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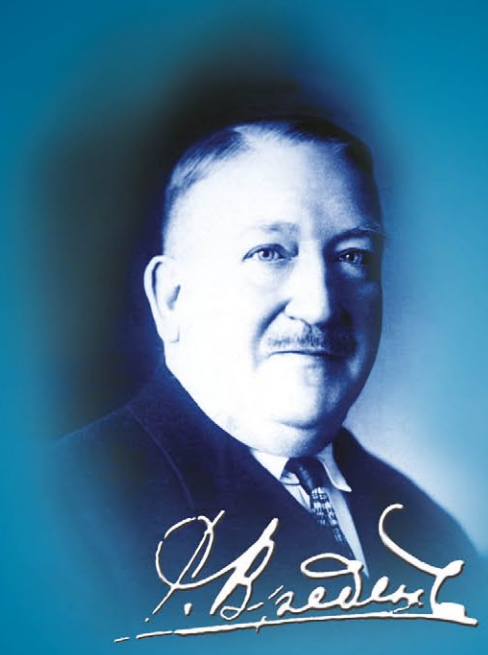

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Адрес: 191186, г. Санкт-Петербург, Аптекарский пер., д. 3, литера А, помещение 1Н
E-mail: info@eco-vector.com
https://eco-vector.com
тел.: +7(812)648-83-67

**РЕДАКЦИЯ**
Адрес: 195427, Санкт-Петербург, ул. Академика Байкова, дом 8;
тел.: +7 (812) 670-86-84
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# СОДЕРЖАНИЕ

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# Outcomes of Revision Hip Replacement After Resection Arthroplasty With a Non-Free Muscle Flap Transfer for Difficult-To-Treat Periprosthetic Infection

Vitaly N. Liventsov, Svetlana A. Bozhkova, Rashid M. Tikhilov, Vasilii A. Artyukh

*Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation*

***Background.*** Resection arthroplasty with non-free muscle flap transfer allows to quickly eliminate the infection, but resulting in functional impairment of hip joint. To date, there are only a few publications with a small number of observations, where the proportion of patients who underwent the second stage of the revision hip arthroplasty (rTHA) is extremely small.

***The aim of the study*** was to evaluate the effect of resection arthroplasty on the functional outcomes and incidence of adverse outcomes in patients with difficult-to-treat (DTT) periprosthetic infection who had previously undergone resection arthroplasty with a non-free transfer of the axial flap fom the vastus lateralis muscle.

***Methods***. The prospective study included 24 patients. During the period 2011–2021, at the first stage of the treatment for chronic recurrent DTT PJI of the hip, resection arthroplasty was performed with a non-free transfer of an island flap from the vastus lateralis muscle. Subsequent reimplantation of the endoprosthesis was performed in at least 1 year after the infection remission. The functional outcomes, degree of the lower limb shortening immediately before and in two or more years after revision arthroplasty (rTHA), the results of the microbiological cultures at the first and second stages of PJI treatment, technical aspects of the surgery as well as the postoperative period and long-term PJI remission were studied.

***Results.*** Revision arthroplasty resulted in a statistically significant improvement of the postoperative functional outcome and quality of life in patients. The average Harris score agter rTHA increased from 53 to 83 points after surgery, EQ-5D degree of the quality of life increased from 50 points to 80, the overall score from 0.61 to 0.74 and average intensity of pain via VAS decreased from 3 points to 1 point in 3.1 years after rTHA ($p<0.05$). After reEP, complete restoration of the limb length was achieved in 29.1% of cases (n = 7) with an average compensation of the limb length for 4.5 cm. In 66.7% of patients (n = 16), the results of the intraoperative tissue biopsy microbiological analysis during reEP were culture negative. The recurrence rate of PJI was 12.5% (n = 3) up to 30 days after rTHA and 4.2% (n = 1) with a follow-up period of 3.1 years (IQR 2.1–4.1). With a single revision surgery performed without a delay, stable remission of DTT PJI was 95.8%.

***Conclusion.*** Complex two-stage surgical treatment using resection arthroplasty with a non-free muscle flap transfer at the stage of debridement and subsequent revision has demonstrated high efficiency in eliminating the infectious process as well as restoring weight-bearing capacity and extremity function. It could be recommended as a method of choice in the treatment of patients with DTT PJI of hip joint.

**Keywords:** difficult-to-treat periprosthetic infection, muscle flap, resection arthroplasty, persistent infection remission, revision arthroplasty, long-term functional outcomes.

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✉ *Vitaly N. Liventsov*; e-mail: vnliventsov@yandex.ru

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# Исходы ревизионного эндопротезирования тазобедренного сустава после резекционной артропластики с несвободной пересадкой мышечного лоскута у пациентов с трудноизлечимой перипротезной инфекцией

В.Н. Ливенцов, С.А. Божкова, Р.М. Тихилов, В.А. Артюх

*ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

***Актуальность.*** Операцией выбора в случае трудноизлечимой перипротезной инфекции (ТИ ППИ) тазобедренного сустава (ТБС) может быть резекционная артропластика с несвободной пересадкой мышечного лоскута, которая характеризуется высокой эффективностью купирования инфекции, но ведет к ухудшению функции оперированного сустава. На сегодняшний день представлены только единичные публикации с малым количеством наблюдений, в которых доля пациентов, которым был выполнен второй этап реэндопротезирования (реЭП), крайне невелика.

***Цель исследования*** — оценить влияние ревизионного эндопротезирования на функциональные результаты и частоту неблагоприятных исходов у пациентов, перенесших ранее резекционную артропластику с несвободной пересадкой осевого мышечного лоскута из латеральной широкой мышцы бедра по поводу трудноизлечимой перипротезной инфекции.

***Материал и методы.*** В проспективное исследование были включены 24 пациента, которым с 2011 по 2021 г. на первом этапе лечения хронической рецидивирующей ТИ ППИ области ТБС была выполнена резекционная артропластика с несвободной пересадкой островкового лоскута из *m. vastus lateralis*. По достижении длительной, не менее года, ремиссии инфекционного процесса вторым этапом было выполнено реЭП. Изучали функциональные результаты по шкале Харриса, степень укорочения нижней конечности до и не ранее двух лет после реЭП, результаты культурального исследования на первом и втором этапах лечения ППИ, а также технические особенности выполнения оперативного вмешательства, течение послеоперационного периода и наличие ремиссии ППИ в отдаленные сроки после реЭП.

***Результаты.*** РеЭП привело к статистически значимому улучшению функциональных результатов и качества жизни пациентов по сравнению с дооперационными показателями. Средний балл по шкале Харриса увеличился с 53 до операции до 83 после операции, согласно шкале EQ-5D удовлетворенность качеством жизни пациентами повысилась при индивидуальной оценке с 50 баллов до 80, по общему баллу-коэффициенту с 0,61 до 0,74, а средняя интенсивность болевого синдрома по ВАШ снизилась с 3 до 1 балла через 3,1 года после выполнения реЭП ($p$<0,05). Полное восстановление длины конечности было достигнуто в 29,1% случаев ($n$ = 7) при средней компенсации укорочения длины конечности 4,5 см. У 66,7% больных ($n$ = 16) результаты микробиологического исследования интраоперационных тканевых биоптатов при выполнении реЭП были культуронегативными. Частота рецидивов ППИ составила 12,5% ($n$ = 3) в сроки до 30 дней после реЭП и 4,2% ($n$ = 1) — при сроке наблюдения 3,1 года (МКИ 2,1–4,1). Проведение своевременных однократных ревизионных вмешательств позволило достичь стойкой ремиссии ТИ ППИ в 95,8% случаев.

***Заключение.*** Комплексное двухэтапное хирургическое лечение с применением на этапе санации резекционной артропластики с пересадкой осевого мышечного лоскута из латеральной широкой мышцы бедра и последующим реЭП продемонстрировало высокую эффективность в отношении купирования инфекционного процесса, а также восстановления опороспособности и функции конечности. Предложенная методика может быть рекомендована как метод выбора при лечении пациентов с ТИ ППИ в области ТБС.

**Ключевые слова:** ревизионное эндопротезирование тазобедренного сустава, трудноизлечимая перипротезная инфекция, мышечный лоскут, резекционная артропластика, этиология перипротезной инфекции.

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*Ливенцов Виталий Николаевич*; e-mail: vnliventsov@yandex.ru

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## BACKGROUND

Difficult-to-treat periprosthetic joint infection (DTT PJI) caused by difficultly-to-eradicate (DTE) pathogens is characterized by a chronic relapsing course [1, 2, 3, 4, 5]. The efficiency of the two-staged technique with an antimicrobial spacer installation in PJI caused by DTE pathogens is extremely low according to our data and publications by international authors, and excision arthroplasty with non-free muscle flap grafting may be the surgery of choice in such cases [6, 7, 8, 9, 10]. Radical surgical debridement with muscle flap transplantation, which is highly effective in stopping the infectious process, has been the gold standard for the treatment of chronic osteomyelitis of any localization, although for a long time, and this technique is used extremely rarely in the hip [11, 12]. This is due not only to the lack of technical skills and the ability to perform the plastic stage of the surgery in most orthopedists but also to the predictably low functional result of excision arthroplasty, according to a few publications [13, 14, 15]. Limb shortening, hip pain, lack of lower limb support ability, and the inevitable need for additional support and assistance when walking worsen not only the functional outcome but also the quality of life [16, 17, 18]. Therefore, some patients are not ready to accept excision arthroplasty as the outcome of the surgical treatment for infectious process and insist on a subsequent stage of revision total hip arthroplasty (rTHA) [19].

Moreover, extensive HJ bone defects, the risk of infection recurrence, and/or the poor general condition of patients are often objective reasons for refusing further endoprosthesis reimplantation [17, 20]. Hence, to date, only a few publications with a small number of cases were reported, with an extremely small proportion of patients who underwent stage 2 rTHA. The rTHA was performed only in 4 out of 18 (22%) patients according to Sharma et al. [16] and in 4 out of 26 (15.4%) patients according to Stoklas et al. [19]. Concurrently, the risk of infectious process resumption after endoprosthesis reimplantation in this category of patients is extremely high, and the recurrence rate of PJI can reach 43% [21, 22]. For example, Rittmeister et al. revealed prolonged healing of the postoperative wound in 17 out of 39 patients who underwent rTHA after excision arthroplasty, which required repeated surgical intervention [23].

Expectedly, the functional results of rTHA were predictably worse after multiple sanitizing surgeries than after primary arthroplasty. The difference in the length of the lower limbs cannot be immediately eliminated in all cases due to the pronounced cicatricial process, the presence of defects of hip bones, and the high risk of sciatic nerve neuropathy. Therefore, up to 39% of patients have persistent lameness [22]. Rittmeister et al. revealed that the mean Harris Hip Score (HHS) after rTHA was 62 (24–93), and only 11.5% of the results were rated as very good, while 88.5% were rated as poor. Concurrently, the causative agent of PJI, the age of the patient, the disease duration, and the number of previous surgical interventions did not correlate in any way with the functional outcome after rTHA [23].

The literature analysis did not reveal published studies on the changes over time in long-term and functional treatment results of patients with PJI after rTHA in the HJ by DTE agents using the hip excision arthroplasty in combination with non-free musculoplasty (NMP) in the history, which determined the aim of our study.

*The study aimed* to evaluate the impact of revision arthroplasty on functional outcomes and the incidence of adverse outcomes in patients who had previously undergone excision arthroplasty with non-free transplantation of an axial muscle flap from the *m. vastus lateralis* due to DTT PJI.

## METHODS

### Study design

The single-center prospective study was conducted from 2011 to 2021.

Inclusion criteria were the following:

– chronic DTT PJI caused by DTE pathogens, namely rifampicin-resistant staphylococci, ciprofloxacin-resistant gram-negative bacteria, and Candida genus fungi;

– performance of excision arthroplasty with non-free transplantation of an island flap from *m. vastus lateralis* at stage 1 of the two-staged treatment of PJI (RF patent for the invention 2299031);

– remission of the infectious process for >1 year;

– technical feasibility of performing rTHA (selection of revision systems depending on bone defects that form the hip);

– the absence of contraindications to rTHA following concomitant pathology.

Of the 57 patients who underwent excision arthroplasty with non-free transplantation of the island flap from *m. vastus lateralis* for recurrent chronic DTT PJI in the hip area, 24 (42%) met the inclusion criteria, including 75% males (n = 18) and 25% females (n = 6). The mean age of patients at the time of rTHA was 53 years (IQR [interquartile range]: 47–64). Lesions of the left and right hip were registered in 45.8% (n = 11) and 54.2% (n = 13) of cases.

## Evaluation of results

Functional results were immediately assessed before the excision arthroplasty and not earlier than 2 years postoperatively. The functional results were assessed using the Harris Hip score; the quality of life of patients was assessed using the EQ-5D scale developed by the EuroQol Group Association [24]; the degree of pain syndrome was assessed using the visual analog scale (VAS) [25]. Additionally, the subjective satisfaction of patients with the treatment result was assessed (answer "yes" or "no").

During the rTHA, at least five tissue biopsies were taken from different paraarticular tissue areas for a culture test and compared with the previous treatment stage.

Additionally, the proportion of patients with early and delayed adverse outcomes of rTHA was assessed. Early complications (30 days postoperatively) included cases that required repeated revision surgery due to a hematoma in the surgical site and/or in case of wound exudate for >7 days and other manifestations of PJI recurrence. Late complications included any signs of an infectious and inflammatory process in the operated joint area during the entire follow-up period, but not earlier than 1 month postoperatively.

## Statistical analysis

The obtained data were recorded in the form of spreadsheets; the data structure was visualized and analyzed using Microsoft Office Excel 2007 (Microsoft, USA) and Statistica for Windows (v. 10) software. The median (Me) was used as a measure of the central tendency for the studied attributes due to the small number of cases, and the lower (Q1) and upper (Q3) quartiles (IQR 25–75%) were used as dispersion measures. A comparison of quantitative characteristics between comparison groups was performed using the Mann-Whitney test. $\chi 2$ was used to analyze relative indicators. Differences in indicators between the groups were considered statistically significant at p-values of $<0.05$.

## RESULTS

The average interval between excision arthroplasty with NMP and rTHA in patients with DTT PJI was 18.6 months (IQR: 12.2–29.3).

All patients used additional support while walking upon admission for endoprosthesis reimplantation, and most of them (87.5%) used two crutches (n = 21). One (4.2%) patient used two canes while walking and two (8.3%) patients used one cane all the time.

All the included patients had a history of more than three surgeries (Me 6, IQR: 5–7), which induced the formation of significant bone defects in the acetabulum and proximal femur. In 29.2% of cases (n = 7), the identified defects of the acetabulum corresponded to type IIIA and types IIA-IIC in other cases; whereas, the defects of the femur corresponded to types III and IV in 66.7% (n = 16) of cases, according to the Paprosky classification and to types I and II in other cases.

The long duration of revision arthroplasty in the studied group of patients (Me 140 min, IQR: 100–160) was due to several technical difficulties associated with the altered joint anatomy. The array of dense cicatricial tissue formed from a long course of infectious processes and numerous surgical interventions, and the need to maintain a rotated muscle flap significantly hindered access to the acetabulum. Surgical access was made along the existing postoperative scar. Most often, the access was made between the anterior edge of the acetabulum and the muscle flap, which was pushed posteriorly with Hofmann retractors. After endoprosthesis implantation, the flap was returned to its place, wrapping it around the endoprosthesis neck, thereby reducing the hip cavity. In variant 2, the access was made between the flap and the posterior edge of the acetabulum and pushed anteriorly. Femoral components with a cemented type of fixation were used only in 3 out of 24 (12.5%) patients, while cementless femoral components, mostly conical with distal fixation, were installed in the remaining 87.5% of cases (n = 21). Therefore, trabecular metal components with a large number of holes were implanted into the acetabulum. Tantalum acetabular augments

or allogenic bone with an antibiotic were used to replace extensive acetabular defects. A cup-cage system was used with an antiprotrusion ring installation in three cases and an individual hemispherical acetabular component in one case. The supply of soft tissues between the fascia and the femur due to the muscle flap prevented the endoprosthesis dislocation, which enabled the use of the dual mobility system only in 6 (25%) cases, despite a significant number of patients with a type III-IV proximal femoral defect according to the Paprosky classification (n = 16).

Long-term functional treatment results after rTHA were assessed after an average of 3.1 years (IQR: 2.1–4.1). The weight-bearing function of the limb was restored in all patients. Concurrently, the proportion of patients who used two crutches decreased by >5 times compared to the preoperative period ($p < 0.05$), and 70.7% of patients used one cane or used no additional support while walking (Fig. 1).

A complete restoration of the limb length was achieved in 29.1% of cases after the endoprosthesis reimplantation (n = 7). On average, compensation for limb shortening was 4.5 cm, namely from 6.5 cm (IQR: 5.0–8.0) to 2.0 cm (IQR: 0–3.8) ($p < 0.05$). The main reasons for the impossibility of complete restoration of the operated limb length were the lower limb shortening by >6 cm, the pronounced cicatricial process of the paraarticular tissues, and the high risk of sciatic nerve neuropathy. Concurrently, gait disturbance of varying degrees was noted in all patients. Additionally, almost all patients compensated for the limb length with orthopedic shoes. Staged limb lengthening by 7 cm using the apparatus of external fixation was performed only in 1 (4.2%) case.

The study of long-term functional results after rTHA using the HHS, EQ-5D, and VAS questionnaires showed statistically significant improvement compared to the preoperative level ($p < 0.05$) (Table 1).

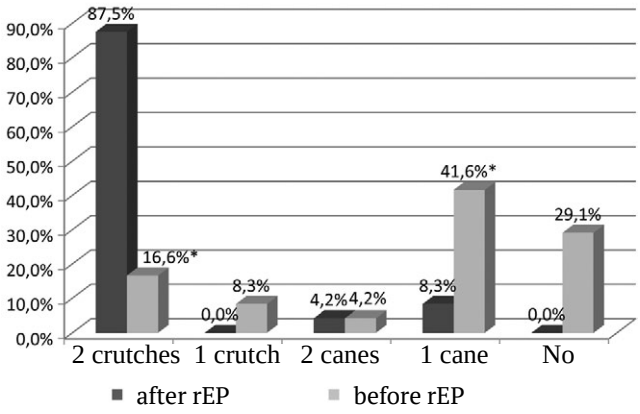



**Fig. 1.** Distirbution of patients depending on the used tools for additional support before and after rTHA
* *p*<0,05

*Table 1*

**Functional results before and after revision hip arthroplasty, Me (IQR)**

| Indicator | Before rTHA | After rTHA |
|---|---|---|
| EQ-5D (total score factor) | 0.61 (0.54–0.65) | 0.74 (0.65–0.85) |
| EQ-5D (individual), points | 50 (40–73) | 80 (79–85) |
| HHS, points | 53 (50–57) | 83 (78–85) |
| VAS, points | 3 (2–3) | 1 (1–2) |
| Shortening, cm | 6.5 (5.0–8.0) | 2 (0–3.5) |
| Satisfied, n (%) | 17 (70.8) | 23 (95.8) |

$p < 0.05$.

The Harris questionnaire in all patients admitted for rTHA after excision arthroplasty with NMP revealed poor functional results. Endoprosthesis reimplantation provided a statistically significant ($p < 0.05$) improvement in the functional state of the operated joints in the vast majority of patients 2 years postoperatively (Fig. 2).

