material used, the surgeon had to additionally fix the graft by pressing it in the defective bed using an extension. In this case, the trabecular architecture of the allograft was destroyed at the border of the “mother bone — bone block” layer, which was manifested by a decrease in the quantitative indicators of bone tissue stiffness and changed the properties and characteristics of the material used. On the one hand, additional pressing of the material promotes its mechanical compaction in the maternal bed, on the other hand, as a result of this manipulation, the quality of the tissue of the transplant used decreased due to microdamage and disruption of the bone architecture and geometry, which is reflected in insufficiently strong fixation of the material [28–30].

The decrease in the Hounsfield index in the R2 zone 3 months after the surgery compared to the values obtained at 1.5 months can be explained by physiological rarefaction of bone substance. During osteoreparation, the formation of new bone tissue occurs through the lysis stage, as a result of which the tissue rigidity expressed in HU decreased. An increase in this indicator by 6 months after the surgery indicates the predominance of the processes of accumulation of the mineral substrate in the substituted bone tissue over the processes of its decay, which is expressed in an increase in the rigidity of the bone graft. The comparison of the indicators 6 months after the surgery found differences in intergroup comparisons of the corresponding study zones, while the indicators of "healthy" metaphyseal bone tissue without osteopenia were not achieved [23, 25, 29, 31, 32].

The study of the results of Doppler sonography of the fracture zone revealed that all patients had a general tendency towards relatively low values of the vascularization index during the period of reparation and the beginning of the formation of primary bone callus after 2 weeks, as well as by the end of the reparative phase of osteosubstitution at 4 months after the injury. At the same time, at 2 months after the operation, during the period of high activity of the secondary bone callus formation phase, an increase in this indicator was noted. Considering that the active blood supply to the fracture zone, namely the outer part of the bone callus, promotes the differentiation of osteogenic cells into osteoblasts, it can be assumed that the presence of osteoplastic material does not change the general direction of osteoreparative processes [15, 17, 18].

The increase in the area of small newly formed vessels in the bone callus zone noted 2 months after surgery in patients of subgroups 1B, 2B, 3B can be explained by both the higher osteointegrative properties of the material used and additional intraoperative measures that contribute to an increase in bioactive substances in the fracture zone [9]. A decrease in the area of formed vessels in the bone callus zone four months after surgery was more pronounced in the patients of subgroups 1A, 2A, 3A and indicates a decrease in the activity of blood supply and metabolic processes in the bone callus formation zone [16, 17]. In the case of a positive radiographic picture and the presence of signs of fracture consolidation, a favorable course and prolonged nature of osteoreparative processes can be assumed with the use of an allogeneic block transplant.

CONCLUSION

The comparison of the results of using allogenic grafting of different nature in comminuted distal humerus fractures of the 13C2 and 13C3 types, accompanied by posttraumatic bone defects found that the indices of medium-term osseointegration are more pronounced if native allogeneic block-type material is used for defect localized in the area of the medial and lateral columns. However, the complications and poor treatment outcomes determine the need for further study of the use of these materials and methods of bone defect plastic surgery.

Conflict of interest *Not declared.*

Funding *Not declared.*

Ethical standards *The study was approved by the Ethics Committee of the Saratov Razumovsky State Medical University and was carried out in accordance with the Helsinki Convention.*

Informed consent *All patients were informed in advance about the conditions of the study and gave written consent to participate.*

