



## Fixation Techniques for Intraarticular Proximal Humeral Fractures

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### Abstract

**Background.** The most severe type of injuries of the proximal epiphysis of the humerus are intraarticular fractures. One of the main complication is the development of avascular osteonecrosis, which is caused by the peculiarities of blood supply of the humeral head and its compromised vascularization as a result of trauma. Current osteosynthesis techniques for intraarticular fractures of the proximal humerus (PH) do not reduce the risk of avascular osteonecrosis of the humeral head (AONHH) and do not reduce the risk of nonunion. To prevent ischemic changes in the humeral head, osteosynthesis with reparative osteogenesis stimulation is recommended.

**Aim of the study** – to specify indications for various fixation techniques of intraarticular fractures of the proximal humerus.

**Methods.** The study enrolled 48 patients with AO/ASIF type 11C1 and 11C2 intraarticular PH fractures requiring surgical treatment. All patients were allocated into 2 groups. Retrospective (control) group included 25 patients who were treated using locking plate osteosynthesis or intramedullary locking osteosynthesis with proximal humeral nails. Prospective (main) group included 23 patients who were additionally treated with a vascularized musculoskeletal graft from the coracoid process of the scapula transplanted to the fracture area.

**Results.** Functional treatment results of patients who underwent surgery using vascularized musculoskeletal grafts from the coracoid processes of the scapula (71.50% were excellent and 14.3% were good) were better than those of the control group (35.28% were excellent and 17.64% were good). Consolidation of the fracture in the control group occurred in 92% of cases (23 patients); the remaining 8% (2) of patients had pseudoarthrosis of the anatomical or surgical neck of the humerus developed within 6 months after the surgery. In the main group, the fractures consolidated in all patients.

**Conclusion.** Fractures with no damage to the bicipital groove should be considered an indication for performing plate osteosynthesis without vascularized musculoskeletal grafting. Locking osteosynthesis in case of intraarticular PH fractures makes it much more difficult to reduce the humeral head and the tubercular area. Locking osteosynthesis decreases the rigidity of fixation of fragments, which may contribute to their secondary displacement.

**Keywords:** proximal humerus fracture, plate osteosynthesis, stimulation of reparative osteogenesis, vascularized musculoskeletal graft, humeral osteonecrosis.

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## Выбор метода остеосинтеза при внутрисуставных переломах проксимального эпифиза плечевой кости

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### Реферат

**Актуальность.** Наиболее тяжелой категорией переломов проксимального эпифиза плечевой кости являются внутрисуставные повреждения. Одним из основных осложнений является формирование аваскулярного некроза, причиной которого служат особенности кровоснабжения головки плечевой кости и нарушение ее васкуляризации вследствие травмы. Существующие в настоящее время способы остеосинтеза внутрисуставных переломов проксимального отдела плечевой кости (ПОПК) не снижают риска развития асептического некроза головки плечевой кости (АНГПК) и не уменьшают риск несращения. Для профилактики ишемических изменений головки плечевой кости рекомендуется использовать метод остеосинтеза с элементом стимуляции репаративного остеогенеза.


**Цель исследования** — уточнение показаний к применению различных методов хирургического лечения внутрисуставных переломов проксимального отдела плечевой кости.


**Материал и методы.** В исследование включено 48 наблюдений пациентов с внутрисуставными переломами ПОПК типов 11-C1 и 11-C2 по классификации АО/ASIF, нуждающихся в оперативном лечении. Из общего количества пациентов были сформированы две группы. В ретроспективную (контрольную) группу вошли 25 пациентов, которых лечили с использованием накостного остеосинтеза пластиной с угловой стабильностью или интрамедуллярного блокируемого остеосинтеза проксимальными плечевыми штифтами. В проспективную (основную) группу вошли 23 пациента, при лечении которых дополнительно выполняли пересадку несвободного костно-мышечного трансплантата из клювовидного отростка лопатки в зону перелома.