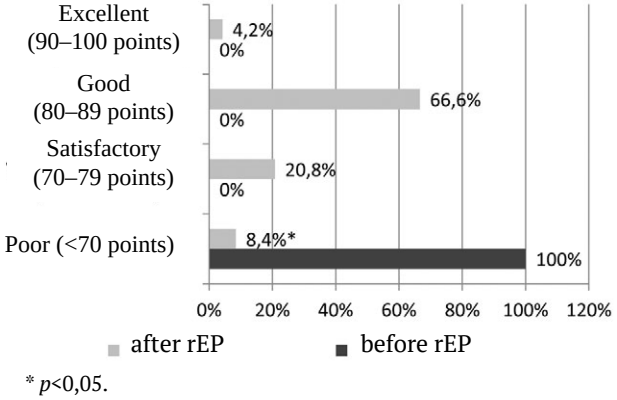
On average, the degree of satisfaction with the quality of life of patients after rTHA increased statistically significantly according to individual assessment and overall score-coefficient based on the EQ-5D questionnaire responses. A significant proportion of patients noted an increased satisfaction for most of the analyzed indicators. Preoperatively, 8.3% (n = 2) of patients had no difficulty in mobility, and 41.7% of patients had no difficulty postoperatively ($p < 0.05$). The proportion of patients who noted positive dynamics concerning pain, anxiety, and depression also increased (Table 2).

Similar results were obtained during the pain syndrome assessment according to VAS. The average intensity of the pain syndrome decreased from 3 points (IQR: 2–3) upon admission to stage 2 of treatment to 1 point (IQR: 1–2) 3.1 years after rTHA ($p < 0.05$). Concurrently, the majority of patients (79.2%) noted a complete absence of pain or minimal pain postoperatively (1–2 points) (Table 1). The pain syndrome was regarded as moderate by 5 (20.8%) patients postoperatively and 12 (50%) preoperatively ($p < 0.05$).

All patients restored the ability to self-service, performed independently light housekeeping, and did not need assistance from others after rTHA.

Of the 24 patients surveyed after rTHA, 23 (95.8%) were satisfied with the treatment results (answer "yes" or "no"). Only one patient has a better condition after excision arthroplasty with NMP. A detailed examination revealed that the pain syndrome was not arrested in the operated joint area, which caused the forced use of two crutches as additional support, thereby indirectly indicating the possible vertebrogenic genesis of the latter, although the patient noted a moderate level of pain syndrome according to VAS.

Notably, patient satisfaction was determined by the relief of the infectious process after long-term treatment of repeatedly recurrent PJI, namely the absence of a fistulous tract with purulent discharge and the need for further staged sanitizing manipulations, while dissatisfaction was associated with impaired limb function due to the lack of support ability.




* $p<0,05$.

**Fig. 2.** Distribution of patients depending on the functional outcomes from the modified Harris hip score before and after rTHA

*Table 2*

**Functional results according to the EQ-5D before and after revision hip arthroplasty, n (%)**

| Category EQ-5D | Answer option | Before rTHA (n = 24) | After rTHA (n = 24) | p |
|---|---|---|---|---|
| Mobility | No difficulties | 2 (8.3) | 10 (41.7) | <0.05 |
| | Minor difficulty | 6 (25) | 12 (50) | >0.05 |
| | Moderately difficult | 10 (41.7) | 2 (8.3) | <0.05 |
| | Great difficulty | 6 (25) | – | >0.05 |
| | Inability to walk | – | – | – |

*End of Table 2*

| Category EQ-5D | Answer option | Before rTHA (n = 24) | After rTHA (n = 24) | p |
|---|---|---|---|---|
| Self-care | No difficulties | 3 (12.5) | 6 (25) | >0.05 |
| | Minor difficulty | 5 (20.8) | 14 (58.3) | <0.05 |
| | Moderately difficult | 11 (45.8) | 4 (16.7) | >0.05 |
| | Great difficulty | 5 (20.8) | – | >0.05 |
| | Unable to wash/dress | – | – | – |
| Habitual daily activities | No difficulties | 1 (4.2) | 4 (16.7) | >0.05 |
| | Minor difficulty | 8 (33.3) | 18 (75) | >0.05 |
| | Moderately difficult | 13 (54.1) | 2 (8.3) | <0.05 |
| | Very difficult | 2 (8.3) | – | >0.05 |
| | Unable to be engaged in usual activities | – | – | – |
| Pain, discomfort | No pain | 3 (12.5) | 13 (54.1) | <0.05 |
| | Minor pain | 14 (58.3) | 10 (41.7) | >0.05 |
| | Moderate pain | 7 (29.2) | 1 (4.2) | <0.05 |
| | Strong pain | – | – | – |
| | Extreme pain | – | – | – |
| Anxiety, depression | No anxiety | 16 (66.7) | 22 (91.7) | <0.05 |
| | Minor anxiety | 5 (20.8) | 2 (8.3) | >0.05 |
| | Moderate anxiety | 3 (12.5) | – | >0.05 |
| | Severe anxiety | – | – | – |
| | Extreme anxiety | – | – | – |

Statistically significant results are highlighted in bold.

*Table 3*

**Results of bacteriological examination of intraoperative materials at stages 1 and 2 of surgical treatment of patients**

| Coincidence rate of bacteriological examination | Pathogen | |
|---|---|---|
| | Stage 1 (excision arthroplasty with NMP) | Stage 2 (rTHA) |
| Complete coincidence | Mycobacterium abscessus | MSSA |
| | Candida parapsilosis + MRSA + Klebsiella pneumoniae | MRSE |
| | MRSE | MSSE |
| Partial coincidence | Pseudomonas aeruginosa | Pseudomonas aeruginosa + MRSE |
| | Klebsiella pneumoniae + MRSA | Klebsiella pneumoniae |
| | MRSE + Pseudomonas aeruginosa | MRSE |

Microbiological examination of intraoperative tissue biopsies after rTHA in 16 out of 24 (66.7%) patients showed negative results. The causative agent of PJI isolated earlier at the stage of NMP was confirmed in 2 (8.3%) patients. The bacteriological examination results did not coincide completely in 3 (12.5%) patients, while they partially coincide in 3 (12.5%) patients (Table 3).

Postoperatively (11 and 21 days), an early revision with endoprosthesis preservation and the mobile component replacement was performed due to PJI recurrence in 2 (8.3%) patients after rTHA. Concurrently, MSSE strain was isolated from tissue biopsy specimens taken during the revision with the endoprosthesis preservation, while initial DTT PJI was caused by MRSA, and the bacteriological examination results of tissues were negative during rTHA in one case. The causative agent of PJI was MRSA in another patient, which was also confirmed during rTHA and revision with preservation. No signs of infectious process recurrence were detected in these patients at the control examination from 3.0 to 3.6 years.

A fistulous tract occurred in another patient (4.2%) with negative tissue biopsy sample culture test results at the stage of rTHA within 30 days. He underwent a one-stage replacement of endoprosthesis 44 days after rTHA. Concurrently, tissue biopsy specimens were culture-negative.

In the long-term (1.5 years after rTHA), a permanent fistulous tract developed in one case (4.2%); however, the patient refused surgery. A revision intervention was performed and a dual mobility system was installed in 2 (8.4%) more cases, due to repeated endoprosthesis dislocations.

## DISCUSSION

Until the present, chronic PJI cannot be considered cured because bacteria can remain latent for many years [26]. In our study, at least five tissue biopsy specimens were taken from all patients for bacteriological examination during rTHA. The results were negative only in 66.7% of cases, which coincides with the findings of Engelbrecht et al., who detected a positive growth of microorganisms in 31.5% of cases, when performing rTHA in a similar cohort of patients [27].

The incidence of early relapses of PJI up to 30 days after rTHA that was performed after excision arthroplasty with NMP for DTT PJI was 12.5% in our study (n = 3). Concurrently, timely single revision interventions enabled the achievement of a stable arrest of the infectious process in all cases. Only one case (4.2%) of PJI recurrence was identified with a median follow-up period of 3.1 years (IQR: 2.1–4.1), which is comparable to the frequency of infectious complications after "clean" revision interventions for HJ, which is 4.5%–7.0%, according to several authors [28, 29, 30, 31]. According to the literature, the recurrence rate of infection during rTHA after excision arthroplasty ranges from 2.3% to 43.0% [22, 23]. Notably, these studies did not consider the nature of the pathogen when forming the study groups. In our study, persistent remission of PJI caused by DE agents remained after repeated endoprosthesis implantation in 95.8% patients with previous excision arthroplasty with NMP.

The rTHA that we performed had statistically significantly improved the long-term functional results and quality of life of patients compared with preoperative indicators. According to the survey results, 95.8% of the respondents were satisfied with the treatment results. The medium-term functional results after repeated endoprosthesis implantation, obtained according to the HHS, were unsatisfactory only in 8.4% of cases despite the initial extremely low level of functionality after excision arthroplasty with NMP. Similar treatment results are demonstrated by Engelbrecht et al., who received 9% of unsatisfactory results on the HHS in their work [27]. According to Charlton et al., the average HHS after rTHA in a similar category of patients increased from 40 points preoperatively to 78 points postoperatively [22], and from 53 to 83 points in our study, respectively. Notably, the functional results that we obtained are comparable with the results of rTHA for non-infectious reasons, which vary from 80 to 91 points on the HHS according to the literature [32, 33, 34].

Klima et al. revealed that the difference in the length of the lower extremities as a result of rTHA decreased on average from 6.8 cm to 1.0 cm [35]. Our study revealed the possibility to restore the length of the operated limb by an average of 4.5 cm. The average intensity of pain syndrome according to VAS decreased from 3 (IQR: 2–3)

points upon admission to stage 2 of treatment to 1 (IQR: 1–2) point 2 years after the rTHA completion. The supporting function of the limb was restored in all patients. Preoperatively, 85% of patients used two crutches, then postoperatively, only 25% ($p < 0.05$) used one or two crutches as additional support, 29.1% of patients walked independently without means of additional support, and 45.8% of patients used a cane constantly or when walking for a long time.

## CONCLUSION

Complex two-staged surgical treatment with excision arthroplasty with NMP at the stage of sanitation and subsequent revision arthroplasty demonstrated high efficiency in terms of arresting the infectious process, as well as restoring weight-bearing capacity and limb function. The obtained results enable us to recommend this technique as a method of choice in the treatment of patients with DTT PJI in the hip area, despite certain technical difficulties in performing surgical interventions.

## DISCLAIMERS

### *Author contribution*

*Liventsov V.N.* — data collection and analysis, data statistical processing, manuscript writing.

*Bozhkova S.A.* — research concept and design, manuscript writing and editing.

*Tikhilov R.M.* — research concept.

*Artyukh V.A.* — treatment the patients, manuscript editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Competing interests.*** The authors declare that they have no competing interests.

***Ethics approval.*** Not applicable.

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## Authors' information

✉ *Vitaly N. Liventsov* — Cand. Sci. (Med.)
Address: 8, Akademika Baykova str., St. Petersburg, 195427, Russia
https://orcid.org/0000-0001-8748-2134
e-mail: vnliventsov@yandex.ru

*Svetlana A. Bozhkova* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-2083-2424
e-mail: clinpharm-rniito@yandex.ru

*Rashid M. Tikhilov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0003-0733-2414
e-mail: rtikhilov@gmail.com

*Vasily A. Artyukh* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-5087-6081
e-mail: artyukhva@mail.ru

Original Article
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# Posteromedial Approach in Fracture Fixation of Malleoli and Posterior Edge of Tibia

Igor' G. Belen'kii [1,2], Boris A. Maiorov [1,3], Aleksandr Yu. Kochish [4,5], Gennadii D. Sergeev [1,2], Yurii V. Refitskii [1], Viktor E. Savello [1,3], Sergei S. Smirnov [3]

[1] *St. Petersburg I.I. Dzhanelidze Research Institute of Emergency Medicine, St. Petersburg, Russia*

[2] *St. Petersburg State University, St. Petersburg, Russia*

[3] *Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia*

[4] *Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation*

[5] *Kirov Military Medical Academy, St. Petersburg, Russia*

***Background.*** Surgical treatment of malleoli injuries is performed according to the principles of articular fractures management. It is particularly true for ankle injuries involving fractures of posterior edge of the tibia. The posteromedial approach enables to improve the results of surgical treatment of patients due to the direct reduction of tibia fragments.
***Aim of the study*** — to evaluate the efficacy and advisability of the modified posteromedial approach in patients with unstable fractures of malleoli and posterior edge of the tibia.
***Methods.*** Twenty two patients with unstable fractures of malleoli and posterior edge of the tibia underwent surgical treatment via the posteromedial approach. The X-ray control was performed the next day after the surgery as well as 6, 12, 24 and 48 weeks from the osteosynthesis. The functional results were evaluated in 12, 24 and 48 weeks after the surgery with the use of AOFAS and Neer scales.
***Results.*** The average duration of postoperative period (9.3±3.8 days) was mainly determined by the state of the soft tissues. 91% of patients had anatomical reduction of posterior edge fragment of the tibia, 17 (77%) from 22 patients demonstrated fracture consolidation in X-rays 12 weeks after the surgery and all 22 patients (100%) 24 weeks after surgery. There were no cases of postoperative complications in patients 24 weeks after the surgery. While managing patients the range of motion in the ankle joint increased from 41.1±6.9° 12 weeks after the surgery to 57.3±4.6° 48 weeks after the surgery, that was statistically significant ($p<0.01$). The functional results improved as well according to both AOFAS and Neer scales and this improvement was also statistically significant ($p<0.01$).
***Conclusion.*** The is rather effective in Patients with unstable fractures of malleoli and posterior edge of the tibia had a statistically significant improvement in function after posteromedial approach.

**Keywords:** fracture fixation, articular fracture, malleoli fracture, posteromedial approach.

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✉ *Igor' G. Belenkiy*; e-mail: belenkiy.trauma@mail.ru

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# Использование заднемедиального хирургического доступа для остеосинтеза при переломах лодыжек и заднего края большеберцовой кости

И.Г. Беленький [1,2], Б.А. Майоров [1,3], А.Ю. Кочиш [4,5], Г.Д. Сергеев [1,2], Ю.В. Рефицкий [1], В.Е. Савелло [1,3], С.С. Смирнов [3]

[1] *ГБУ «Санкт-Петербургский научно-исследовательский институт скорой помощи им. И.И. Джанелидзе», г. Санкт-Петербург, Россия*

[2] *ФБГОУ ВО «Санкт-Петербургский Государственный университет», г. Санкт-Петербург, Россия*

[3] *ФГБОУ ВО «Первый Санкт-Петербургский государственный медицинский университет м. акад. И.П. Павлова» Минздрава России, г. Санкт-Петербург, Россия*

[4] *ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

[5] *ФГБВОУ ВО «Военно-медицинская академия им. С.М. Кирова» Минобороны России, г. Санкт-Петербург, Россия*

***Актуальность.*** Хирургическое лечение повреждений лодыжечного сегмента осуществляется в соответствии с принципами лечения внутрисуставных переломов. Применение заднемедиального доступа за счет прямой репозиции фрагментов большеберцовой кости позволяет улучшить результаты хирургического лечения пострадавших.

***Цель исследования*** — оценить эффективность и целесообразность применения модифицированного заднемедиального доступа у пациентов с нестабильными переломами лодыжек и заднего края большеберцовой кости.

***Материал и методы.*** Двадцать два пациента с нестабильными переломами лодыжек и заднего края большеберцовой кости прооперированы с применением заднемедиального хирургического доступа. Рентгенологический контроль осуществляли на следующий день после операции и через 6, 12, 24 и 48 нед. после остеосинтеза. Функциональные результаты лечения оценивали через 12, 24 и 48 нед. после операции по шкалам AOFAS и Neer.

***Результаты.*** Медиана (Me) длительности предоперационного периода составила 9 дней (min = 6, max = 24 дней, Q1-Q3 = 7–10 дней) и во многом определялась состоянием мягких тканей. У 91% пациентов была достигнута анатомичная репозиция фрагмента заднего края большеберцовой кости. Рентгенологические признаки сращения отмечены у 17 (77%) пациентов через 12 нед. после операции и у 22 (100%) пациентов через 24 нед. Случаев развития осложнений не выявлено. За время наблюдения объем движений в голеностопном суставе статистически значимо ($p$<0,01) увеличивался: Me через 12 нед. после операции составила 40° (min = 30°, max = 55°, Q1–Q3 = 35–45°), через 48 нед. — 55° (min = 50°, max = 65°, Q1–Q3 = 55–60°). Отмечалось статистически значимое ($p$<0,01) улучшение показателей с течением времени при оценке функциональных исходов по шкалам AOFAS и Neer.

***Заключение.*** Заднемедиальный доступ эффективен при нестабильных переломах лодыжек и заднего края большеберцовой кости и позволяет добиться высоких функциональных результатов лечения.

**Ключевые слова:** остеосинтез, внутрисуставной перелом, перелом лодыжек, заднемедиальный доступ.

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*Беленький Игорь Григорьевич*; e-mail: belenkiy.trauma@mail.ru

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## BACKGROUND

Malleolar fractures are rather severe injuries with high complication rate [1]. Failure in achieving good fracture fragments reduction leads to pronounced functional impairment of the ankle joint [2]. This is more typical for unstable fractures of the ankle joint, associated with the fracture of the posterior edge of tibia. That is why modern trauma surgery pays great attention to such type of injuries. The paradigm of treatment of patients with these complex injuries have changed significantly over the recent years. Earlier on these fractures supposed close reduction of the posterior edge of tibia fragment and its fixation with front to back screws was preferable. Nowadays more and more specialists emphasize that only precise restoration of the anatomy of all injured bone structures can ensure optimal functional recovery of the ankle joint and reduce the risk of clinically significant posttraumatic arthritis [3, 4]. In accordance with this concept, an open and precise reduction of the posterior edge of tibia and its back to front fixation are required, that can be performed via posterior surgical approaches only [5].

Posterolateral approach is widely applied in the surgical treatment of patients with unstable malleolar fractures associated with posterior tibia edge fracture [6, 7]. Despite the fact that this approach allows open and precise (anatomical) reduction of the posterior edge of tibia with simultaneous osteosynthesis of the lateral malleolus and fixation of distal tibiofibular syndesmosis, it may have disadvantages and cannot be used in all clinical situations. In addition, most surgeons perform it in prone position of patient, which complicates the reduction and fixation of the medial malleolus fragment significantly, as well as the reduction of the anterior part of the distal tibiofibular syndesmosis and fixation of the tibia anterolateral fragment (Tillaux-Chaput fragment) and the fibula anterolateral fragment (LeFort fragment) [6]. Therefore, the injuries discussed suppose intraoperative rotation of the patient in case of performing posterolateral approach, which increases the surgery time and the risk of infectious complications.

In addition, the use of posterolateral approach is also inconvenient with type 3 fracture of the posterior edge of tibia according to J. Bartoníček et al. [8], which suggests the presence of posterior fragment of the medial malleolus. The reason is that a direct access to the specified bone fragment via this approach is impossible. In such cases, a number of authors recommend to use alternative posteromedial approach justified in many clinical situations, since it allows to restore the anatomy of the injured ankle and achieve stable fixation of the posterior edge of tibia and medial malleolus fractures [9, 10].

At the same time, the surgical technique of posteromedial approach, its advantages, disadvantages and indications for clinical use for osteosynthesis in unstable malleolar fractures and posterior edge of tibia have not been definitively determined, and we have not discovered scientific publications in Russian on this relevant problem of modern traumatology. These reasons laid significant groundwork for the preliminary clinical trial, and its results are presented and discussed in this article.

The *aim of the study was* to evaluate the features of the modified posteromedial surgical approach technique and its effectiveness for osteosynthesis in patients with unstable malleolar fractures and the posterior edge of tibia, as well as to clarify the indications for its clinical use.