REFERENCES

1. Chibirov GM, Soldatov YuP. Treatment of patients with the elbow function disorder accompanied by posttraumatic pseudoarthrosis of humeral condyle. *Genij Ortopedii*. 2013;(3):80-81. (In Russ.)
2. Gritsyuk AA, Lychagin AV, Kryukov EV, et al. Peculiarities of elbow joint replacement in case of wounds and injuries: long-term results. *Military Medical Journal*. 2017; 338(12): 37-44. (In Russ.) doi: 10.17816/RMMJ73433.
3. Khodzhanov IY, Borzunov DY, Bayimbetov GD. Treatment of children with multiple injuries of the bones forming the elbow joint. *Genij Ortopedii*. 2023;29(1):12-19. doi: 10.18019/1028-4427-2023-29-1-12-19.
4. Popkov AV, Popkov DA. Biocompatible implants in orthopedics: bone tissue engineering. *Genij Ortopedii*. 2023;29(6):662-668. doi: 10.18019/1028-4427-2023-29-6-662-668.
5. Borzunov DYu, Gilmanov RT. Promising osteoplastic materials and surgical technologies in reconstructive treatment of patients with bone nonunion and defects. *GenijOrtopedii*. 2024;30(2):263-272. doi: 10.18019/1028-4427-2024-30-2-263-272.
6. Molenaars RJ, Schoolmeesters BJA, Viveen J, et al. There is a role for allografts in reconstructive surgery of the elbow and forearm. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(6):1840-1846. doi: 10.1007/s00167-018-5221-y.
7. Kirilova IA, Sharkeev YuP, Podorozhnaya VT, et al. Structural and functional studies of bioobjects prepared from femoral heads. *AIP Conf. Proc*. 2015;1688(1): 030005. doi: 10.1063/1.4936000.
8. Eremin AV, Sorokin GV, Gorgun AA, et al. Adhesive properties of natural and artificial osteoplastic materials. *Department of Traumatology and Orthopedics*. 2014;(2):11-15. (In Russ.)