**Результаты.** Функциональные результаты лечения пациентов, оперированных с использованием несвободных костно-мышечных трансплантатов из клювовидного отростка лопатки (71,5% отличных и 14,3% хороших результатов), лучше результатов контрольной группы (35,28% отличных и 17,64% хороших результатов). В контрольной группе консолидация перелома произошла в 92% случаев (23 пациента), у остальных 8% (2) пациентов отмечен исход в виде ложного сустава области анатомической или хирургической шейки плечевой кости в течение 6 мес. после операции. В основной группе у всех пациентов переломы консолидировались.

**Заключение.** Показанием для выполнения накостного остеосинтеза без несвободной трансплантации костно-мышечного лоскута следует считать переломы без нарушения целостности межбугорковой борозды. Применение блокирующего остеосинтеза при внутрисуставных переломах ПОПК значительно затруднено необходимостью репозиции головки и бугорковой зоны. При блокирующем остеосинтезе снижается жесткость фиксации отломков, что может способствовать их вторичному смещению.

**Ключевые слова:** внутрисуставной перелом проксимального отдела плечевой кости, накостный остеосинтез, стимуляция репаративного остеогенеза, несвободный костно-мышечный трансплантат, асептический некроз проксимального эпифиза плечевой кости.

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## BACKGROUND

Fractures of the proximal humerus (PH) account for about 6% of all fractures, with a peak incidence in the age group of 60 to 90 years [1]. Among patients over 65 years old, these fractures are the third most common after the injuries of osteoporosis critical areas [2]. Despite many studies proving the inefficiency of conservative methods of PH treatment, the comparison of surgical and conservative methods is constantly under study. Currently, the prevailing opinion is that the conservative treatment of unstable comminuted fractures of the proximal humerus leads to unsatisfactory results in the majority of cases [3]. Their surgical treatment is represented by three main techniques: osteosynthesis with angular stable locking plates, intramedullary locking osteosynthesis with different modifications of proximal humeral nails (PHN) and shoulder arthroplasty. There are also original fixators of limited use. External fixation of PH fractures is not widespread due to its technical complexity and the need for regular control of fixator's state.

Despite the developed clinical guidelines for treatment, the choice of osteosynthesis method for intraarticular PH fractures remains a relevant problem, primarily due to a high incidence of postischemic changes in the humeral head.

*Aim of the study* – to clarify indications for various techniques of surgical treatment of intraarticular fractures of the proximal humerus.

## METHODS

### Study design

A single-center retrospective prospective cohort non-randomized controlled (active control) study was performed and included 48 cases of patients with intraarticular PH fractures who were treated on an inpatient basis and subsequently followed up on an outpatient basis.

*Inclusion criteria:* patients aged 20 to including 80 years with AO/ASIF type 11C1 and 11C2 fractures [4] (excluding fracture dislocations) or with the consequences of PH fractures requiring surgical treatment.

All patients were allocated into 2 groups. Retrospective (control) group included 25 patients who were treated using locking plate osteosynthesis or intramedullary locking osteosyn-

thesis with proximal humeral nails. Prospective (main) group included 23 patients who were additionally treated with a vascularized musculoskeletal graft from the coracoid process of the scapula transplanted to the fracture area.

### Examination of patients

All patients underwent clinical and radiological examinations. Clinical examination included history and complaints intake, as well as assessment of patients' *status localis*. Radiological examination consisted of shoulder X-rays in two or three views, MRI and multispiral computed tomography (MSCT) and aimed to assess the degree of osteosclerosis and associated dystrophic changes and/or damages to the shoulder rotator cuff tendon and the severity of the secondary omarthritis. Radiological dynamics of changes in the fracture area and bone structure of the humeral head were studied.

### Assessment of results

Clinical outcomes were assessed using the ASES questionnaire: intensity of pain syndrome (PS) and level of activities of daily living (ADL). The grade of avascular osteonecrosis of the humeral head (AONHH) was assessed using the radiological data.