## METHODS

### Research design

A prospective multicenter cohort study was conducted on the basis of the traumatology departments of two hospitals in the Leningrad region: Vsevolozhsk Region Hospital and Tosnenskaya Region Hospital, as well as the I.I. Dzhanelidze St. Petersburg Institute of Emergency Medicine in the period from 2020 to 2021.

### Patients

The study group included 22 patients (5 men and 17 women) with unstable malleolar fractures associated with posterior edge of tibia fracture, who underwent surgery performed via posteromedial surgical approach. An important inclusion criterion was the ability to evaluate the dynamics of the functional results of treatment 12, 24 and 48 weeks after surgery. The age of patients ranged from 31 to 80 years: median (Me) — 50.5 years, interquartile range (IQR) — from 44 to 61 years.

As for the mechanism, most patients got injured by twisting the ankle when falling from their own height, i.e., the injury had an indirect low-energy character. High-energy injury was di-

agnosed in two patients who fell from a bicycle, and two – from small height.

## Preoperative examination

The type of fracture and injury of the ankle joint structures was assessed based on the analysis of two views of X-rays with using the classification of the Association of Osteosynthesis (AO) [11]. 12 (55%) patients had the comminuted trans-syndesmotic fracture with involvement of the posterior edge of tibia type 44B3, 3 (14%) patients had simple supra-syndesmotic fracture type 44C1.3, 5 (23%) patients - comminuted fracture type 44C2.3. 2 more patients (9%) had fibula fracture localized in its upper third type 44C3.3. The majority of patients (64%) suffered pronounced ankle valgus deformation, lateral and posterior subluxation of the foot.

During the treatment 19 (86%) patients got primary reduction of fragments and cast immobilization upon admission under local anesthesia. However, three patients (14%) were put on skeletal traction through the calcaneal bone due to significant soft tissue edema and irreducible foot subluxation. For high-quality preoperative planning and determination of surgical tactics (selection of approaches), all patients underwent preoperative CT scanning of the ankle joint area with an assessment of the fracture pattern and the existing injury components based on 3D reconstruction, analysis of sagittal, frontal and axial scans.

The degree of distal tibial syndesmosis disruption was determined by assessing the contours of fibula and tibia in the distal fibular notch area by axial CT scans. Separately the size of the fragment of the posterior edge of tibia was estimated using common method involving measuring the proportion of the articular surface of fragment from the entire tibial articular surface on a lateral X-ray [7]. The configuration of the posterior edge of tibia was determined from CT data, mainly axial sections, using the methodology and classification of J. Bartoniček et al. [8]. Analyzing axial CT scans, it was possible to determine the localization and dimensions of the identified fragments of the tibial articular surface interposing the fracture line (Fig. 1).

Bone fragments were measured on lateral radiographs of the ankle joint in Radiant Dicom Viewer X-ray image viewer. In particular, the proportion of the articular surface of the posterior edge of tibia fragment was determined, and the results were presented in the form of decimal fractions, where the entire articular surface of the distal tibia was taken as 1.

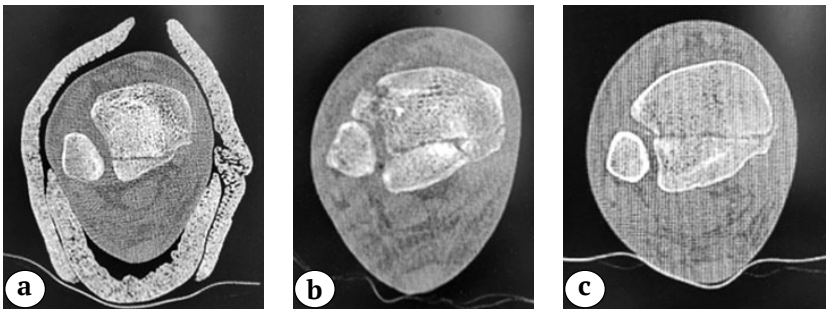


**Fig. 1.** Differences in the size of the tibia posterior edge fragment on axial CT sections of different patients: a — intra-incisural posterolateral fragment involving 1/3–1/4 fibular incisura (type 2 according to J. Bartoniček et al.);
b — intra-incisural posteromedial two-fragmental fracture, including the posterior part of the fibular incisura laterally and the posterior part of the medial ankle medially (type 3 according to J. Bartoniček et al.);
c — large posterolateral fragment of triangular shape, including the posterior half of the fibular incisura (type 4 according to J. Bartoniček et al.)

## Surgical technique

The surgical technique generally corresponded to the method of extended posteromedial approach described by Y. Wang et al. [12]. The surgery was performed in supine position of the patient with the lower limb bent at the knee joint and rotated laterally. The skin incision started 10 cm from the level of the apex of the medial malleolus and was extended longitudinally in the middle of the distance between the medial edge of the Achilles tendon and the malleolus, starting vertically at the level of the proximal and middle thirds of the incision, followed by anterior bend in its lower third and extension just below apex of medial malleolus. The fascia propria of the lower third of the leg and the flexor tendon retinaculum were dissected longitudinally, obtaining two possible "surgical windows": between the tendons of the posterior tibial muscle and the flexor digitorum longus, as well as between the tendons of the latter and the flexor hallucis longus. Dissection of tissues was performed carefully due to the risk of injury to the posterior tibial vessels and the tibial nerve. At the same time, the indicated neurovascular bundle was diverted posteriorly without its mobilization in contrast to the generally accepted technique described in the literature [4].

Bone fragments were reduced by manipulating the fragment of the tibia posterior edge, focusing on the upper fracture line — directly in the wound — and the tibia articular surface, visualized using C-arm in lateral and AP views. K-wires were used to temporarily fix the fragment of the posterior edge of tibia. In 3 cases (14%) it was necessary to remove a small fragment of the articular surface interposing between the main fragment of the posterior edge and its bed to achieve anatomical reduction of the posterior edge of tibia fragment. In 1 case (4%) it was possible to perform reimpaction of the fragment of articular surface of the tibia posterior edge, since the impact zone was localized on the posteromedial side of the latter, which was the reason for choosing posteromedial approach in this patient.

In number of cases a "pointed" bone clamp was used for the reduction of posterior edge of tibia fragment, placing it under visual control. If there was a tendency to vertical displacement the method of sequential compression on an anti-glide plate under C-arm control was applied, i.e., due to the pressing of the plate to the tibia diaphyseal part above the fracture of the posterior edge, its correct positioning occurs (pressing to the bed) followed by interfragmentary compression [7, 13].

Fixation of the fragment of the posterior edge of tibia was performed using cancellous screws 4.0 mm with partial thread in 6 cases and plates in 16 cases. Short 1/3-tubular plates with 3-5 holes, T-shaped plates from a set for fixing small bone fragments were used, introducing 3.5 mm cortical screws and 4.0 mm cancellous screws with partial thread (Fig. 2). The reduction of the medial malleolus was performed via the anterior window of the posteromedial surgical approach with its fixation with two cancellous screws 4.0 mm with partial thread in 15 cases, one screw and a K-wire — in 3 cases of comminuted fractures, and 1/3-tubular plate with 3.5 mm screws — in 1 case with a vertical fracture line. In 2 patients without bone injury to the medial structures of the ankle joint, the suture of the deltoid ligament was not performed, since foot subluxation could

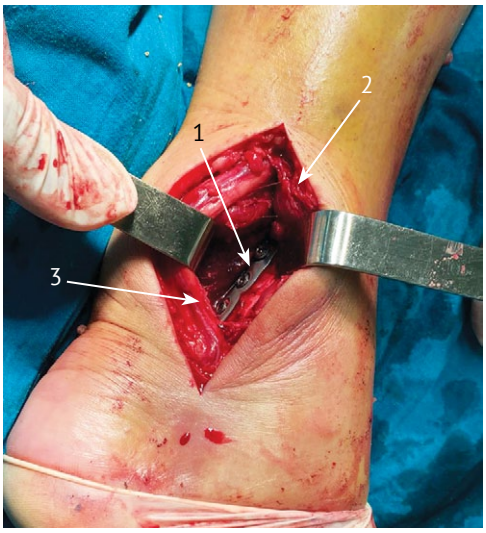


**Fig. 2.** Intraoperative image of the posteromedial approach at the stage of fixation of the posterior edge of the tibia with a 1/3-tubular plate:
1 — 1/3-tubular plate fixation the posterior fragment of the tibia;
2 — posterior tibial muscle, flexor digitorum longus, retracted by the Farabeuf hook;
3 — the flexor hallucis longus and the posterior neurovascular bundle, retracted by the Farabeuf hook

be reduced after osteosynthesis of the tibia posterior edge, lateral malleolus and splinting of distal tibiofibular syndesmosis.

Reduction and fixation of lateral malleolus were performed via standard lateral approach in supine position of the patient. In most cases, fibula osteosynthesis was performed using 1/3-tubular plates, 3.5 mm cortical screws and 4.0 mm cancellous screws with partial thread. In 2 cases of type 44 C3.3 fractures osteosynthesis of fibula was not performed, since the fracture zone was in its upper third. However, in both cases fixation of the distal tibiofibular syndesmosis was performed with a positional screw. The reconstruction of the ankle joint was concluded by examining the stability of distal tibiofibular syndesmosis by lateral stability stress tests [14]. In 10 cases (46%) of the revealed lateral instability, one 3.5 mm cortical positional screw was used to fix distal tibiofibular syndesmosis.

All stages of osteosynthesis were accompanied by intraoperative fluoroscopy in standard AP, AP with internal rotation at 15° and lateral views. The time of each surgery was recorded and their average duration in minutes was calculated. The surgery ended with active drainage and wound suturing. Only skin sutures were applied using the Allgower or Donati suture in case of excessive tension of the wound edges.

Active movements in the ankle joint were permitted the day after the surgery. The axial load was restricted until the appearance of radiological signs of bone union. As a rule, this period ranged between 10 and 12 weeks after the surgery.

## Results assessment

The quality of the reduction of posterior edge of tibia fragments was determined by the presence or absence of residual displacement along the line of articular cartilage and/or diastasis in the fracture zone on the lateral radiograph. The result of the reduction with a complete restoration of the anatomy of the articular surface, the absence of diastasis between fragments and subluxation in the ankle joint was considered excellent. A satisfactory result suggested the presence of a step of the articular surface and/or diastasis in the fracture zone up to 2 mm; the displacement of bone fragments along the line of the articular surface and/or diastasis in the fracture zone of more than 2 mm and/or subluxation in the ankle joint was considered unsatisfactory.

X-ray was performed the day after the surgery and within 6, 12, 24 and 48 weeks after osteosynthesis. All radiographs were evaluated in order to identify possible signs of osteosynthesis failure, implant migration, loss of reduction and increase in deformation, as well as the appearance of radiological signs of bone union of the tibia posterior edge, fibula and medial malleolus. These signs included a distinct “darkening” or disappearance of the fracture line in the case of simple fractures, as well as the appearance of a visible callus in the area of a comminuted fracture. In addition, standard X-rays were evaluated 24 and 48 weeks after the injury to identify the signs of post-traumatic arthritis, especially if its symptoms (persistent pain syndrome, edema and pronounced restriction of movements in ankle joint) were present.

During the patients’ follow-up, attention was paid to the maintenance of the correct relationship of articular surfaces of the ankle joint, the increase of deformation, secondary displacement and migration of implants. The functional results of treatment were evaluated 12, 24 and 48 weeks after surgery according to the AOFAS and Neer scales. The ankle joint range of motions was measured within the time specified according to standard technology using an orthopedic goniometer. The ankle joint range of motions was determined as the sum of deviations from the zero position of the foot (90° relative to the axis of the lower leg) with its plantar and dorsal flexion. The data obtained were used to evaluate the functional results of treatment according to the AOFAS and Neer scales.

Cases of deep and superficial infection in the area of surgical intervention, failure of osteosynthesis manifested by migration of implants, delayed union of fractures, secondary displacement of fragments, post-traumatic arthritis were taken into account analyzing early and delayed complications of surgical treatment. At the same time, the relative values characterizing the frequency of occurrence or proportion were expressed as a percentage.

## Statistical analysis

Statistical analysis of the obtained quantitative data was performed using Excel, as well as Statistica 8 for Windows (StatSoft) program. The median (Me) and interquartile range (IQR) were calculated using the programs mentioned above (the values of the first and third quartiles are presented). The type of distribution of the obtained digital values was evaluated using the Shapiro–Wilk test. Non-parametric Friedman test was used to determine the statistical significance of the differences between the analyzed samples due to non-normal type of data distribution. The statistical significance of changes during the observation period in the parameters of the ankle joint range of motion and scores reflecting the functional results of treatment according to the AOFAS and Neer scales was determined.

## RESULTS

CT scan of all patients before surgery allowed us to analyze the structure of the ankle joint injury, identify all its components and evaluate the individual architectonics of fractures, which facilitated preoperative planning greatly, allowing us to determine the sequence of fixation of all injury components via rational surgical approaches.

After analysis the CT scans fractures of 3 classical components were detected in 14 patients: fractures of the lower third of fibula above syndesmosis, medial malleolus with a fragment of its anterior tubercle or both tubercles, as well as the posterior edge of tibia. Four patients had only a fracture of the posterior tubercle of the medial malleolus adjacent to the fragment of the posterior edge of tibia. In these 4 patients and in 3 more with a medial malleolus fracture, the presence and fracture pattern of its posterior tubercle were revealed only by analyzing CT scans. Three patients had no bone injury to the ankle joint medial complex, but deltoid ligament injuries were present. Two of our patients did not have fibula fractures in the ankle joint area or in the lower third of the lower leg. Two patients suffered a fracture with the presence of tibia anterolateral fragment (Tillaux-Chaput fragment), and 2 more patients had a displacement of a similar fibula anterolateral fragment (LeFort fragment). In 3 patients, according to preoperative CT scans, impacted fractures of the articular surface of the posterior edge of tibia were found.

Division of patients depending on the type of fracture of the posterior edge of tibia according to the classification of J. Bartoniček et al. was performed only after evaluation of CT data. In 13 (59%) patients the 3rd type of fracture of the posterior edge of tibia was identified, in 3 (14%) patients — the 2nd type, in 6 (27%) patients — the 4th type. The Me of the fragment size of the posterior edge of tibia was 0.28 (from 0.1 to 0.5 of the tibia articular surface), the interquartile range was from 0.2 to 0.4.

Thus, the use of spiral CT at the stage of preoperative planning revealed a wide variety of injuries that occurred in patients with unstable malleolar fractures and the posterior edge of tibia, and also made it possible to make a reasoned choice of tactic for fixing bone fragments.

Normalization of the soft tissues condition was a crucial moment determining the timing of surgery. The optimal time for the surgery was determined by the appearance of clinical signs of normalization of microcirculation in the injury area, manifested by regression of soft tissue edema and epithelization of skin blisters, if they were present. The Me duration of the preoperative period was 9 days (from 6 to 24 days), IQR — from 7 to 10 days.

Open osteosynthesis of the posterior edge of tibia via posteromedial surgical approach allowed to achieve its anatomical reduction in the absolute majority (20 out of 22 or 91%) of patients.

An example of using the technique is shown in Figure 3.

Results of reduction of only 2 (9%) patients were recognized as satisfactory due to the presence of intraarticular step with a size of up to 2 mm between the posterior tibial fragment and the rest part of articular surface, which was revealed on the lateral view x-rays of ankle joint. At the same time, no residual subluxation in the injured joints was detected in any of the patients.

There were no local complications in the early postoperative period. All wounds healed by primary tension without inflammation and infectious complications. There was no migration of implants and secondary displacement of fragments in the early postoperative period.

The studied stage radiographs during the follow-up did not reveal the failure of fixation, secondary displacement of fragments, migration of implants in any patient. Bone union of the posterior edge of tibia, lateral and medial malleolus

was noted on X-rays in 17 (77%) of 22 patients examined 12 weeks after surgery, and in all patients after 24 weeks.

The increase over time in ankle joint range of motions in patients was statistically significant ($p<0.01$) (Table 1).

The increment of scores over time according to both evaluation scales was statistically significant ($p<0.01$). Only 3 (14%) patients examined 48 weeks after osteosynthesis had complaints of moderate pain and swelling in the ankle joint area after physical activity.

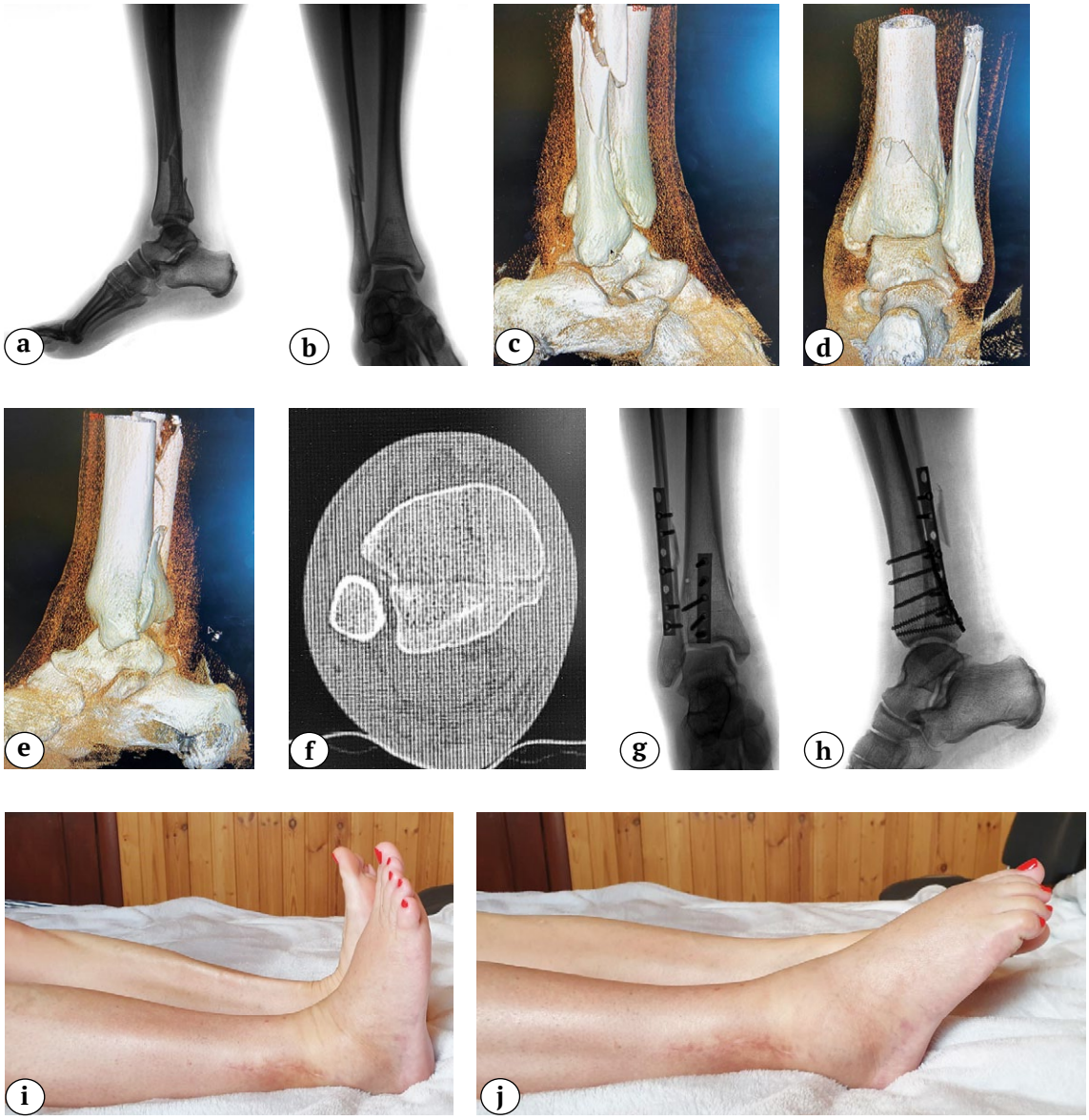


**Fig. 3.** Surgical treatment of a patient with a fracture 44C2.3:
a, b — primary X-rays in AP and lateral projections;
c, d, e, f — CT data showing the size of the posterior edge of the tibia;
g, h — postoperative X-rays in AP and lateral projections — anatomical reposition of bone fragments in the ankle joint;
i, j — functional result of treatment 48 weeks after injury

*Table 1*

**Parameters of the range of motions in the ankle in dynamics**

| Parameter | | Observation period | | |
|---|---|---|---|---|
| | | 12 weeks. | 24 weeks. | 48 weeks. |
| The range of motions in the ankle, deg. | Median | 40 | 55 | 55 |
| | Min/Max | 30/55 | 45/65 | 50/65 |
| | IQR | 35–45 | 55–60 | 55–60 |
| AOFAS, points | Median | 67,5 | 88 | 90 |
| | Min/Max | 61/72 | 78/95 | 85/97 |
| | IQR | 64–70 | 82–90 | 90–95 |
| Neer, points | Median | 67,5 | 90 | 94 |
| | Min/Max | 62/74 | 82/96 | 86/96 |
| | IQR | 64–70 | 85–93 | 94–96 |

$p<0,01$.