9. Davydov AP, Petrov AB. *Method of plastic surgery of post-traumatic periarticular defects of long tubular bones (variants)*. Patent RF, no. 2798904. Bulletin No. 19. 2023. Available at: https://www.fips.ru/registers-doc-view/fips_servlet?DB=RUPAT&DocNumber=2798904&TypeFile=html. Accessed May 23, 2025. (In Russ.)
10. Moreno M, Amaral MH, Lobo JM, Silva AC. Scaffolds for Bone Regeneration: State of the Art. *Curr Pharm Des*. 2016;22(18):2726-2736. doi: 10.2174/1381612822666160203114902.
11. Sletov A. A., Zhidovinov A. V., Mozheiko R. A. Comparative analysis of the effectiveness of visual methods of diagnosis in patients with osteonecrosis and aseptic osteomyelitis of jaw bones. *Journal of Volgograd State medical university*. 2017;(1):78-81. (In Russ.)
12. Vasyliev R, Oksymets V, Rodnichenko A, et al. Tissue engineering-based approach for restoration of combat related critical sized bone defects. *Cytotherapy*. 2017;19(5):223-224.
13. Rerikh VV, Predein YuA, Bataev VA, et al. Formation of a bone block during interbody fusion with an osteograft and autobone in conditions of fixation of a spinal segment with ceramic implants in experiment. *Modern Problems of Science and Education*. 2020;(5):131-133. (In Russ.) doi: 10.17513/spno.30221.
14. Misch CE. The implant quality scale: a clinical assessment of the health--disease continuum. *Oral Health*. 1998;88(7):15-20, 23-25; quiz 25-26.
15. Kormilina AR, Tukhbatullin MG. Capabilities of multiparametric ultrasound in assessing bone callus maturation. *Proceedings of the XV All-Russian National Congress of Radiation Diagnosticians and Therapists "Radiology-2021"*. Moscow: MEDI Expo; 2021:46-47. (In Russ.) URL: https://www.mediexpo.ru/fileadmin/user_upload/content/pdf/rad2021--abstracts.pdf.
16. Kormilina AR. *Multiparametric ultrasound examination of long tubular bone fractures: Cand. Diss*. Kazan; 2016:123. Available from: https://www.dissercat.com/content/multiparametricheskoe-ultrazvukovoe-issledovanie-pri-perelomakh-dlinnykh-trubchatykh-kostei. Accessed May 23, 2025. (In Russ.)
17. Nicholson JA, Tsang STJ, MacGillivray TJ, et al. What is the role of ultrasound in fracture management?: Diagnosis and therapeutic potential for fractures, delayed unions, and fracture-related infection. *Bone Joint Res*. 2019;8(7):304-312. doi: 10.1302/2046-3758.87.BJR-2018-0215.R2.
18. Cocco G, Ricci V, Villani M, et al. Ultrasound imaging of bone fractures. *Insights Imaging*. 2022;13(1):189. doi: 10.1186/s13244-022-01335-z.
19. Kennedy OD, Herman BC, Laudier DM, et al. Activation of resorption in fatigue-loaded bone involves both apoptosis and active pro-osteoclastogenic signaling by distinct osteocyte populations. *Bone*. 2012;50(5):1115-1122. doi: 10.1016/j.bone.2012.01.025.
20. D'yachkov AN, Migalkin NS, Stogov MV, et al. Safety and Effectiveness of Using Double-Ended Allograft in the Repair of Large Defects of Bi-Epiphyseal Bones in Experiment. *IP Pavlov Russian Medical Biological Herald*. 2022;30(2):139-148. doi: 10.17816/PAVLOVJ100480.
21. Tipton S, Nunez FA, Vazquez FAN, et al. Reconstruction of Distal Humerus Fractures with Severe Bone Loss: A Case Series and Review of the Literature. *J Surg Orthop Adv*. 2020;29(2):65-72.
22. Chesnokov SA, Kovylin RS, Yudin VV, et al. Bone substituting materials based on oligoether methacrylates. *Oligomers-2024: Proceedings of the XX International Conference on the Chemistry and Physicochemistry of Oligomers. Plenary lectures*. Chernogolovka: FRC PCF and MCh RAS; 2024;(1):178-200. Available from: https://oligomers.ru/wp-content/uploads/2024/09/Сборник-Том1-2024_c.pdf. Accessed May 23, 2025. (In Russ.)
23. Shibuya N, Jupiter DC. Bone graft substitute: allograft and xenograft. *Clin Podiatr Med Surg*. 2015;32(1):21-34. doi: 10.1016/j.cpm.2014.09.011.
24. Misch CE. Bone character: second vital implant criterion. *Dent Today*.1988;7:39-40.
25. Yezhov MY, Yezhov IY, Kashko AK. Unresolved issues of the cartilage and the bone regeneration (review). *Advances in current natural sciences*. 2015;(5):126-131. (In Russ.) URL: https://natural-sciences.ru/ru/article/view?id=35113.
26. Kirilenko SI, Nikolaev VI, Nadyrov EA, et al. Results of transforaminal lumbar interbody fusion using new method ofspine fusion. *Meditsinskie novosti*. 2022;(3):69-72. (In Russ.)
27. Netsvetov PV, Khudyaev AT, Dyachkova GV, et al. The role of computed tomography in assessing the density of the bone block of the damaged segment of the spine at different stages of treatment with an external transpedicular fixation device. *Bulletin of Roentgenology and Radiology*. 2007;(2):23-26. (In Russ.)
28. Chernyaev VS, Fomenko MA, Tsygankova AV. Clinical aspects of modern radiation diagnostics in traumatology and orthopedics. *Trends in the development of science and education*. 2021;71:65-68. (In Russ.) doi: 10.18411/lj-03-2021-15.
29. Diachkova GV, Mitina YuL, Diachkov KA, et al. Clinical aspects of current radial diagnostics in traumatology and orthopaedics. *Genij Ortopedii*. 2011;(2):84-90. (In Russ.)
30. Burr DB. Bone quality: understanding what matters. *J Musculoskelet Neuronal Interact*. 2004;4(2):184-186.
31. Rozhinskaya L.Ya. Concept of bone quality: influence of antiresorptive drugs on bone quality parameters. *Osteoporosis and osteopathy*. 2003;3:25-29. (In Russ.)
32. Aleksandrov SM. *Multislice computed tomography in determining bone quality in patients with chronic osteomyelitis: Cand. Diss*. St. Petersburg; 2016:172. Available from: https://www.dslib.net/luch-diagnostika/multisrezovaja-kompjuternaja-tomografija-v-opredelenii-kachestva-kosti-u-bolnyh-s.html. Accessed May 23, 2025. (In Russ.)

The article was submitted 23.04.2025; approved after reviewing 22.05.2025; accepted for publication 05.06.2025.

Information about the authors:

Aleksey P. Davydov — Assistant,alexeydawidow@gmail.com, https://orcid.org/0000-0003-4181-3844;

Andrej G. Chibrikov — Candidate of Medical Sciences, Head of Department, https://orcid.org/0009-0006-8273-4113;

Vladimir Yu. Ulyanov — Doctor of Medical Sciences, Associate Professor, Vice-Rector, v.u.ulyanov@gmail.com, https://orcid.org/0000-0002-9466-8348;

Igor A. Norkin — Doctor of Medical Sciences, Professor, Head of Department, norkinsgmu@yandex.ru, https://orcid.org/0000-0002-6770-3398.