### Statistical analysis

Distributions of the samples of continuous variables of age, postoperative examination time, ASES, abduction, flexion, internal and external rotation were tested for agreement with the law of normal distribution using Shapiro-Wilk test; equality of variance in the compared groups was tested using Fisher's criterion. Most distributions were non-normal and heteroscedastic. Therefore, continuous variables were compared using the nonparametric Mann-Whitney U-criterion. Pseudomedian of differences (PM) and standardized mean difference (SMD) were calculated to assess the difference between the groups. Continuous variables were described as median [first quartile; third quartile] (M [Q1; Q3], minimum and maximum values (min-max).

Binary variables of consolidation and elevation were described as the number of events and incidence with 95% confidence interval (CI) using Wilson's formula (n, % [95% CI]). Risk difference (RD) and odds ratio (OR) with 95% CI

were calculated to assess group differences. The number of patients and detection rate (grade – n (%)) were calculated for the grades of categorical AONHH. Binary and nominal variables were compared using two-tailed Fisher's exact test. Comparing grades in nominal variables, the multiple comparison error was corrected by Benjamini-Hochberg criterion.

Statistical hypotheses were tested at the critical level of significance  $p = 0.05$ , i.e. the difference was considered statistically significant at  $p < 0.05$ . Statistical analysis was performed using the Rstudio software (version 2022.07.2+576, 2022-09-06) in the R language (version 4.1.3).

**RESULTS**

Results were evaluated 12-24 months after the surgery (Table 1).

The distribution of grades of AONHH in the main and control groups differed statistically significantly ( $p = 0.010$ ): grade 0 in 12 (48.0%) and 20 (87.0%) patients, respectively ( $p = 0.018$ ), grade 4 in 10 (40%) and 2 (8.7%) patients, respectively ( $p = 0.028$ ). No differences in grade 3 were found ( $p = 0.610$ ) (Fig. 1).

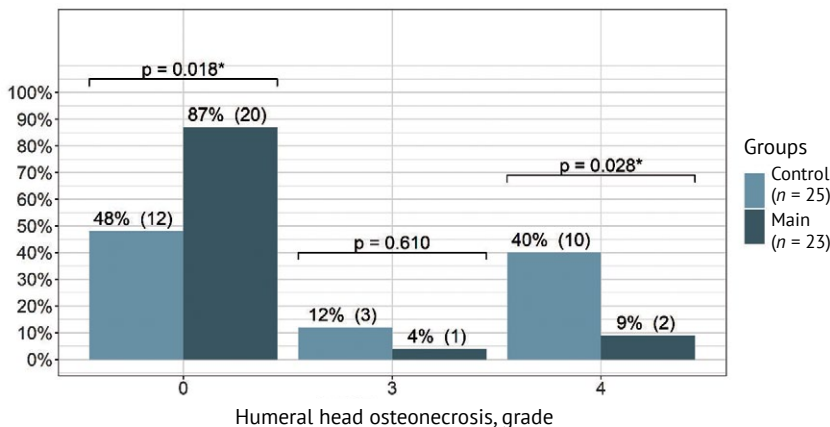
Range of active motions in the groups was comparable: in the main group it was on average 5-10° lower ( $p = 0.483-0.532$ ) (Fig. 2).

Table 1

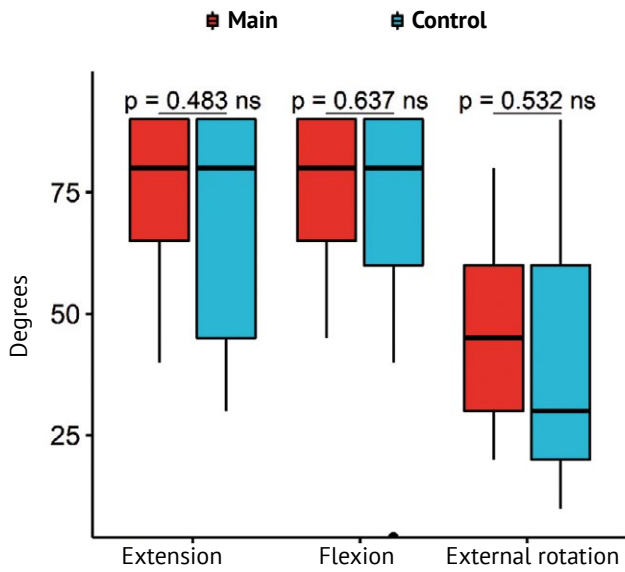
**Comparison of values of parameters between the main group and the control group**