## DISCUSSION

Fractures of the posterior edge of tibia are typical intraarticular fractures. Therefore, standard principles of treatment of such injuries should be applied, among which accurate (anatomical) reduction and interfragmentary compression of the articular surface fragments are especially important. Nevertheless, until recently, it was believed that these principles for fractures in question can be applied with certain limitations. Thus, many authors reported that only fragments of the posterior edge of tibia containing at least 1/3 of the articular surface require fixation [4, 5, 15]. In addition, a number of authors recommend close reduction of the posterior edge of tibia fragments with minimally invasive fixation with screws introduced from front to back [4, 16]. However, this technique often does not allow anatomical reduction and reliable fixation of fragments of the fractures discussed. Moreover, for adequate interfragmentary compression, it is necessary that the entire threaded part of the screw is located in the fragment of the posterior edge of tibia, but in case of fragment of small size, it is technically impossible to create an interfragmentary compression. It must be taken into account that in cases of impaction of tibia articular surface, it is impossible to achieve precise reduction. Therefore, open reduction of bone fragments seems to be more adequate.

It should be noted that nowadays, the choice of surgical approaches for osteosynthesis of unstable malleolar fractures and the posterior edge of tibia is largely determined by the dread of trauma surgeons to excessively injure soft tissues in the ankle joint area, which can lead to serious complications that negate even the impeccable anatomical result of the surgery. As a matter of fact, for anatomical reduction of the posterior edge of tibia, it is necessary to perform one of posterior approaches to the ankle joint, which increases surgical trauma. At the same time, in order to lessen it, it is logical to couple the fixation of the posterior edge of tibia with osteosynthesis of one of the malleoli via the same surgical approach. This is exactly what surgeons do performing posterolateral approach to the posterior edge of tibia with subsequent fixation of the lateral malleolus via the same approach [17, 18]. However, this approach does not allow adequate visualization of the posteromedial fragment of the posterior edge of tibia in case of type 3 fracture according to J. Bartoniček et al. Therefore, in such cases, in our opinion, it is logical to use posteromedial surgical approach with simultaneous fixation of fragments of the posterior edge of tibia and medial malleolus.

Surgical technique of posteromedial approach described in the literature may somewhat differ. So, in the manual of Ch.M. Court-Brown et al., it is proposed to perform a longitudinal incision of the skin in the middle of the distance between the medial malleolus and the Achilles tendon. After dissection of the fascia, the tendons of the

posterior tibial muscle, flexor digitorum longus and flexor hallucis longus muscles are identified, and the approach to the posterior edge of tibia is provided between the last two tendons. In this case, the posterior tibial vessels and the tibial nerve are situated anteriorly from the tendon of the flexor hallucis longus. Approach to the posterior part of the medial malleolus opens by bypassing these vessels and nerve from the front. At the same time, it is recommended to be careful to avoid injury to the posterior tibial vessels and the tibial nerve [4].

Although such approach is not used very often, it gives better visualization of the posterior edge of tibia compared to the posterolateral approach according to M. Philpott et al. [19]. M. Assal et al. consider that the approach between the tendon of the flexor hallucis longus from behind and the neurovascular bundle with the tendon of the flexor digitorum longus from the front gives the widest (up to 91%) field of view of the posterior edge of tibia with the least tension of soft tissues, vessels and nerves [20]. In addition, posteromedial approach can be performed in supine position of the patient and combined with traditional lateral approach to the lateral malleolus, thereby simplifying ankle joint space orientation, including when performing intraoperative control radiographs [21].

Y. Wang et al. proposed a modified posteromedial approach, which was used in our study. According to this technique, the approach to the posterior edge of tibia fragment is performed between the tendon of the flexor hallucis longus and the neurovascular bundle, which is carefully withdrawn anteriorly together with the tendon of the flexor digitorum longus. The approach to the posteromedial part of the medial malleolus is made between the tendon of the flexor digitorum longus, which is diverted posteriorly together with the neurovascular bundle and the tendon of the posterior tibial muscle, which is shifted anteriorly, exposing the posterior surface of the medial malleolus. Surgeon passing anteriorly of the tendon of the posterior tibial muscle can get a full view on the anterior medial malleolus via the same approach. Thus, the authors achieved direct visualization of both the tibia posterior fragment and all parts of the medial malleolus and performed an open anatomical reduction and osteosynthesis of all fracture fragments [12].

Separate lateral approach was used with patient in the same supine position for osteosynthesis of the lateral malleolus and fixation of distal tibiofibular syndesmosis. Notably authors obtained an anatomical reduction of the posterior fragment of tibia in all 16 operated patients, and the average functional result graded on the AOFAS scale was 85.6 points [12].

Z.B. Lai et al. compared two groups of patients in which they used two modifications of the posteromedial approach for osteosynthesis of the posterior edge of tibia, first passing behind the tendon of the flexor digitorum longus, and second anteriorly from the latter. In both groups authors achieved anatomical reduction of the posterior edge of tibia fragment in more than 80% of patients and good functional recovery of ankle joint — in average more than 84 points on the AOFAS scale. At the same time, the authors noted even slightly better outcomes in the group with posteromedial approach passing posteriorly from the tendon of the flexor digitorum longus, due to less duration of surgery. In addition, the proportion of patients with anatomical reduction of the posterior edge of tibia was 90.5%, and the average functional outcome on the AOFAS scale was 88.2 ± 7.8 points. However, the advantages identified by the authors were not statistically significant [22].

Currently, it is obvious that CT scan is necessary for adequate preoperative planning and the choice of surgical approaches for fractures of the posterior edge of tibia and malleoli [23]. In case of such complex fractures G.M. Arrondo and G. Joannas recommend to evaluate preoperative axial CT scans first and then choose between three types of posterior approaches depending on the involvement of the fracture components: posterolateral, posteromedial and modified posteromedial [21].

S. Donohoe et al. state that ideas about the pattern of fractures in discussion change in 52% of cases after studying the CT scans, and in 44% of cases adjustments are made to the surgery plan and patient positioning [24]. The results of our study confirm the data of these authors. We decided on the optimal approaches for performing osteosynthesis in each case individually depending on the fracture patterns acquired using CT scans. For example, posteromedial surgical approach for reduction and fixation of the fracture

was chosen in case of identifying by CT scan impacted articular surface of the posterior edge of tibia, since this approach is most convenient for osteosynthesis and provides a better view. This is exactly what seems essential when it is necessary to eliminate the impaction, which requires adequate visualization of the fracture zone of the tibia articular surface.

It should be noted that our study included patients with fractures of the posterior edge of tibia of the 2nd, 3rd and 4th types according to J. Bartoniček et al. requiring surgical treatment. Thus, it was shown that the use of posteromedial approach is possible for all the variants of fractures of the posterior edge of tibia that we studied associated with malleolar fractures. At the same time, out of several options for posteromedial approach, we chose modified technique [12], since in our opinion it provides the best view with the least traction of soft tissues and neurovascular bundle [20].

It is known that many authors perform posteromedial approach with patient in prone position [21, 25]. However, we prefer to perform it in a supine position and consider this possibility one of the advantages in some clinical situations. These include, for example, the need for direct anterolateral approach in combined Tillaux-Chaput, LeFort injuries or the necessity of visualization of the anterior portion of distal tibiofibular syndesmosis. At the same time, supine position ща the patient does not complicate the surgery and allows performing all its stages without changing it.

In general, our accumulated clinical experience has shown that the described technique of posteromedial surgical approach allows achieving a good anatomical result of osteosynthesis in the vast majority of cases (91%) of unstable malleolar fractures and the posterior edge of tibia due to good visualization of the posterior edge of tibia and intraoperative control of bone fragments reduction using C-arm. This creates, in our opinion, the necessary conditions for achieving good functional results of surgical treatment of patients and reduces risk of complications.

### Limitations of the study

A small number of patients were included in the study, and a comparative analysis of the results of osteosynthesis of the studied fractures using alternative surgical approaches on our own clinical material was not performed.

## CONCLUSION

Despite the fact that the present clinical study of usage of posteromedial approach for osteosynthesis of fractures of the posterior edge of tibia and malleoli was preliminary, it can already be stated that the approach we used has shown its convenience and clinical effectiveness, as well as the possibility of application for osteosynthesis in unstable ankle fractures in many clinical situations. These, in our opinion, include first of all cases in which the use of posterolateral approach is impossible or excessively traumatic (the presence of a fracture of the tibia anterolateral edge, the need for its reduction and fixation, the need for revision of the anterior portion of the tibiofibular syndesmosis), as well as fracture of the posterior edge of tibia in combination with fracture of the medial malleolus of the 3rd type by J. Bartoniček et al. In addition, we have shown the possibility of successful application of posteromedial approach in other clinical situations: in fractures of the 2nd and 4th types according to J. Bartoniček et al. In our opinion, that indicates that when trauma surgeons master the rational technique of posteromedial surgical approach, the indications for its use can be expanded.

## DISCLAIMERS

### *Author contribution*

*Belen'kii I.G.* — research concept and design, data statistical processing, manuscript writing and editing.

*Maiorov B.A.* — research concept and design, data statistical processing, manuscript writing and editing.

*Kochish A.Yu.* — research concept and design, data statistical processing, manuscript writing and editing.

*Sergeev G.D.* — data collection and analysis, manuscript writing.

*Refitskii Yu.V.*— research concept and design, data statistical processing, manuscript writing and editing.

*Savello V.E.* — research concept and design, data statistical processing, manuscript writing and editing.

*Smirnov S.S.* — data collection and analysis, manuscript writing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Igor' G. Belen'kii* — Dr. Sci (Med.)
Address: 3, Budapeshtskaya str., St. Petersburg, 192242, Russia
https://orcid.org/0000-0001-9951-5183
e-mail: belenkiy.trauma@mail.r

*Boris A. Maiorov* — Cand. Sci (Med.)
https://orcid.org/0000-0003-1559-1571
e -mail: bmayorov@mail.ru

*Aleksandr Yu. Kochish* — Dr. Sci (Med.), Professor
https://orcid.org/0000-0002-2466-7120
e-mail: auk1959@mail.ru

*Gennadii D. Sergeev* — Cand. Sci (Med.)
https://orcid.org/0000-0002-8898-503X
e-mail: gdsergeev@gmail.com

*Yurii V. Refitskii*
https://orcid.org/0000-0002-6437-6424
e-mail: yur1140@yandex.ru

*Viktor E. Savello* — Dr. Sci (Med.), Professor
https://orcid.org/0000-0002-4519-4844
e-mail: prof_savello@emergency.spb.ru

*Sergei S. Smirnov*
https://orcid.org/0000-0002-3210-996220
e-mail: saveliy.morozov.93@mail.ru

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# Trends in Revision ACL Reconstruction: Analysis of 257 Procedures

Aleksandr S. Saprykin, Mikhail V. Ryabinin, Nikolai N. Kornilov

*Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation*

***Background.*** Despite the anterior cruciate ligament reconstruction (ACL-R) is considered to be routine and successful procedure the burden of patients who needs revision surgery is growing worldwide.
***Purpose*** — to describe the gender and social-demographic characteristics of this cohort of patients, analyze the reasons leading to revision ACL-R (re-ACL-R), estimate survival-ship of primary procedure as well as highlight clinically relative aspects of revision surgery.
***Methods.*** The database of Vreden Orthopaedic Center for the period from 01.01.2011 to 31.12.2021 searched for patients admitted for re-ACL-R. 234 patients (257 knees) agreed to take part in the study. Patient records with surgery reports, clinical exams and PROM's were analyzed.
***Results.*** There was a tendency to annual increase of re-ACL-R while the time between primary and revision procedures was just 4.0 years in average. Young males dominated among re-ACL-R cohort (75.2%, 31.0 years). The acute trauma prevailed over other reasons of ACL-R failure however, it was absent in 39.1% of cases. Patients who injured performing sports were significantly younger than the rest of the cohort ($p = 0.005$). Allografts were the most popular choice both for first re-ACL-R (53.0%) and re-revision ACL-R (60.9%). Interestingly that majority of re-ACL-R were performed in one stage while two-staged approach implemented only in 4.3% of cases.
***Conclusion.*** The main cause for re-ACL-R is repeated injury but significant percentage of patients develops recurrence of instability without trauma in middle-term period after ACL-R. Therefore to reduce the numbers of re-ACL-R both the proper post-op sport injury prevention program and improvement of surgical technique are of the same importance.

**Keywords:** knee, anterior cruciate ligament reconstruction, revision surgery, knee arthroscopy.

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✉ *Aleksandr S. Saprykin*; e-mail: saprykin.a.s.93@gmail.com

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# Структура операций ревизионной пластики передней крестообразной связки: анализ 257 наблюдений

А.С. Сапрыкин, М.В. Рябинин, Н.Н. Корнилов

*ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

***Введение.*** В настоящее время на фоне широкого распространения реконструкции передней крестообразной связки (ПКС), несмотря на довольно высокие показатели успешных исходов, возрастает потребность в ревизионных реконструкциях, которые более сложны, чем первичные вмешательства.
***Цель исследования*** — изучить структуру операций ревизионной реконструкции передней крестообразной связки, определить роль повторной травмы в причинах несостоятельности первичного трансплантата, объем вмешательств, а также сроки с момента выполнения предшествующей операции.
***Материал и методы.*** Проведен ретро- и проспективный анализ 257 ревизионных реконструкций ПКС у 234 пациентов, выполненных в НМИЦ ТО им. Р.Р. Вредена с 2011 по 2021 г. Исследование включало оценку половозрастного состава пациентов, причин выполненных ревизий, объема и особенностей вмешательств, а также сроков с момента выполнения предшествующей реконструкции ПКС.
***Результаты.*** Отмечена тенденция к ежегодному росту количества выполняемых ревизионных реконструкций ПКС, причем медиана срока выполнения ревизии составляет всего 4,0 года. Среди пациентов, которым выполнялась ревизионная реконструкция ПКС, преобладали мужчины (75,2%), а медиана возраста составила 31,0 год (25,0–36,0 лет). Среди причин ревизионной пластики ПКС на первом месте была повторная травма, однако в 38,9% наблюдений она отсутствовала. Пациенты, получившие повторную травму во время занятий спортом, были достоверно моложе остальной когорты ($p$ = 0,005). Наиболее популярными при ревизионной реконструкции ПКС были трансплантаты аллогенного происхождения: они использовались в 53,0% случаях первичных ревизий и в 60,9% повторных ревизий. Большинство ревизионных реконструкций ПКС (95,7%) выполнялось одноэтапно, и только в 4,3% случаев применялся двухэтапный подход.
***Заключение.*** Несмотря на то, что основными причинами ревизионных реконструкций ПКС явились повторные травмы, существенная доля пациентов нуждалась в данном вмешательстве без повторного повреждения, что обусловлено погрешностями выполнения первичного вмешательства. Таким образом, для снижения тренда к увеличению подобных операций необходимо создание системы профилактики повторных травм у прооперированных пациентов, а также совершенствование технологий первичного вмешательства.

**Ключевые слова:** коленный сустав, передняя крестообразная связка, реконструкция, ревизия, артроскопия.

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*Сапрыкин Александр Сергеевич*; e-mail: saprykin.a.s.93@gmail.com

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## BACKGROUND

Anterior cruciate ligament (ACL) injuries are one of the most common knee injuries, especially among young patients [1]. Specifically, up to 200,000 cases of ACL rupture are registered annually in the USA alone [2]. With persistent pain and various symptoms of instability, surgical treatment is indicated to restore knee function and allow the patient to return to his/her habitual level of physical activity and sports. In this regard, ACL reconstruction is now widely used.

Although ACL reconstruction is a successful orthopedic surgery that enables achieving a high rate of positive outcomes, the proportion of poor outcomes with graft failure can reach 17% [3]. As the total number of primary ACL reconstructions increases, the need for revision surgeries also increases. In major multicenter cohort studies, ACL revision rates range from 1.7% to 7.7% [4, 5]. Moreover, approximately 13,000 revision interventions on the ACL are performed annually in the USA alone [6].

The increased interest in this problem in the scientific community, which can be assessed by the dynamics of publication activity, is also noteworthy. The first single report on various aspects of ACL revision in the PubMed dates back to the early 1980s (Fig. 1). However, from 2000 to the present, the number of publications increased exponentially, reaching 191 in 2021.

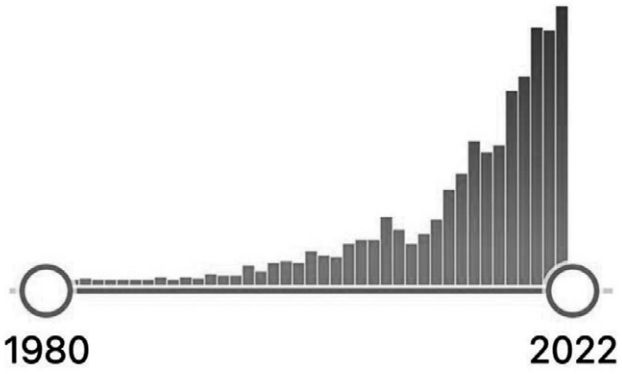


**Fig. 1.** Dynamics of publication activity in the PubMed database upon request 'revision ACL reconstruction'

Thus, in recent decades, interest in ACL revision reconstruction has increased significantly in the presence of an increasing need for such interventions in clinical practice. Clinical experience gained in Vreden Russian Center of Traumatology and Orthopedics enabled analysis of ACL revision reconstructions using large data and highlighted the most relevant aspects.

This study aimed to analyze the structure of revision reconstructions of the ACL and consider the role of repeated trauma in the occurrence of primary graft failure, scope of interventions, and time elapsed since the previous intervention.

## METHODS

Data were obtained retrospectively and prospectively from the general base of surgeries of the Vreden Russian Center of Traumatology and Orthopedics on 234 patients, including 176 men (75.2%) and 58 women (24.8%), who underwent ACL revision grafting from 2011 to 2021. The median age of the patients during the intervention was 31.0 (25.0–36.0) years. These patients underwent 257 surgical interventions in total, including 234 primary interventions and 23 repeated (re-revisions) revisions of the ACL. The retrospective part of the study included 164 cases, whereas the prospective part included 70 cases.

We analyzed the number of variables, namely, dynamics of the number of revision surgeries over the study period, presence and nature of injuries after primary ACL reconstruction, types of grafts used, and frequency of their use during primary and repeated ACL reconstructions.

### Statistical analysis

Accumulation, correction, and systematization of initial information and visualization of the results obtained were performed in Microsoft Office Excel (2020). Statistical analysis was performed using the StatTech v. 2.5.9 software (Stattech, Russia). Quantitative indicators were assessed for compliance with the normal distribution using the Shapiro-Wilk test (<50 participants) or the Kolmogorov-Smirnov test (>50 participants). In the absence of a normal distribution, quantitative data were described using the median (Me) and lower and upper quartiles (Q1-Q3).

Categorical data were described with absolute values and percentages. Comparison of three or more groups in terms of a quantitative indicator, which distribution differed from the normal one, was performed using the Kruskal-Wallis test, and a

posteriori comparisons were performed using the Dunn test with Holm's correction. Percentages in the analysis of multifield contingency tables were compared using Pearson's $\chi^2$ test.

## RESULTS

The number of ACL revision reconstructions performed at the Vreden Russian Scientific Center of Traumatology and Orthopedics from 2011 to 2021, constantly increased (except for 2019 and 2020), which reached 43 in 2021 (Fig. 2).

Regarding the timing of revision surgery for the primary reconstruction of the ACL, more than half of the revisions (57.1%) were performed during the first 5 years (Fig. 3). The median period for revision interventions was only 4.0 (3.0–8.0) years.

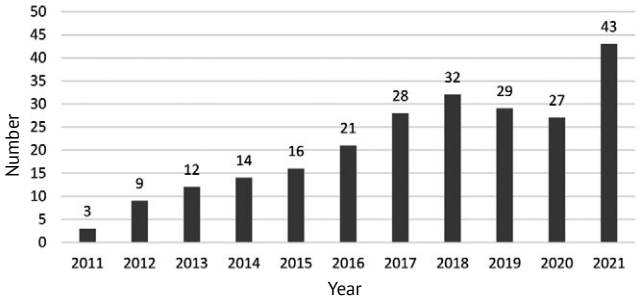


**Fig. 2.** Dynamics of revision ACL reconstructions at Vreden Orthopedic Center

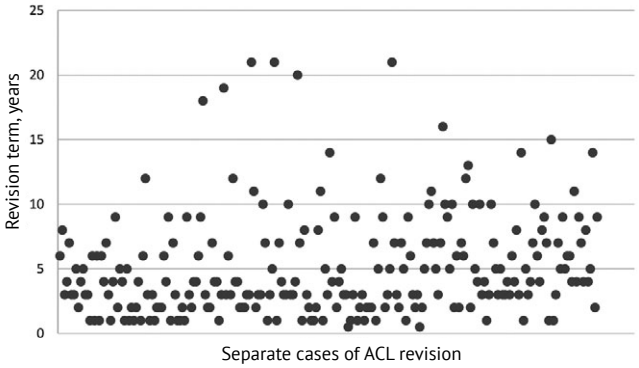


**Fig. 3.** Terms of revision ACL reconstruction from the primary (previous), years

As regards the dependence of the time elapsed between the surgeries on the type of primary graft, significant differences were revealed ($p = 0.013$) (Table 1). Thus, the highest median revision term was registered in patients with synthetic prosthesis and autotendon graft from the middle third of the patellar ligament with bone blocks (bone-patellar tendon-bone [BTB]), followed by allografts and autografts from the tendon of the semitendinosus and gracilis (STG) muscles.

Repeated injuries, which necessitate ACL revision reconstruction, were registered in 143 (61.1%) patients. Moreover, injuries received at home prevailed over sports injuries (79 – 33.8%) and 64 (27.4%), respectively). The proportion of patients without a history of injury before ACL revision reconstruction was smaller, and their number was nevertheless quite large (91 (38.9%) patients).

In our comparison of re-injury rate with the type of primary graft ($p = 0.366$) and patient's sex ($p = 0.281$), significant relationship was not found. However, when determining the dependence of re-injury and its type on the patient's age, significant differences were noted ($p = 0.005$). Thus, patients with sports-related re-injuries were younger than the others (Table 2).

We analyzed the types of grafts used and the frequency of their use in patients during primary and repeated ACL reconstructions. Accordingly, the types of grafts used during primary and revision surgeries were comparable; however, the frequency of their use varied significantly. Thus, autologous tendons of the STG muscles, middle third of the patellar ligament with BTB, quadriceps tendon (QT), and peroneus longus (PL); allografts of the long peroneal, posterior tibial muscles, and ligaments of the patella; and synthetic prostheses were used as grafts for ACL replacement. During ACL revision and re-revision, surgeons more often than others preferred allotendinous grafts, compared with autotendons of the STG muscles during primary reconstruction (Table 3).

*Table 1*

**Period of time between surgeries depending on the primary graft type**

| Graft type | Period between surgeries, years | | n | p* |
|---|---|---|---|---|
| | Me | Q1–Q3 | | |
| Auto STG | 3.6 | 2.2–5.7 | 138 | $p_{auto\ BTB—auto\ STG} = 0.026$<br>$p_{allo—auto\ STG} = 0.421$<br>$p_{synthetic—auto\ STG} = 0.031$<br>$p_{allo—auto\ BTB} = 0.138$<br>$p_{synthetic—auto\ BTB} = 0.967$<br>$p_{synthetic—allo} = 0.218$<br>$p_{tot.} = 0.013$ |
| Auto BTB | 6.0 | 2.8–8.4 | 35 | |
| Allo | 4.2 | 2.4–6.9 | 41 | |
| Synthetic prosthesis | 6.4 | 2.5–12.1 | 20 | |

STG — tendon of the semitendinous and gracilis muscles; BTB — middle third of the patellar ligament with bone blocks; Allo — allotendinous graft; * differences in indicators are significant ptot. = 0.013 (<0.05).

*Table 2*

**Dependence of repeated injuries on age**

| Re-injury | Age, years | | n | p* |
|---|---|---|---|---|
| | Me | $Q_1–Q_3$ | | |
| None | 33.0 | 25.0–38.0 | 91 | $p_{sports-related—none} = 0.011$<br>$p_{home—none} = 0.931$<br>$p_{home—sports-related} = 0.020$<br>$p_{tot.} = 0.005$* |
| Sports-related | 28.0 | 24.0–34.0 | 64 | |
| Home | 31.0 | 26.0–37.0 | 79 | |

*Differences in indicators are significant $p_{tot.} = 0.005$* (<0.05).

*Table 3*

**Types of grafts used, *n* (%)**

| Graft type | Primary reconstruction of the ACL | ACL revision | ACL re-revision |
|---|---|---|---|
| Auto STG | 138 (59.0) | 33 (14.1) | 1 (4.3) |
| Auto BTB | 35 (15.0) | 70 (29.9) | 8 (34.8) |
| Allo TP | 26 (11.1) | 88 (37.6) | 9 (39.1) |
| Allo PL | 15 (6.4) | 35 (15.0) | 3 (13.1) |
| Allo BTB | 0 (0.0) | 1 (0.4) | 2 (8.7) |
| Synthetic prosthesis | 20 (8.5) | 3 (1.3) | 0 (0.0) |
| Auto QT | 0 (0.0) | 1 (0.4) | 0 (0.0) |
| Auto PL | 0 (0.0) | 2(0.9) | 0 (0.0) |
| Contralateral auto STG | 0 (0.0) | 1 (0.4) | 0 (0.0) |
| Total | 234 (100) | 234 (100) | 23 (100) |

STG — tendon of the semitendinous and gracilis muscles; BTB — middle third of the patellar ligament with bone blocks; QT — quadriceps tendon; PL — peroneus longus tendon; TP — posterior tibial tendon; Allo — allotendinous graft.

Among the allografts, the tendon of the posterior tibial muscle was preferred. All allografts were prepared by the Department of Organ and Tissue Conservation of the Vreden Russian Center of Traumatology and Orthopedics. An antiseptic complex in a frost-resistant liquid medium was used to sterilize tissues. This method has certain advantages over others such as gamma irradiation, gaseous ethylene oxide, diluted solutions of formalin with antibiotics, and hydrogen peroxide. The main advantages of sterilization using an antiseptic complex in a frost-resistant liquid medium are the ease of storage, convenient transportation of grafts, and minimal influence on the material structure and biological properties [7].

In this study, 203 (86.8%) patients underwent isolated revision reconstruction of the ACL, and only 31 (13.2%) required combined surgery with additional grafting of other stabilizers of the knee joint, namely, posterior crucial ligament, medial and lateral collateral ligaments, etc.

Mostly, surgeons resorted to the one-stage revision technique, whereas the two-stage technique was performed in only 10 (4.3%) cases. A two-stage revision reconstruction of the ACL was performed if bone grafting of the canals was required (5 (2.1%)), after sanitizing surgeries because of complications such as surgical infection (3 (1.3%)), or arthrolysis in the case of severe arthrofibrosis of the knee joint, which was performed as stage 1 before ACL revision remodeling (2 (0.9%)).

Bone grafting during ACL revision was necessary in only 12 (5%) cases. In addition to bone grafting at stage 1 of treatment, it was also performed simultaneously with ACL revision in 7 (2.9%) cases. Spongious allogenic bone grafts (n = 9) were used more often than autologous (from the iliac crest) bone grafts (n = 3). A bone defect (2.5%, n = 6) in the femoral canal required plastic replacement slightly less frequently than a tibial defect (4.2%, n = 10).

## DISCUSSION

In this study, the key aspects established were the characteristics of demographic indicators, assessment of the role of repeated trauma in graft failure and revision reconstruction of the ACL, and change over time in the number of such interventions and clinical features of their implementation, including the frequency of use of various grafts.

First, our data on the age and sex distribution of patients who underwent ACL revision reconstruction are comparable with the global scientific literature, as the majority of patients are young people, mostly men [8]. This can be due to the high prevalence of sports-related knee joint injuries with ACL rupture, requiring its reconstruction, in this population. This predetermines possible revision surgery at various terms after primary surgery.

Second, the materials analyzed enabled the evaluation of the effect of repeated trauma on ACL graft failure and damage. Generally, the reasons for the revision reconstruction of the ACL are quite diverse, and they are usually grouped into larger categories. Specifically, it is proposed to consider separately traumatic and atraumatic causes of ACL revision reconstruction. Category 1 includes patients who sustained repeated trauma in various conditions (at home and/or sports-related), after which instability recurrence was noted following graft damage and/or failure [9]. The proportion of patients in whom recurrent instability and subsequent ACL revision remodeling occurred after re-injury was 61.1%. According to scientific studies, this indicator ranges from 18% to 79% [10, 11]. Category 2 includes patients in whom an unsatisfactory result (persistent instability, pain, and limited knee joint range of motion) is not associated with repeated episodes of injury and manifests at different times after the primary surgical intervention. In this study, 38.9% of the cases were included in this category, and technical errors are the most common cause of complications. These include incorrect positioning of the channels, graft, and undiagnosed combined injuries of other stabilizers of the knee joint [12, 13]. Among atraumatic causes, rehabilitation failure, biological factors, and infectious complications are less often registered [14]. In this study, we did not aim to provide details of atraumatic causes of ACL graft failure.

Third, in the vast majority of the cases (95.7%) analyzed in this study, surgeons resorted to a one-stage ACL revision technique. This approach eliminates the risks of repeated surgery and anesthesia, reduces the period of persistent instability in the knee joint and the time for complete

recovery, and has economic advantages [15]. Nevertheless, a one-stage revision of the ACL is not always indicated and technically possible. The most common reason for a two-stage revision of the ACL is the need for plastic replacement of extensive bone defects in the area of existing canals [16]. In addition, such an approach is appropriate in cases of surgical infection and arthrofibrosis. Data from the Multicenter Revision ACL Reconstruction Study (MARS) show that two-stage revision reconstruction is performed in 8–9% of cases [17].

Fourth, during revision surgery, a rather wide variability in the use of various grafts remains; however, allotendinous materials prevailed, which account for 52.6% during primary revisions and 60.9% during re-revisions, which is comparable with publications by other authors. Thus, according to MARS, 54% of the surgeons preferred allografts, whereas 27% preferred primary grafting [17]. The problem of choosing the optimal graft remains for both primary and revision ACL reconstructions. In the scientific community, this aspect is still actively discussed; however, there is no clear answer to the question of which transplant is preferable [18, 19]. The high popularity of allografts can be explained by the limited choice of autografts and technical aspects of the ACL revision reconstruction. Allografts, due to their varying sizes and conditionally unlimited number, are quite convenient for ACL revision grafting, especially when multi-ligament reconstruction and filling of limited bone defects are required [20]. In this study, multi-ligamentary reconstructions account for only 13% of all ACL revision surgeries.

Thus, the annual increase in the number of revision reconstructions of the ACL and the short periods when it becomes necessary to perform repeated surgeries require the creation of a system of measures aimed at preventing repeated injuries in operated patients, not only during sports activities, but also in everyday life, and the improvement of primary intervention technologies. Considering that different methods of primary and revision reconstruction of the ACL is currently used in clinical practice, including various approaches to the formation of channels, types of grafts, and methods of their fixation, the national registry of ACL grafting could become the best tool for studying modifiable risk factors for repeated surgeries. International analogs of ACL registers have been successfully functioning over the past years in several countries [21, 22]. The creation and implementation of such a register of ACL reconstruction in Russia could increase the amount of clinical materials available for analysis from various medical institutions, which is necessary for a qualitative increase in the clinical and scientific value of further research in this field.

## CONCLUSION

Among patients undergoing ACL revision grafting, men predominate significantly (>75%). In most cases, repeated trauma is the reason necessitating revision reconstruction of the ACL. However, the proportion of patients requiring this intervention without a history of re-injury remains very high (38.9%), which is most often due to primary surgery failure. In the vast majority of cases, surgeons resort to one-stage revision reconstruction of the ACL, which has advantages in cases where its implementation is technically possible and does not worsen the outcomes. Allogeneic tendon and tendon-bone grafts are popular because they facilitate the technical solution of the tasks that the surgeon faces during ACL revision reconstruction.

## DISCLAIMERS

### *Author contribution*

*Saprykin A.S.* — the concept and design of study, data collection, analysis and interpretation of the obtained data, statistical data processing, writing of the manuscript.

*Rybinin M.V.* — the concept and design of the study, writing and editing of the manuscript.

*Kornilov N.N.* — the concept and design of the study, writing and editing of the manuscript, interpretation the obtained data.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Aleksandr S. Saprykin*
Address: 8, Akademika Baykova str., St. Petersburg, 195427, Russia
https://orcid.org/0000-0003-2315-4160
e-mail: saprykin.a.s.93@gmail.com

*Mikhail V. Ryabinin* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-7504-3086
e-mail: ryabininm@rambler.ru

*Nikolai N. Kornilov* — Dr. Sci. (Med.)
https://orcid.org/0000-0001-6905-7900
e-mail: drkornilov@hotmail.com

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# Factors Associated With Revision Surgery in Long Bones Metastases

Jun Wang [1], Natalya V. Kharchenko [1], Gadzhimurad M. Zapirov [1], Andrey D. Kaprin [1,2], Artem V. Bukharov [2], Vitaliy A. Derzhavin [2], Anna V. Yadrina [2]

[1] *RUDN University, Moscow, Russia*

[2] *P.A. Herzen Moscow Research Institute of Oncology — Branch of National Medical Research Center of Radiology, Moscow, Russia*

***Background.*** Bones as an organ are one of the most common targets for tumor metastasis. Currently, the number of patients undergoing surgical treatment for metastatic bone lesions is steadily increasing. In most patients, after surgical treatment, the manifestation of clinical symptoms decreases, primarily pain syndrome, which improves their quality of life. However, it should be noted that the number of patients with bone metastases who underwent revision surgery is also increasing. This article retrospectively analyzes the factors leading to revision after surgical treatment of metastases in long bones.

***The aim of this study*** was to identify factors leading to revision after surgical treatment of patients with metastases in long bones.

***Methods.*** A retrospective medical records analysis of 247 patients who underwent surgical treatment for metastases in long bones in 2006–2020 was performed. Of these, 33 patients underwent revision surgery. The median age was 62 years. The localization of the primary tumor was as follows: breast cancer — 10 cases, kidney cancer — 13, lung cancer — 3, prostate cancer — 2, rectal cancer — 3, liver cancer and Ewing's sarcoma with bone metastases — 1 case each.

***Results.*** The following factors led to revision surgery: mistakes in preoperative diagnosis (3 patients); postoperative infectious complication (6 patients); dislocation of the endoprosthesis (4 patients); continued growth of solitary metastasis after osteosynthesis (5 cases); aseptic instability after intramedullary osteosynthesis (14 patients); traumatic fracture of the endoprosthesis stem (1 patient).

***Conclusions.*** Revision after surgical treatment of metastases in long bones, in addition to postoperative complications, lead to mistakes in diagnosis and incorrect choice of surgical treatment method. To reduce the risk of revision surgical interventions, a multidisciplinary approach is needed with the development of surgical treatment tactics in consultation and the use of specialized scales of oncological prognosis.

**Keywords:** metastasis, long bones, surgical treatment.

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✉ *Jun Wang*; e-mail: kbcbwb2000@163.com

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# Факторы, приводящие к повторному хирургическому вмешательству при метастатическом поражении длинных костей

Ц. Ван [1], Н.В. Харченко [1], Г.М. Запиров [1], А.Д. Каприн [1,2], А.В. Бухаров [2], В.А. Державин [2], А.В. Ядрина [2]

[1] *ФГАОУ ВО «Российский университет дружбы народов» Минобрнауки России, г. Москва, Россия*

[2] *Московский научно-исследовательский онкологический институт им. П.А. Герцена — филиал ФГБУ «Национальный медицинский исследовательский центр радиологии» Минздрава России, г. Москва, Россия*

***Актуальность.*** Кости как орган являются одной из наиболее распространенных мишеней для метастазирования опухолей. Число пациентов, подвергшихся хирургическому лечению по поводу метастатического поражения костей, неуклонно растет. Количество пациентов с метастазами в кости, которым проводили повторную операцию, также увеличивается.
***Цель*** — выявление факторов, приводящих к повторным операциям после хирургического лечения пациентов с метастазами в длинных костях.
***Материал и методы***. Выполнен ретроспективный анализ историй болезни 247 пациентов, которым на базе МНИОИ им. П.А. Герцена в 2006–2020 гг. было проведено хирургическое лечение по поводу метастазов в длинных костях. Из них у 33 пациентов выполнены повторные хирургические вмешательства. Средний возраст составил 62 года. Локализация первичной опухоли: рак молочной железы — 10 случаев, рак почки — 13, рак легких — 3, рак предстательной железы — 2, рак прямой кишки — 3, рак печени и саркома Юинга с метастазами в кости — по 1 случаю.
***Результаты.*** К повторной операции приводили следующие факторы: ошибки в предоперационной диагностике (3 пациента), послеоперационное инфекционное осложнение (6 больных), вывих эндопротеза (4 больных), продолженный рост солитарного метастаза после остеосинтеза (5 случаев), асептическая нестабильность после интрамедуллярного остеосинтеза (14 больных), травматический перелом ножки эндопротеза (1 пациент).
***Выводы.*** К повторным операциям после хирургического лечения метастазов в длинных костях, кроме послеоперационных осложнений, приводят ошибки в диагностике и некорректный выбор метода хирургического лечения. Для уменьшения риска повторных хирургических вмешательств необходим мультидисциплинарный подход с выработкой тактики хирургического лечения на консилиуме и использованием специализированных шкал онкологического прогноза.