Parameter	Control group <i>n</i> = 25	Main group <i>n</i> = 23	Evaluation of differences	<i>p</i>
Age, y.o. M [Q1; Q3] (min-max)	67 [55; 70] (33-77)	65 [62; 76] (46-81)	ΠM: 4 [-3; 9] CPC: 0.43	0,296
Term of postoperative examination, mos. M [Q1; Q3] (min-max)	48 [24; 48] (12-68)	18 [11; 24] (6-36)	ΠM: 24 [12; 36] CPC: 1.52	<0,001*
Bone union, number (%) [95% CI]	23 (92) [75%; 98%]	23 (100%) [86%; 100%]	PP: 8% [3%; 19%]	0,491
PS, points M [Q1; Q3] (min-max)	45 [35; 50] (5-50)	45 [45; 50] (35-50)	ΠM: 5 [0; 10] CPC: 0.83	0,017*
ADL, points M [Q1; Q3] (min-max)	37 [22; 45] (12-50)	33 [29.5; 42] (22-50)	ΠM: 0 [-6; 10] CPC: 0.18	0,877
ASES, total score M [Q1; Q3] (min-max)	80 [62; 88] (27-100)	80 [77; 88.5] (68-95)	ΠM: 4 [-5; 16] CPC: 0.54	0,535

\* – statistically significantly different values.

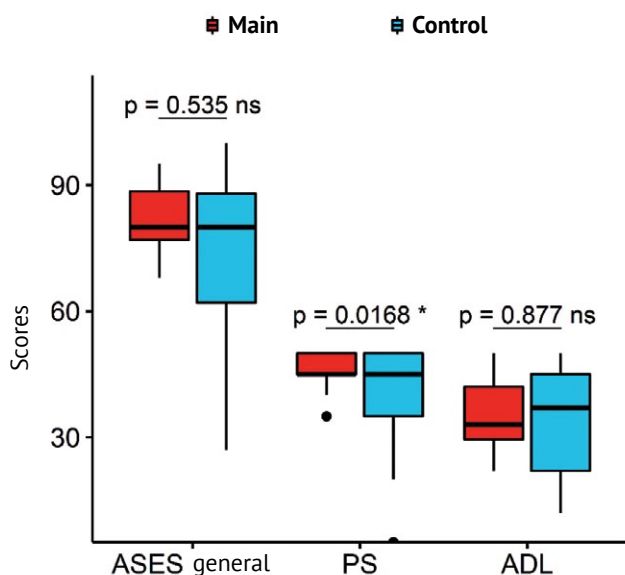


**Fig. 1.** Distribution of grades of avascular osteonecrosis of the humeral head in the groups



**Fig. 2.** Range of active motions in the shoulder in the groups

Median PS values in the main and control groups were 45 [35; 50] and 45 [45; 50] points, respectively. In the main group, PS was statistically significantly greater by an average of 5 points ( $p = 0.017$ ). Median ADL values were 37 [22; 45] and 33 [29; 42] points. In the main group, ADL was statistically significantly greater by an average of 3 to 5 points ( $p = 0.088$ ) (Fig. 3).



**Fig. 3.** PS and ADL values in the groups

In the control group, bone union occurred in 92% of cases (23 patients) ( $p = 0.491$ ); the remaining 8% (2) of patients, developed pseudoarthrosis of the anatomical or surgical neck of the humerus within 6 months after surgery. There were no cases of pseudoarthrosis in the main group; fractures in all patients healed.