**Ключевые слова:** метастазы в длинные кости, хирургическое лечение.

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*Ван Цзюнь;* e-mail: kbcbwb2000@163.com

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## BACKGROUND

The improvement in diagnostics and of the techniques of surgical interventions and the development of drug therapy and radiation method of treatment have enabled to increase the life expectancy of cancer patients significantly. However, a significant proportion of patients has regional and/or distant metastases. Primary malignant tumors can metastasize to almost all body tissues, but some types of tumors, such as breast cancer, prostate cancer, lung cancer, thyroid cancer, and kidney cancer, metastasize preferentially to bones. According to the literature, the bone is the third most common site of metastasis after the lungs and liver [1, 2].

According to the American Cancer Society, more than 65% of breast and prostate cancers and 30–40% of lung, thyroid, and kidney cancers have bone metastases [3]. Metastases are most often localized in the femur and humerus among the long bones [3]. For most cancer patients, the emergence of metastases usually indicates an advanced stage of the disease and a poor prognosis. However, surgical treatment of patients with bone metastases improves the quality of life of patients and restores the function of the affected limb [4]. Along with the expansion of indications for surgical intervention, with metastatic lesions of long bones, there is an increase in the frequency of repeated surgeries due to the recurrence of the pain syndrome induced by various factors.

The study aimed to identify factors leading to revision surgeries after surgical treatment of patients with metastases in long bones.

## METHODS

### Study design

This is a retrospective analysis of the case histories of patients who underwent surgical treatment of metastases in long bones at the Hertsen Moscow Oncology Research Institute in 2006–2020. The study did not include patients in whom the identified metastatic focus was not surgically removed, as well as those who refused to undergo repeated surgical intervention.

### Patients

Out of 247 patients, 181 (73.3%) with metastatic lesions of long bones underwent removal of the metastatic focus with total joint replacement. Internal osteosynthesis was performed in 65 (26.3%) cases, and one patient (0.4%) underwent radiofrequency thermal ablation of the lytic femoral focus with osteoplasty.

In 33 (13.3%) patients, repeated surgical interventions were performed, including amputation in one patient, reduction of the endoprosthesis dislocation in four cases, one-staged or two-staged repeated endoprosthesis replacement in five patients, and segmental resection with endoprosthesis replacement was performed in 23 cases.

There were 15 men and 18 women. Their age ranged from 23 to 80 yr, with a mean age of 62 yr.

The primary tumor was as breast cancer in 10 patients, kidney cancer — in 13 patients, lung cancer — in three patients, prostate cancer — in two patients, rectal cancer — in three patients, liver cancer — in one patient and Ewing's sarcoma — in one patient.

Total joint replacement was performed in 11 (33.3%) patients as a primary surgery, intramedullary osteosynthesis in 21 (63.6%) patients, and radiofrequency thermal ablation of the femoral lytic focus with osteoplasty was performed in one patient (3%). At the same time, 20 (60.6%) patients had a pathological bone fracture, and seven (21.2%) patients had a risk of its occurrence. In five (15.2%) patients, the indication for surgery was the continued growth of solitary metastasis in the long bone.

The primary surgery in 11 patients was performed at the Hertsen Moscow Oncology Research Institute, and in 22 patients, it was performed in another clinic. During hospitalization 31 out of 33 patients had a pronounced pain syndrome, 17 patients had a limitation in the range of motion, and swelling of the affected extremities was registered in five patients.

### Evaluation of results

The visual analog scale (VAS) was used to assess the pain syndrome severity, and the Eastern Cooperative Oncology Group (ECOG)

and Karnofsky scales were used to assess the patients' quality of life before and after surgery [5].

## Statistical analysis

Statistical analysis of the data obtained was performed using the Solutions Statistical Package for the Social Sciences 22 (SPSS Statistics) program. Survival rate analysis was performed using the Kaplan-Meier method. Survival curves were compared using the log-rank test. Differences were considered statistically significant at $p<0.05$.

## RESULTS

The changes over time of pain syndrome according to VAS before and after repeated surgical intervention are presented in Table 1.

The follow-up revealed that 24 (72.7%) patients passed away as a result of repeated surgical interventions. Six of the 24 patients underwent total joint replacement during primary surgery, and 17 patients underwent intramedullary osteosynthesis. One patient underwent radiofrequency thermal ablation of the lytic lesion of the femur with osteoplasty. The median survival rate after repeated surgical interventions was 15 months (6–28 months). When studying the long-term results of treatment of patients after repeated surgical interventions, we revealed that the overall 1-year survival rate was 73%, and the 2- year survival rate was 24% (Figure 1).

The majority (226 [91.5%] patients) showed an improvement in the quality of life after surgery according to the Karnofsky and ECOG scales, and in 21 (8.5%) patients, the quality of life did not change. However, after repeated surgeries, all 33 patients showed an improvement in the quality of life, according to the Karnofsky and ECOG scales (Table 2).

*Table 1*

**Dynamics of pain syndrome according to VAS**

| Score | Number of patients | |
|---|---|---|
| | Before surgery | After surgery |
| 0–2 | 2 | 28 |
| 3–4 | 5 | 5 |
| 5–6 | 20 | 0 |
| 7–8 | 3 | 0 |
| 9–10 | 3 | 0 |
| Total | 33 | 33 |

Pearson's $\chi^2$ value is 48.533; $p < 0.001$.

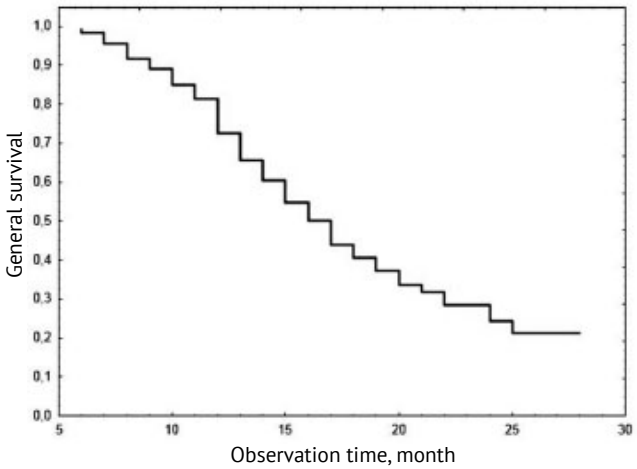


**Fig. 1.** Survival rate of patients after revision surgery

Indications for revision surgery were errors in preoperative diagnostics (three patients), postoperative infectious complication (six patients), endoprosthesis dislocation (four patients), continued growth of solitary metastasis after osteosynthesis (five patients), aseptic instability after intramedullary osteosynthesis (14 patients), and traumatic fracture of the endoprosthesis stem (one patient) (Table 3).

*Table 2*

**Changes in the level of quality of life after the initial surgery and repeated surgical interventions according to the ECOG and Karnofsky scales**

| Description | Karnofsky scores | ECOG scores | Number of patients (n = 247) | | Number of patients (n = 33) | |
|---|---|---|---|---|---|---|
| | | | Before the primary surgery | After the primary surgery | Before repeated surgical interventions | After repeated surgical interventions |
| The patient is fully active and is capable to perform activities as before the disease | 90–100 | 0 | 3 | 143 (3*) | 0 | 26 |
| The patient is unable to do heavy work but can do light or sedentary work (e.g., light housework or deskwork) | 70–80 | 1 | 12 | 50 (3*) | 2 | 7 |
| The patient is treated on outpatient basis, is capable of self-care but unable to work. He spends more than 50% of his waking time actively in an upright position | 50–60 | 2 | 18 | 28 (4*) | 8 | 0 |
| The patient is only capable of limited self-care and spends more than 50% of the time in a chair or bed | 30–40 | 3 | 64 | 19 (4*) | 17 | 0 |
| Disabled person, completely incapable of self-care, confined to a chair or bed | 10–20 | 4 | 150 | 7 (7*) | 6 | 0 |

* Number of patients whose quality of life has not changed after surgery; $p < 0.001$.

*Table 3*

**Causes of revision surgeries after treatment of metastases in long bones**

| Primary surgery | Number of patients | Complication | Revision surgery |
|---|---|---|---|
| Total arthroplasty | 4 | Dislocation | Revision arthroplasty |
| | 6 | Infection | Repeated endoprosthesis replacement |
| | 1 | Endoprosthesis fracture | |
| Osteosynthesis | 14 | Aseptic instability | Arthroplasty |
| | 4 | Continued growth of solitary metastasis | |
| | 1 | | Amputation |
| | 2 | Errors in preoperative diagnostics | Arthroplasty |
| Radiofrequency thermal ablation with osteoplasty | 1 | Errors in preoperative diagnostics | Arthroplasty |

## DISCUSSION

Currently, patients have higher demands on restoring the quality of life. Most of them hope for the fastest possible restoration of the affected limb function and the maximum reduction of pain after surgery. In order to remove metastatic foci and correct pathological fractures, surgical methods, such as intramedullary fixation, total joint replacement, and plate fixation, are used in clinical practice to restore the functional characteristics of the affected bone [6, 7]. An analysis of the literature shows that surgical treatment of metastases in long bones allows good immediate results and significantly improves the quality of life of this category of patients [8, 9, 10, 11].

Our study presents a retrospective analysis of data from 247 patients with long bone metastases, who underwent surgical treatment. The study of immediate results and data obtained during follow-up of patients in this group showed that the use of surgical interventions for the treatment of metastatic lesions of long bones is justified in most cases, since they provide good functional results and improve the quality of life of this category of patients (91%). However, at the same time, we concluded that due to the recurrence of pain syndrome and other clinical symptoms caused by various factors, the number of patients requiring repeated surgeries is increasing simultaneously.

Thus, according to the study results, the main factors of repeated surgical interventions were identified.

### 1. Errors in preoperative diagnostics

The above group of 33 patients included three patients with diagnostic errors. Two patients with suspected traumatic fracture were hospitalized in the trauma department of clinics, where intramedullary osteosynthesis was performed. One of the patients was diagnosed with osteosarcoma of the femoral metaphysis during the initial visit to a medical institution, and then radiofrequency thermal ablation in combination with osteoplasty was performed.

In clinical practice, bone metastases in patients can be asymptomatic and diagnosed incidentally during routine examinations or in case of a pathological fracture [12]. T. Sun et al. reported that 15 out of 121 patients (12.4%) with metastases to the femur did not have a clearly verified primary tumor during examination [13]. X.D. Tang et al. analyzed 125 cases of malignant tumors with bone metastases and revealed that 29.6% of patients did not receive diagnosis of metastases. At the same time, the frequency of positive results of physical examination was 9.6%, that of the study of specific tumor antigens was 43.2%, imaging study showed positive results in 60% of cases, and post-mortem examination showed positive results in 66.4% of cases [14].

According to research results, the bone microenvironment contributes to metastatic injury by changing the phenotype of tumor cells and plays a key role in the vicious circle of bone metastasis. The bone matrix is rich in many growth factors (e.g., TGF-α, IGF-I, and IGF-II), which are released because of osteolysis and stimulate simultaneously the proliferation of both bone and tumor cells. The physical factors of the bone matrix (e.g., acidic environment) create a favorable environment for tumor growth. Physical factors interact with growth factors, thereby contributing to the formation of a vicious circle of bone metastases development and accelerating the process of bone metastasis [11, 15, 16, 17, 18].

In our opinion, in most cases, diagnostic errors occur due to low oncological alertness of the general clinical health care unit, particularly among orthopedic surgeons. However, the progression of a malignant tumor is often associated to a greater extent with the development of metastases than with the growth of the primary focus, and even a small primary tumor can have obvious distant metastases.

### 2. Incorrect method of surgical treatment

In our study, aseptic instability developed in 19 patients after osteosynthesis of long bones for a verified metastatic lesion, and growth of a solitary tumor was recorded 6–12 months after the surgery, which subsequently required amputation in one patient, and segmental resection with joint replacement in the rest of the cases.

Functional results after segmental resection with joint replacement and osteosynthesis after 6 months were significantly different in favor of joint replacement due to tumor growth in

the affected bone segment after osteosynthesis and the development of aseptic instability. Due to the absence of tumor growth in the affected bone segment, the eradication of the tumor during segmental resection with joint replacement provides good functional results for a longer period. At the same time, it is noteworthy that there are no significant differences in the average duration of surgery, the volume of blood loss, and the terms of activation of patients after osteosynthesis and joint replacement [19].

The life expectancy of oncological patients has increased significantly in connection with the development of oncological science and the improvement of treatment methods, and this has led to an increase in the number of patients with bone metastases [20]. The complicated course of metastatic bone lesions affects significantly the quality of life of patients [21]. Indications for surgical treatment and methods of orthopedic management in patients with bone metastases can vary significantly in different countries. Thus, in the USA, 71% of patients with bone metastases undergo surgery due to the risk of pathological fractures, while it is performed only in 18% of cases in the Nordic countries [20, 22].

Predicting the life expectancy of patients with bone metastases is significant in the choice of treatment options, but the accuracy of such a prognosis is still insufficient. Over the past decades, there have been numerous attempts to develop new systems to assist in making decisions about the approach of treating patients with bone metastases [23, 24, 25, 26, 27]. Another important factor for determining the approach of surgical treatment is the metastatic lesion localization, as well as the presence or risk of a pathological fracture [12, 28, 29, 30]. Fracture risk is assessed using the Mirels scale; if there are more than 9 points, surgical treatment should be performed [31]. Currently, intramedullary osteosynthesis in the treatment of metastatic bone lesions has limited indications and is almost not used. Preference is given to oncological joint replacement [32, 33, 34, 35, 36].

For patients with long bone metastases associated with or at risk of pathological fractures, the optimal surgical method must be determined, taking into account the patient's life expectancy, fracture location, and many other factors. In breast cancer, prostate cancer, and other cancer sites with a long patient survival period, when the primary tumor has been removed or the tumor process manifests itself as a relatively slowly developing isolated bone metastasis, extensive tumor resection can be performed to reduce the incidence of local recurrences. However, the choice of surgical methods for restoring the affected limb function is focused on the pathological fracture area. If bone metastasis is located near the joints in combination with pathological fractures, total joint replacement may be the optimal treatment. This surgical method can replace a bone defect effectively during tumor removal and provide affected limb with sufficient functional performance and strength after surgery. Within a week after the surgery, functional exercises can be performed to avoid prolonged bed rest. If the pathological fracture is localized in the bone diaphysis, intramedullary osteosynthesis can be considered, since this method provides uniform tension and minor blood loss [32, 33]. Intramedullary osteosynthesis can also be used in the case when the tumor does not destroy strongly the bone tissue at the fracture site and the cortical bone is in good condition. The addition of bone cement to the site of a bone defect increases its stability and can destroy tumor cells and nerve endings in the lesion by increasing the temperature during the bone cement hardening. When the tumor destroys significantly the cortical bone at the fracture site or other methods of osteosynthesis are not effective, total joint replacement is preferred [34].

In our opinion, intramedullary osteosynthesis can prevent fractures of the proximal femur and femoral diaphysis. However, pathological fractures also occur in the greater or lesser trochanters of the bone, which is accompanied by severe damage to the cortical bone; in this case, arthroplasty should be used.

## 3. Postoperative complications

Infection and endoprosthesis dislocation are the most common postoperative complications in the surgical treatment of metastases to long bones; these situations were identified in 10 out of 33 patients.

### *3.1. Infection*

In this study, six patients underwent revision surgery due to postoperative infection of the endoprosthesis bed. At the same time, four patients underwent a two-staged revision athroplasty, and in two patients, after revision and debridment, a new endoprosthesis was immediately installed. There were no cases of amputation.

The most serious complication of oncological arthroplasty is postoperative infection. Infection can cause pain, severe joint function limitation, and, if not treated properly, can lead to limb amputation [37]. The probability of amputation due to suppuration has been reported to be 19–47% [38, 39]. It should be noted that the surgery is performed in a laminar flow operating room, bone cement with antibiotics is used, and patients take antibiotics before and after the surgery to prevent infection. However, postoperative infection is still a major concern for orthopedic oncologists. Literature data indicate that revision surgery enables to control the infection in most cases [37, 40]. Efficiency of revision surgeries in terms of stopping the infection can reach 70% [40].

Based on our experience and literature data, it can be assumed that postoperative infections leading to revision surgery may be associated with the following factors:

– adjuvant therapy reduces the patient's autoimmune resistance;

– intraoperative aseptic treatment is not performed carefully enough, which leads directly to intraoperative contamination;

– the tumor widely invades, and as a result, the local soft tissues become thin after resection of the tumor site, the ability to absorb exudate and combat infection decreases, and there is a predisposition to postoperative infection;

– poor drainage of the wound after surgery can lead to accumulation of fluid and blood;

– after the surgery, the surrounding soft tissues are not adjacent to the prosthesis, so a cavity can form around it, where fluid accumulates easily and infection develops;

– between the body and the prosthesis, a rejection reaction occurs, which manifests itself in the form of exudation of a brown liquid, while at first there is no growth of bacteria, however, a large amount of exudate over a long period of time creates conditions for the growth of bacteria, and repeated dressings can easily induce the wound contamination;

– soft tissues do not close the wound well; after an extensive marginal tissue resection, wound closing with tissues is often complicated, poor healing of the incision and even necrosis of the skin edge are noted, which can lead to secondary infection.

### *3.2. Dislocation*

Dislocation is a serious complication after total hip replacement and usually requires revision surgery. According to the literature, the incidence of dislocations after shoulder joint replacement is 12% to 54.5% [41]. Research by C.U. Gwam et al. showed that joint dislocation after hip arthroplasty is the main cause for revision surgery (17.3%) and is more common than infection and aseptic instability [42].

In our study, four patients underwent revision surgery for dislocation. In two patients, dislocation occurred 15 and 45 days after total joint replacement of the shoulder joint, unipolar (anatomical) endoprosthesis replacement was performed in one patient, and reverse arthroplasty was performed in the other patient. In two more patients, dislocation occurred after hip arthroplasty on the days 3 and 35 after surgery. All patients underwent surgical intervention in the scope of the revision with reduction of the dislocation. Various types of reconstruction and grafting were used to prevent repeated dislocations.

As a rule, dislocation after oncological arthroplasty is associated with massive removal of the soft tissues surrounding the tumor and the entire ligamentous apparatus. Surgical prevention of dislocations includes the restoration of tendon fixation points and the use of various types of plasty by biosynthetic materials.

## 4. Other factors

One patient underwent joint replacement for breast cancer with metastases to the femur in combination with pathological fractures; 19 months after the surgery, she was hospitalized again with a fracture due to an accidental fall, while the X-ray showed implants failure. This patient underwent revision joint replacement.

## Study limitations

This study was a single-center, represented a retrospective analysis, and had a limited data sample size. Multicenter prospective studies are required to clarify the factors leading to revision surgery in long bone metastases.

## CONCLUSION

The study showed that the main causes of revision surgery in patients with bone metastases were insufficiently accurate preoperative diagnostics, associated errors in the choice of surgical intervention options, as well as postoperative complications.

In our opinion, for the effective treatment of patients with metastases in long bones, a multidisciplinary approach is required with the development of treatment approach at a case conference with the participation of chemotherapists, radiologists, and orthopedic oncologists, as well as using specialized scales of oncological prognosis. The surgical team should have experience in working with cancer patients. This will increase the probability of success of the surgery, restore the function of the affected limb, improve the quality of life of patients, and reduce the risk of revision surgery.

## DISCLAIMERS

### *Author contribution*

*Wang J.* — concept and research design, collection and statistical processing of data, writing text.

*Kharchenko N.V.* — research concept and design.

*Zapirov G.M.* — collection and analysis of materials, editing text.

*Kaprin A.D.* — research concept and design.

*Bucharov A.V.* — concept and research design, writing text, text editing.

*Derzhavin V.A.* — collection and analysis of materials, text preparation and editing.

*Yadrina A.V* — collection and analysis of materials, text preparation and editing.

All authors read and approved the final version of the manuscript in the article. All authors agree to be responsible for all aspects of the work to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Jun Wang*
Address: 6, Miklukho-Maklaya str., Moscow, 117198, Russia
https://orcid.org/0000-0001-5625-0509.
e-mail: kbcbwb2000@163.com

*Natalya V. Kharchenko* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-5352-492X
e-mail: docsemi@yandex.ru

*Gadzhimurad M. Zapirov* — Cand. Sci. (Med.)
https://orcid.org/0000-0003-2347-4615
e-mail: zapirov@mail.ru

*Andrey D. Kaprin* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0001-8784-8415
e-mail: kaprin@mail.ru

*Artem V. Bukharov* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-2976-8895
e-mail: artembuharov@mail.ru

*Vitalii A. Derzhavin* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-4385-9048
e-mail: osteosa@yandex.ru

*Anna V. Yadrina* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-7944-3108
e-mail: anna_16.06@mail.ru

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# Assessment of the Foot Donor Site Morbidity After Non-Vascularized Toe Phalanx Transfer to the Hand

Pavel A. Matveev [1], Igor V. Shvedovchenko [1], Lyudmila M. Smirnova [1, 2], Andrey A. Koltsov [1]

[1] *Albrecht Federal Scientific Centre of Rehabilitation of the Disabled, St. Petersburg, Russia*

[2] *St. Petersburg Electrotechnical University «LETI» named after V.I. Ulyanov (Lenin), St. Petersburg, Russia*

***Background.*** Non-vascularized is one of the available methods of reconstructive surgery for the treatment of the hand congenital anomalies. The the impact of toe phalanx transfer on the appearance and functionality of the donor site in the long term is relevant.
***Aim of the study*** — an objective assessment of the appearance, shape and functional state of the foot in the long-term period after the toe phalanx transfer into defects of the fingers in congenital and obtained hand pathologies.
***Methods.*** On the basis of the Federal Scientific Center for the Rehabilitation of the Disabled named after G.A. Albrecht 40 patients were examined, who, aged from 8 months to 11 years (in the period 2013-2022), underwent 54 toe phalanx transfer to the hand. The proximal or middle phalanx of the IV and II toes were used as a graft. To assess the condition of the feet in the long term, all patients underwent clinical and radiological studies. 12 patients aged 3 to 13 years underwent computerized plantography, podometry and barodynamoplantography.
***Results.*** After donor feet examination in the long-term period, lots of them showed a linear shortening of the donor toes compared to the contralateral foot, which was recorded by a computer planto-podometric method for evidence. The barodinamoplantographic study did not show significant signs of a decrease in the support ability of the foot, which could be associated with non-vascularized toe phalanx transfer. When walking, there were no obvious signs of impaired motor functions of the donor foot.
***Conclusion.*** It was objectively confirmed that the non-vascularized toe phalanx transfer to the hand does not significantly affect the shape and statodynamic function of the foot in the long-term follow-up period, despite the shortening of the donor toes.

**Keywords:** hand, congenital anomalies, autografts, free bone grafting, phalanx transfer, toes, non-vascularized graft, biomechanical examination, children.

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✉ *Pavel A. Matveev*; e-mail: p-matveyev@narod.ru

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# Оценка состояния стопы после заимствования некровоснабжаемых фаланг пальцев для аутотрансплантации на кисть

П.А. Матвеев [1], И.В. Шведовченко [1], Л.М. Смирнова [1,2], А.А. Кольцов [1]

[1] *ФГБУ «Федеральный научный центр реабилитации инвалидов им. Г.А. Альбрехта» Минтруда России, г. Санкт-Петербург, Россия*

[2] *ФГАОУ ВО «Санкт-Петербургский государственный электротехнический университет «ЛЭТИ» им. В.И. Ульянова (Ленина)» Минобрнауки России, г. Санкт-Петербург, Россия*

***Актуальность.*** Аутотрансплантация некровоснабжаемых фаланг пальцев стопы является одним из доступных методов реконструктивно-пластической хирургии для лечения недоразвитий кисти. Актуален вопрос влияния заимствования фаланг на внешний вид и функциональность донорской стопы в отдаленном периоде.

***Цель*** — объективная оценка внешнего вида, формы и функционального состояния стопы в отдаленном периоде после заимствования некровоснабжаемых фаланг пальцев и последующей пересадки для замещения дефекта пальцев кисти при врожденных и приобретенных патологиях.

***Материал и методы.*** Обследовано 40 пациентов, которым в возрасте от 8 мес. до 11 лет были выполнены в совокупности 54 пересадки фаланг по поводу редукционных аномалий кисти. В качестве трансплантата использовали проксимальные или средние фаланги IV и II пальцев стопы. Для оценки состояния стоп в отдаленном периоде всем пациентам проводили клинико-рентгенологические исследования. 12 пациентам в возрасте от 3 до 13 лет проведены компьютерные плантография, подометрия и бародинамоплантография.

***Результаты.*** При осмотре стоп оперированных пациентов в отдаленном периоде у многих было выявлено линейное укорочение донорских пальцев стопы по сравнению с контралатеральной стопой, что для доказательности фиксировали компьютерным планто-подометрическим методом. Бародинамоплантографическое исследование не показало значимых признаков снижения опороспособности стопы, которые можно было бы связать с пересадкой некровоснабжаемой фаланги пальца стопы. При ходьбе не наблюдалось явных признаков нарушения двигательных функций оперированной стопы.

***Заключение.*** Объективно подтверждено, что заимствование некровоснабжаемых фаланг пальцев стопы для их последующего перемещения на кисть не оказывает существенного влияния на форму и статодинамическую функцию стопы в отдаленном периоде наблюдения, несмотря на укорочение донорских пальцев стопы.

**Ключевые слова:** кисть, пороки развития, аутотрансплантация, свободная костная пластика, транспозиция фаланги, пальцы стопы, некровоснабжаемый трансплантат, биомеханическое исследование, дети.

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*Матвеев Павел Андреевич*; e-mail: p-matveyev@narod.ru

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## BACKGROUND

The reported literature presents various methods of reconstructive plastic surgery that are used in the treatment of congenital hand underdevelopment (brachydactyly, ectrodactyly, and hypoplasia) and acquired hand deformities, characterized by decreased linear and volumetric parameters and decreased number of hand segments, which lead to significant functional and cosmetic upper limb disorders [1]. Reconstruction methods include microsurgery [2], compression-distraction osteosynthesis [3, 4, 5, 6], various types of skin, tendomuscular, and bone grafting [6, 7], and prosthetics [8]. Concurrently, a less common, but effective and affordable variant of bone grafting for restoring hand functionality and cosmetic condition is known, which includes autografting of non-vascularized toe phalanges [9, 10, 11, 12].

The method for autografting of non-vascularized toe phalanges gained popularity in the early 20th century. The phalanges of the fingers deformed due to tuberculosis infection or enchondroma were resected and replaced with non-vascularized toe phalanges, and grafts from the costal cartilage were transplanted into the resulting defects in the donor areas of the toes. During the follow-up examination of patients after a year, there were no major cosmetic or functional defects in the donor's toes and recipient's fingers, the position of the bone grafts was satisfactory on the radiographs, the epiphyses in the formed fingers were congruent, and no signs of resorption were noted [9, 10]. New cases of finger reconstruction using the toe phalanges have also been reported in some studies [11, 12, 13].

The method for autografting of non-vascularized toe phalanges in congenital hand maldevelopment became more widely known in 1990 after the study of 57 patients who had undergone 97 phalanx transplantations since 1976 [14, 15].

Gradually, new studies on the transplantation of non-vascularized toe phalanges to the hand have been conducted. These studies revealed that autografting of non-vascularized toes in the case of the hand underdevelopment improves its appearance and function [16, 17, 18, 19], provides an opportunity for toe growth due to the growth zone of the transplanted phalanx [18, 20, 21, 22], is characterized by low-injury rate for the donor foot [16, 22, 23] and has a minimal resorption risk of the transplanted graft [21, 22, 23, 24].

Concurrently, the long-term effect of phalanx transplantation on the appearance and functionality of the donor foot remains relevant. Several have reported the clinical studies on donor feet of patients after harvesting non-vascularized phalanges [16, 17, 22, 25]. Donor toe shortening, flexibility, and instability were registered in several cases. However, we did not find any information about the study of the feet, which would enable us to objectively assess (using instrumental methods) the degree of phalanx transplantation affecting the change in the shape and function of the foot after harvesting phalanges for autografting to the hand.

The study objectively assessed the appearance, shape, and functional state of the foot at the long-term period after harvesting non-vascularized finger phalanges and their subsequent transplantation to replace the defects of the fingers in congenital and acquired pathologies.

## METHODS

### Study design

This prospective single-center observational study of the effect of harvesting non-vascularized toe phalanges (for transplantation into a finger defect) on the anatomical and functional state of the foot was conducted at the clinic of the G.A. Albrecht Federal Scientific Center of Rehabilitation of the Disabled of the Ministry of Labor of Russia.

### Patients

This study examined 40 patients (21 boys and 19 girls), who underwent 54 phalanx transplantations for hand underdevelopment (ectrodactyly, brachydactyly, and hypoplasia) and acquired hand deformities from 2013 to 2022 at the ages of 8 months to 11 years, including 2 children aged under 1 year, 22 pediatric patients aged 1–3 years, 11 patients aged 3–7 years, and 5 children aged 7–11 years). Proximal or middle phalanxes of the toes IV or II were used for transplantation, focusing on linear and volumetric dimensions of the suspected defect in the recipient zones (Table 1). Table 2 presents the distribution of recipient zones in patients by localization on the hand.

*Table 1*

**Distribution of donor zones during transplantation of non-vascularized toe phalanges to the hand**

| Toe | Localization of donor zones | | Total |
|---|---|---|---|
| | Proximal phalanges | Middle phalanges | |
| II | 2 | 7 | 9 |
| IV | 26 | 19 | 45 |
| Total | 28 | 26 | 54 |

*Table 2*

**Localization of the recipient zone during transplantation of non-vascularized phalanges of the toes to the hand**

| Hand ray | Localization of recipient zones | | | Total |
|---|---|---|---|---|
| | Metacarpal bones | Proximal phalanges | Middle phalanges | |
| I | 8 | 8 | – | 16 |
| II | – | 5 | 7 | 12 |
| III | – | 6 | 4 | 10 |
| IV | – | 3 | 6 | 9 |
| V | – | 5 | 2 | 7 |
| Total | 8 | 27 | 19 | 54 |

## Results assessment

We performed a clinical examination, the Oxford Ankle Foot Questionnaire Children (OAFQ-C) for subjective assessment of the patient's foot postoperatively and the identification of complaints of impaired support ability [26, 27]. We also performed an X-ray examination to assess their foot condition in the long-term period. The long-term follow-up period ranged from 1 to 8 years postoperatively (49 of 54 cases of harvesting of the toe phalanges), with an average of 3.04±1.20 years, up to 3 years in 18 cases, 3–6 years in 28 cases, and ≥6 years in 3 cases.

The following instrumental studies were conducted on 12 patients aged ≥3 years, who underwent surgery at least 6 months before the examination [28]:

– computer plantography and podometry by the three-coordinate optical plate scanning method of the feet using the hardware and software package (HSP) Scan (registration certificate No. FSR 2010/07441 dated 04/22/2010) with the calculation of parameters reflecting the foot shape;

– barodynamic plantography on the HSP with matrix underfoot pressure meters in the form of insole HSP DiaSled (registration certificate No. FSR 2009/06416 dated 26.02.2010) to assess the statodynamic function of the foot.

Among 12 patients, 4 had previously undergone phalanx transplantation of both feet. One patient underwent transplantation of the main phalanges of toe IV, two patients of the middle phalanges of toe IV, one patient of the main phalanx of toe IV of the left foot and the middle phalanx of toe IV of the right foot, one patient of the middle phalanx of toe II of the right foot, three patients of the main phalanx of toe IV, and seven patients of the middle phalanx of toe IV. Concurrently, one patient underwent plantography and podometry twice, which was a year after the middle phalanx transplantation of toe IV of the right foot, and 2 years after the examination and a year after the middle phalanx transplantation of toe IV of the left foot.

The effect of autografting of non-vascularized toe phalanges on the statodynamic function of the foot was studied using the barodynamic

plantography method using the HSP DiaSled under static conditions (standing) and when walking in standard shoes. Patients with a foot size of at least 190 mm were examined for the available size range of measuring sensors in the form of insoles with pressure sensors. Therefore, 7 of 12 patients were examined using the DiaSled complex who underwent plantopodometry. The measuring sensors were inserted into the shoes for the examination, which minimally affected the foot function.

## Statistical analysis

Descriptive statistics of quantitative indicators were calculated using the IBM Statistical Package for the Social Sciences version 23.0 system for the entire traditional set of characteristics (mean value, scatter of data [standard deviation], minimum, maximum, median, and quartiles, as well as coefficients of variation of the study characteristics for a group of patients were examined by biomechanical methods).

## RESULTS

Forty operated patients were distributed into four groups based on the degree of shortening of the donor toes compared with the contralateral foot by performing physical examination of the feet (Fig. 1). The middle phalanx of toes II or IV was harvested in 78% of children without shortening or with minor shortening of the donor toes. One child underwent middle phalanx transplantation of toe II, while the rest of the proximal phalanges of toe II (1 patient) or toe IV (6 patients), in the group of patients with moderate shortening of the donor toe (8 children). The main phalanx of toe IV was previously harvested in the 11 children with a pronounced toe shortening (by >1 nail plate).

The distribution of 49 cases according to the degree of shortening of donor toes after harvesting of non-vascularized phalanges for transplantation to the hand revealed nil, minimum, moderate, and pronounced shortening in 12 (24.5%), 18 (36.7%), 8 (16.3%), and 11 (22.5%) patients, respectively.

## Questionnaire score

None of the patients or their parents expressed regret after the surgery despite the noted toe shortening. They did not notice any visible changes in gait after the treatment. During the Oxford Ankle Foot Questionnaire, parents of 4 children (one 1-year-old boy and three 6–10-year-old girls) noted a little discomfort by the foot appearance.

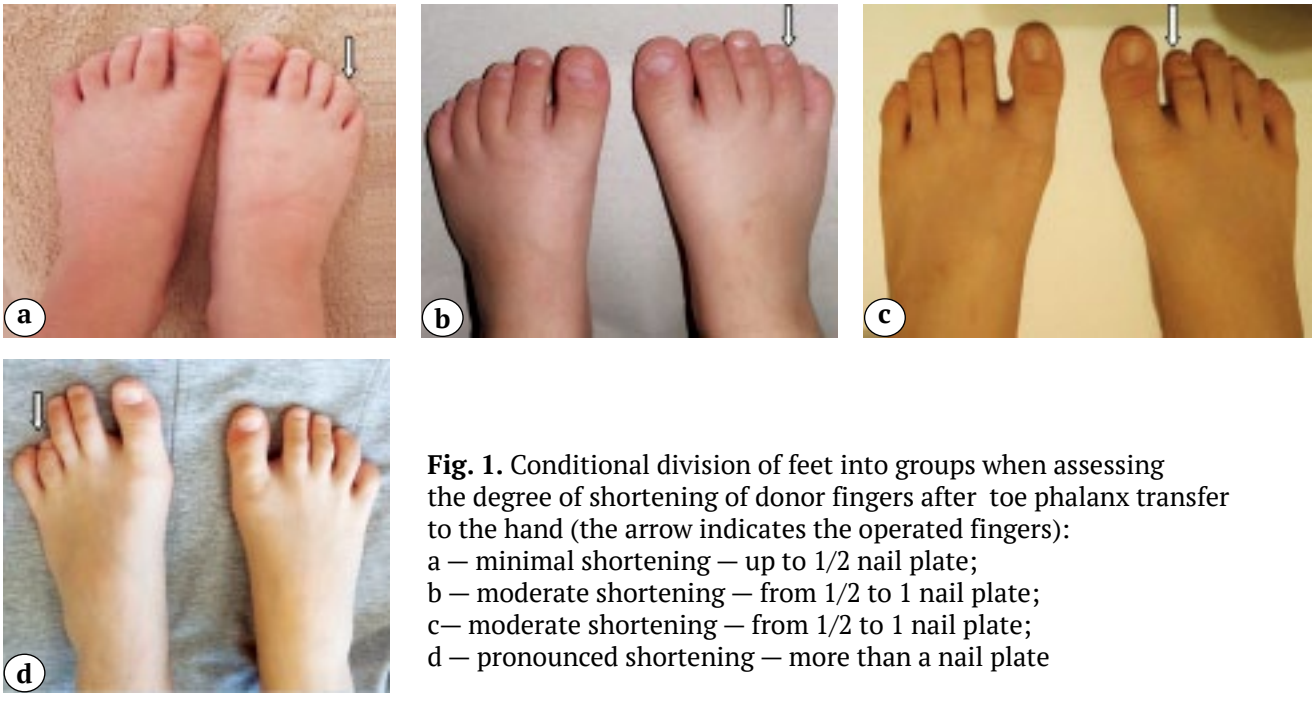



**Fig. 1.** Conditional division of feet into groups when assessing the degree of shortening of donor fingers after toe phalanx transfer to the hand (the arrow indicates the operated fingers):
a — minimal shortening — up to 1/2 nail plate;
b — moderate shortening — from 1/2 to 1 nail plate;
c— moderate shortening — from 1/2 to 1 nail plate;
d — pronounced shortening — more than a nail plate

## Planto-podometric study

To assess the foot shape in 12 pediatric patients, using the planto-podometric study based on the graphic calculation analysis of the plantogram (an imprint of the plantar surface, reflecting the inclusion of foot zones in the perception of static load, as well as signs of local overloads of the plantar surface) and podometric images in projection onto three orthogonal planes, the following parameters characterizing the foot shape were evaluated (Fig. 2):

1) *Chopart joint angle* ($\alpha_1$) characterizes the lateral deviation of the midfoot, formed by two rays originating from a point located on the outer contour of the foot image below at the level of 0.36-foot length from the heel (which corresponds to the level of the calcaneocubital joint). One of which is directed forward and passes through the most laterally protruding point of the foot contour in the bundled region, and the other is directed backward and passes through the most protruding point of the foot contour in the heel region;

2) *Angle of the toe I deviation* ($\alpha_2$) characterizes the presence and severity of hallux valgus and represent an angle between the tangent to the contour of the main part of the foot on the medial side and the tangent to the toe contour on the same side;

3) *Forefoot coefficient* ($k_1$) characterizes the forefoot position (adduction or abduction) relative to the hindfoot and is calculated as the ratio of the width of the medial part of the line of bundles to the width of the lateral part of this line;

4) *Coefficient of the forefoot flatness* ($k_2$) characterizes the degree of the forefoot flattening and is calculated as the ratio of the foot width at the level of bundles to the foot length;

5) *Height of tuberosity of the navicular bone* (G′) characterizes the height of the internal longitudinal arch, but it reflects the arch pronouncement only indirectly because it also depends on the foot length, which correlates with the patient's age and is defined as the distance from the plane of support to the lower edge of the navicular bone tuberosity;

6) *Podometric index* (p) characterizes the pronouncement of the internal longitudinal arch of the foot; calculated as the ratio of the height of the navicular bone tuberosity to the foot length;

7) *Angle of valgus or varus deviation of the hindfoot* (β) characterizes the position of the hindfoot in the frontal plane and is calculated as the angle between the vertical and the median line of the hindfoot, connecting the middle of the Achilles tendon and the middle of the supporting surface of the heel.