**DISCUSSION**

When choosing a method of osteosynthesis for intraarticular fractures of the proximal epiphysis of the humerus, the practicing surgeon is faced with the problem of minimizing the surgical trauma and preserving the blood supply of the fragments, on the one hand, and ensuring accurate reduction and stable rigid fixation, on the other. Intramedullary osteosynthesis is widely used in the treatment of type C fractures mainly due to advanced screw locking system and is considered to be the method of choice in elderly patients because it provides sufficient stability of fragments [5]. Angular stable locking fixation systems have higher internal stability values, so they maintain better reduction at the stage of postoperative functional treatment [6]. In 2013, P.G. Kogan et al. considered intramedullary osteosynthesis to be one of the most promising methods of treatment of comminuted fractures of the proximal epiphysis of the humerus [7]. However, with the development of minimally invasive techniques, some studies have appeared revealing negative aspects of closed fracture reduction.

C. Rajasekhar et al. reported 59 complications in 115 patients. Screw migration accounted for the largest number (26 out of 59). Authors draw attention to the necessity of more accurate fixation of the tubercles and improvement of screw placement technique to prevent this complication [8]. Similar complication rate, which was 39% (26 of 61 patients), was noted by C. Witney-Lagen et al. Impingement syndrome accounted for the largest number of complications (7 out of 26), requiring nail removal [9].

Due to some technical difficulties in restoring the anatomical relationships in the joint in case of closed reduction, reduction methods using mini-open approach with soft tissue stabilization of the tubercles [10] or their fixation with single



implants have been being developed. The screw-in-screw technique, in addition to PH fragments stabilization, to some extent solves the problem of their secondary displacement, but it is less reliable than the osteosynthesis with the use of LCP plates.

Primary shoulder arthroplasty is considered to be the method of choice for comminuted PH fractures. Most recent studies show that early arthroplasty is usually preferable to arthroplasty in the long-term period, since the primary surgery is technically easier to be performed [11]. Nevertheless, U. Prakash et al. found no difference between the primary and delayed arthroplasty more than 30 days after the injury [12]. Recently, there are more and more reports on poor outcomes of shoulder arthroplasty for PH fractures. In 2010, D. den Hartog et al. published the results of meta-analysis of 33 studies that included 1096 patients with three- and four-fragment PH fractures. Patients who underwent arthroplasty showed worse functional outcomes compared to non-operated patients, with a difference of 10.9 points according to the Constant-Murley 100-point score [13]. Comparative study of long-term consequences of arthroplasty revealed moderate and severe limb dysfunction in 30% of cases [14]. Despite the ambiguity of obtained results of shoulder arthroplasty in case of fractures, current prevailing opinion is that intraarticular PH fractures are an indication for primary arthroplasty of the joint [15]. In addition to technical difficulties, long-term results of osteosynthesis of intraarticular PH fractures are always uncertain due to its impaired vascularization at the time of the injury and surgery, which then leads to head osteonecrosis and collapse, taking place in 30-100% of cases [16]. Thus, one of the main factors influencing the choice of surgical management in case of intraarticular fractures of the proximal humerus is the probability of damage to the main sources of blood supply to the humeral head.

Studies of the vascular network of the proximal humerus have shown that the blood supply to the humeral head is mainly through the arcuate artery, which branches from the ascending branch of the anterior circumflex humeral artery. When the arcuate artery is damaged, the blood supply to the humeral head cannot be compensated by other sources, which leads to AONHH [17].

Crucial significance of the damage to the arcuate artery was confirmed by C.H. Brooks et al. who studied the anatomy of PH arteries and the impact of four-fragment fractures on the blood supply to the humeral head. In most cases, simulated four-fragment fractures interrupted the perfusion of the humeral head. However, if the fracture line passed distally below the articular surface and medially, some perfusion of the head was preserved due to the posteromedial vessels. These vessels play an important role in the treatment of comminuted PH fractures [18]. Therefore, it is necessary to stimulate reparative osteogenesis in case of intraarticular fractures to reduce the time of bone union and prevent ischemic changes in the humeral head. Using vascularized grafts to stimulate osteogenesis appears to be the most promising.

Blood supply of the osteotomized fragment of the coracoid process was verified in the anatomical and morphological study performed by R. Khundkar et al. Experimental cadaveric and clinical studies demonstrated the presence of a previously unidentified direct arterial branch from the second (middle) part of the axillary artery feeding the anterior 2-3 cm of the coracoid process of the scapula [19]. A. Hamel et al. performed postmortem arteriography of the upper limb. Results were as follows: the vertical part of the coracoid process was supplied by the suprascapular artery, and the horizontal part — by branches of the axillary artery [20]. Another study of the blood supply of the coracoid process by Z. Deng et al. revealed that the coracoid process is supplied by the suprascapular artery, the thoracoacromial artery, and a branch from the second part of the axillary artery. Moreover, there is a possibility that the vessels derived from *m. biceps* fed the inferior side of the coracoid process [21].

Modern methods of stimulation of reparative processes that are most feasible for execution in a general hospital are considered. The use of free cancellous bone autografts from the wing of the iliac bone is considered exclusively for the replacement of PH defects arising due to osteoporotic bone collapse at the moment of injury [1]. This option of bone grafting is optimal due to many factors, including the absence of immune response and the presence of live osteogenic cells. The main disadvantages of autografting are well known to every trauma practitioner: ad-

ditional trauma to the donor site, increased surgery duration, emergence of additional infection portals of entry. Some sources indicate the possibility of using allogeneic and synthetic materials for this purpose [22]. Unfortunately, these materials cannot in any way stimulate osteogenesis in the ischemic zone of bone tissue, except in cases of saturation of the allograft bone structure with osteostimulating substrates. The study of osteostimulation by the graft from the preparation of the head, neck and part of the diaphysis of the cadaver fibula, saturated with collagen solution can be an example. According to study results, the developed combined allogeneic graft from the head of the fibula, saturated with type I collagen, is nontoxic, has no immunogenicity and has more pronounced osteoconductive properties in comparison with native bone allografts, which contributes to its colonization by cells [22].

Wide application of autologous platelet-rich plasma, autologous human platelet lysate and autologous human bone marrow aspirate is limited as it requires special expensive equipment. The most promising method for stimulation of osteogenesis appears to be the vascularized autografts, preserving the blood supply of the parafracture area from an additional source. Along with our proposed technique, the method of vascularized bone grafting for the treatment of pseudoarthrosis in the upper third of the humerus proposed by Tikhilov R.M. et al. [23] attracts attention. The idea of this method is to form a musculoskeletal graft, including a fragment of the lower angle of the scapula, which is transferred to the reconstruction area in the upper third of the shoulder.

## CONCLUSION

Intraarticular PH fractures with displacement of fragments along the bicipital groove of more than 2 mm are indications for osteosynthesis. Fractures with no damage to the bicipital groove should be considered an indication for performing osteosynthesis without vascularized musculoskeletal grafting. The use of locking osteosynthesis for intraarticular PH fractures is significantly complicated due to the need of reduction of the head and tubercular area. Locking osteosynthesis decreases the rigidity of fixation of fragments, which may contribute to their sec-

ondary displacement. Given the closed reduction of fragments, the probability of damage to the arcuate branch of the anterior circumflex humeral artery increases.

## DISCLAIMERS

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**Disclosure competing interests.** The author declares that they have no competing interests.

**Ethics approval.** The study was approved by the local ethics committee of Novosibirsk Research Institute of Traumatology and Orthopedics n.a. Ya.L. Tsivyan, protocol No 001/23, 17.01.2022.

**Consent for publication.** The author obtained written consent from patients to participate in the study.

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