A more detailed definition of these HSP Scan parameters is presented in the methodological manual [28].

The coefficient of interlimb asymmetry of the foot shape was calculated by correlating the parameter value obtained when measuring one foot with the value of the contralateral foot for each of these parameters. Here, the lower value was always divided by the larger one for a more demonstrational comparison of the obtained results when examining different patients (Table 3).

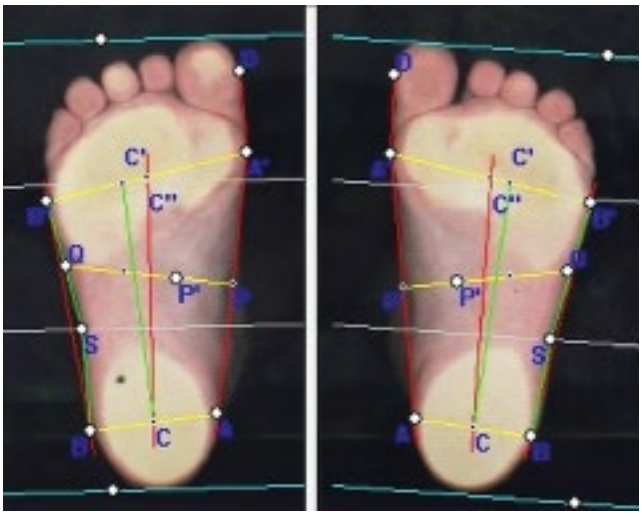



**Fig. 2.** A plantogram combined with a podometric image of the feet from below, of patient at the age of 5, 3.5 years after the middle phalanx of the IV finger of the right foot transfer and 1 year after a similar surgery on the left foot: no signs of the feet shape asymmetry were revealed

*Table 3*

**Descriptive statistics of the assessment of interlimb asymmetry of the foot shape in the group of operated patients, n = 12**

| Statistical parameter | Coefficient of interlimb asymmetry of planto-podometric parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | $K_{\alpha 1}$ | $K_{\alpha 2}$ | $K_{k1}$ | $K_{k2}$ | $K_{G'}$ | $K_p$ | $K_\beta$ |
| Mean value ($\bar{M}$) | 0.99 | 0.55 | 0.79 | 0.98 | 0.85 | 0.84 | 0.68 |
| Standard deviation (m) | 0.02 | 0.35 | 0.21 | 0.02 | 0.14 | 0.14 | 0.19 |
| Median (Me) | 0.99 | 0.53 | 0.90 | 0.98 | 0.88 | 0.88 | 0.71 |
| Coefficient of variation (Cv), % | 1.6 | 64.5 | 27.1 | 1.8 | 16.1 | 16.3 | 28.0 |

A significant asymmetry of the plantographic and podometric parameters of the donor and contralateral feet in the group of patients was revealed only for two parameters, including the angle of deviation of the toe I ($\alpha_2$) and the angle of the frontal deviation of the hindfoot (β). Such asymmetry of these parameters in the group ($\bar{M}[K_{\alpha 2}] = 0.55$; $\bar{M}[K_\beta] = 0.68$) is accompanied by their pronounced variability ($Cv[K_{\alpha 2}] = 64.5\%$; $Cv[K_\beta] = 28.0\%$). A particularly pronounced asymmetry of the angle of deviation of the toe I of the donor and non-operated foot in a case was due to the congenital syndactyly of rays I-II of the donor foot in the patient. The patients' data were evaluated individually and in the group to clarify whether the detected asymmetry of the foot shape on an average was associated with the previous surgery (Table 4).

*Table 4*

**Results of planto-podometric examination of patients**

| No. | Donor foot | | Age, years | $\alpha_1$, deg. | | | $\alpha_2$, deg. | | | $k_1$ | | | $k_2$ | | | G′, mm | | | p, % | | | β, deg. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | R | | L | R | Cs | L | R | Cs | L | R | Cs | L | R | Cs | L | R | Cs | L | R | Cs | L | R | Cs |
| 1 | | + | 4 | 176 | 168 | 0,95 | -2 | -2 | 1,00 | 1,65 | 1,00 | 0,61 | 0,42 | 0,41 | 0,97 | Unmeasurable | | | | | | 4 | 3 | 0,75 |
| 2 | | + | 4 | 170 | 163 | 0,96 | 9 | 9 | 1,00 | 0,59 | 0,67 | 0,89 | 0,43 | 0,42 | 0,96 | 19 | 19 | 1,00 | 11,31 | 11,52 | 0,98 | 4 | 5 | 0,80 |
| 3 | + | + | 5 | 171 | 173 | 0,99 | 11 | 10 | 0,91 | 1,63 | 1,47 | 0,90 | 0,45 | 0,46 | 0,98 | 23 | 22 | 0,96 | 12,04 | 11,46 | 0,95 | 11 | 11 | 1,00 |
| 4 | | + | 5 | 169 | 171 | 0,99 | 7 | **14** | **0,50** | 1,22 | 1,23 | 0,99 | 0,41 | 0,39 | 0,95 | 36 | 22 | 0,61 | 21,3 | 12,72 | 0,6 | 7 | 8 | 0,88 |
| 5 | + | + | 5 | 170 | 171 | 0,99 | **12** | 9 | **0,75** | 0,79 | 0,87 | 0,91 | 0,45 | 0,43 | 0,97 | 26 | 18 | 0,69 | 14,77 | 10,17 | 0,69 | 3 | 2 | 0,67 |
| 6 | + | | 6 | 172 | 171 | 0,99 | **11** | 2 | **0,18** | 0,76 | 0,77 | 0,98 | 0,42 | 0,41 | 0,98 | 49 | 45 | 0,92 | 24,26 | 22,39 | 0,92 | 5 | 4 | 0,80 |
| 7 | + | | 7 | 169 | 169 | 1,00 | **-4** | 1 | **0,25** | 1,11 | 1,05 | 0,95 | 0,39 | 0,41 | 0,97 | 25 | 26 | 0,96 | 12,69 | 13,27 | 0,96 | 2 | 5 | 0,40 |
| 8 | + | + | 7 | 170 | 168 | 0,99 | 1 | 9 | 0,11 | 0,92 | 1,00 | 0,92 | 0,36 | 0,36 | 1,00 | 38 | 28 | 0,74 | 18,27 | 13,27 | 0,73 | 5 | 4 | 0,80 |
| 9 | + | | 9 | 170 | 170 | 1,00 | 9 | **16** | 0,56 | 1,08 | 0,95 | 0,89 | 0,42 | 0,42 | 1,00 | 38 | 33 | 0,87 | 18,54 | 15,79 | 0,85 | 5 | 2 | 0,40 |
| 10 | + | + | 9 | 176 | 173 | 0,98 | -2 | -1 | 0,50 | 0,7 | 1,33 | 0,52 | 0,4 | 0,4 | 1,00 | 8 | 7 | 0,88 | 3,09 | 2,71 | 0,88 | 5 | 3 | 0,60 |
| 11 | | + | 10 | 173 | 173 | 1,00 | 9 | 11 | 0,82 | 0,5 | 1,13 | 0,44 | 0,38 | 0,38 | 1,00 | 37 | 38 | 0,97 | 16,59 | 17,04 | 0,97 | 2 | 1 | 0,50 |
| 12 | + | | 13 | 171 | 171 | 1,00 | 2 | 0 | 0,00 | 0,38 | 0,84 | 0,46 | 0,4 | 0,41 | 0,99 | 27 | 19 | 0,70 | 11,64 | 7,98 | 0,69 | 7 | 4 | 0,57 |

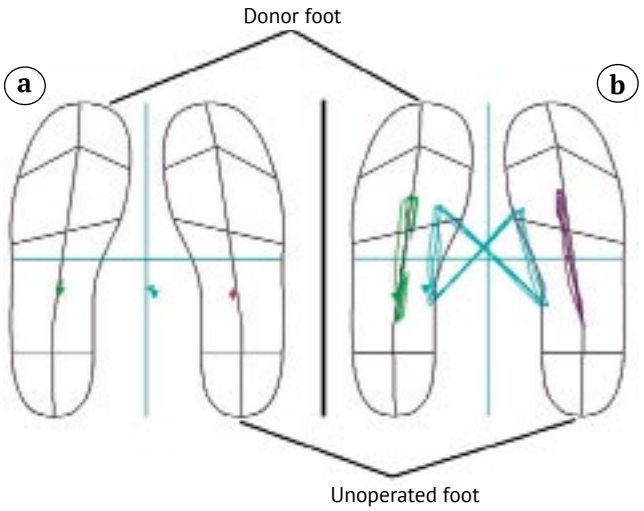
L — left foot; R — right foot; Cs — symmetry coefficient; bold font indicates the values of the operated foot parameters that are beyond the normal range in case there is also a significant asymmetry of the parameter when comparing both feet.

We paid special attention to the cases when the parameter values of the operated foot were beyond the normal range with the presence of asymmetry compared with the contralateral foot, which could indicate a pathological change as a result of surgery.

Data of patients 4 and 7 were noteworthy when analyzing the results of the deviation angle of the toe I. Valgus deviation of toe I on the operated foot was noted in patients 4 and 6, both the feet were donors in pediatric patient 5, and the deviation was on one of them (up to 12°). Varus deviation (up to 4°) was noted in toe I of patient 7 instead of valgus deviation. Additionally, patient 9 had a valgus deviation in toe I up to 16° on the contralateral foot. However, this is not regarded as a negative impact of surgery on the foot shape because a deviation from the norm for these patients was detected in the donor and contralateral limbs.

An analysis of the deviation parameters of the hindfoot showed that the results were within the reference values in most patients and slightly exceeded the norm in some cases.

A planto-podometric study of the operated and contralateral feet did not reveal any changes in other parameters (Chopart joint angle, arch height, coefficients and flattening of the forefoot, and podometric index), which could be directly related to the transplantation of the non-vascularized toe phalanges.




## Barodynamic and plantographic examinations

The position and migration of the trajectory of the underfoot pressure center were analyzed during the examinations (Fig. 3).

The assessment in statics identified the displacement of the general load center in the frontal plane, which characterizes the support function of the lower limb. Concurrently, we did not reveal a support preference for a healthy limb, which would indirectly indicate a decrease in the static support ability of the donor foot.

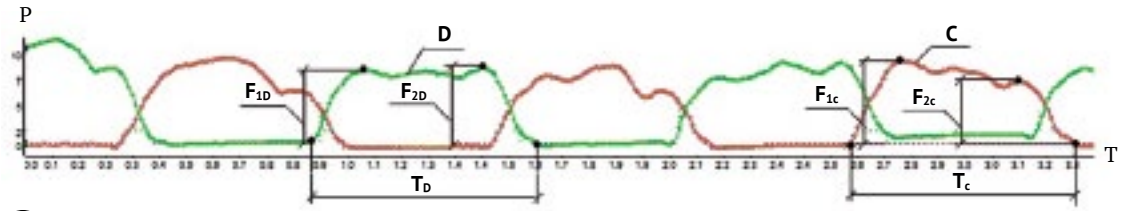
The study of patients' gait also included the measurement and analysis of asymmetry of the duration of the rolling motion on the donor ($T_d$) and contralateral feet ($T_c$), the anterior push forces ($F_{1d}$ and $F_{1c}$), and the posterior push forces ($F_{2d}$ and $F_{2c}$) (Fig. 4).

The interlimb asymmetry was assessed by correlating the parameter value obtained for the donor foot to the value of the contralateral one for each of the biomechanical parameters.

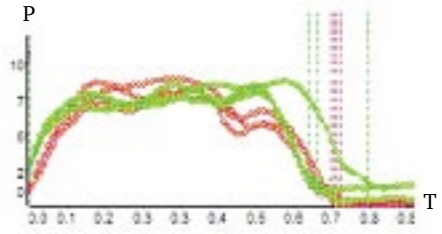
The barodynamic and plantographic examination results are presented individually because of the small group of examined patients (Table 5).

In 5 out of 7 pediatric patients examined, one foot was donor and the other foot was intact, which enabled us to compare them with each other to identify changes in the biomechanical characteristics of the operated foot. A decrease in the forces of the anterior and posterior push in the rolling motion ($F_1$ and $F_2$) and the rolling duration (T) of the donor foot was detected and compared with the contralateral one in 2 (No. 1 and No. 3) out of these 5 patients; whereas the reverse presentation was noted in 1 patient (No. 2). Concurrently, no significant decrease was found in the involvement of the donor forefoot (no decrease in the trajectory length of the pressure center in the forefoot area was detected), as well as a zonal or local overload of the operated or contralateral forefoot.

**Fig. 3.** Load distribution in the supporting contour of the feet of patient B. at the age of 9 years, 3 years after the the middle phalanx of the IV finger of the left foot transfer:
a — the position of the pressure centers in static;
b — migration of the trajectory of the pressure center when walking




a




b

**Fig. 4.** Measurement of the load on the feet when walking patient at the age of 9 years, 3 years after the middle phalanx of the 4th toe of the left foot transfer:
a — in the mode of viewing the sequential display of graphs of the integral load on the feet in time by steps;
b — in the mode of transposition (overlapping) graphs of the integral loads in steps.
*Designations*: T — duration of rolling over the foot, sec; $F_1$ — force of anterior thrust; $F_2$ — posterior; D — donor foot; C — contralateral foot; P — pressure under the feet, conventional units

## DISCUSSION

Autografting of non-vascularized toe phalanges improves the appearance and function of the hand by restoring the finger anatomy by transplanting the toe phalanx into the finger defect; however, according to some authors, it negatively impacts the appearance of the donor feet, worsens the quality of life due to difficulties with the selection and wearing of shoes and causes emotional problems [17, 25]. Concurrently, changes in gait, associated with toe phalanges transplantation, were not observed [16, 22].

An interesting clinical and radiological study by Garagnani et al., showed that changes in donor sites in 40 patients with underdevelopment of the fingers after 136 toe phalanges transplantations with extensor tendon restoration after the phalanx harvesting was performed from 1991 to 2007. The Oxford Ankle Foot Questionnaire study, which reflects the degree of satisfaction of patients and their parents was carried out, and X-rays were examined. Patients reported a tendency to hide their feet, where >80% of patients and their legal representatives reported some degree of emotional problems related to their feet and >60% of patients noted problems with the selection and wearing of the shoes. From a clinical perspective, the shortening of donor toes was individual, and excessive mobility was registered in 76%–100% of cases; thus, the increase in clinical deformity of the donor feet was expected during the harvest of several phalanges from one foot. X-ray examination also revealed hypoplasia of the surrounding bone structures, including the distal phalanx, the middle phalanx, and the metatarsal. One patient underwent amputation of toe IV of both feet due to their instability and to improve the appearance of the feet [25].

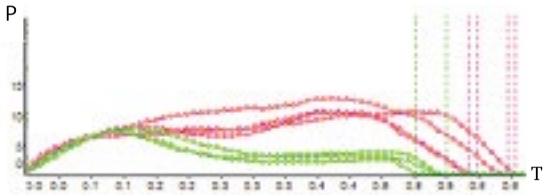
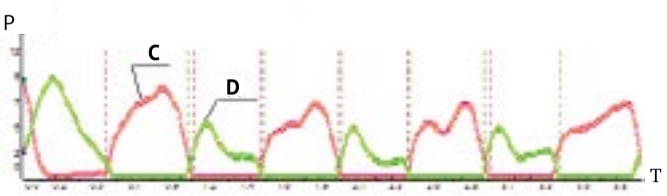
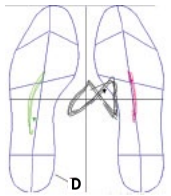
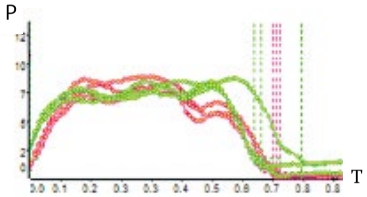
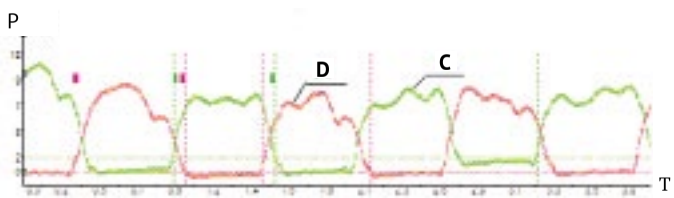
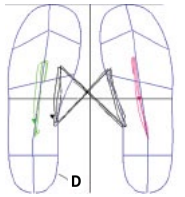
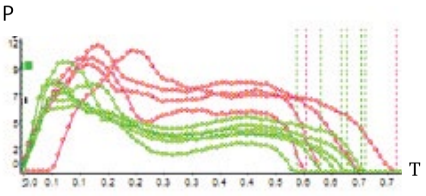
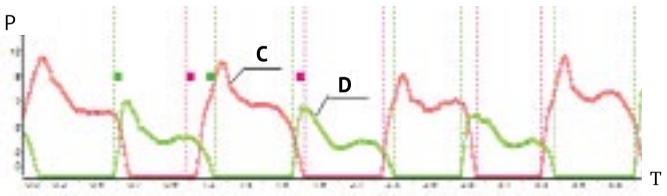
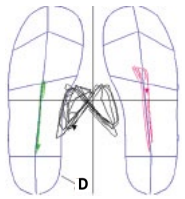
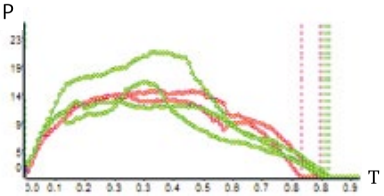
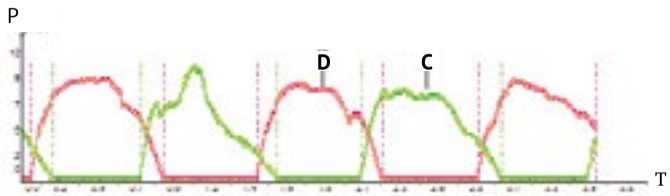
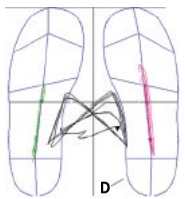
Bone autografting of the formed defect [10, 15, 16, 17], as well as suturing together the flexor and extensor tendons of the toe [14], or fixation of the toe for 4–5 weeks with preservation of diastasis, was performed to prevent donor toe shortening and deformity [14, 17]. Concurrently, the foot is compromised to the least extent during bone autografting; however, there is a risk of graft lysis, and an absence of mobility in the toe is also noted [16, 17].

Unglaub et al. followed up cases of linear shortening of donor toes in the previously operated patients, who did not significantly affect their gait [22].

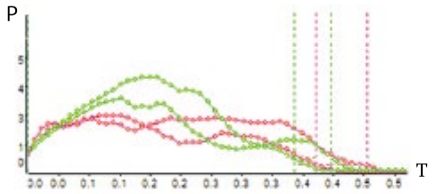
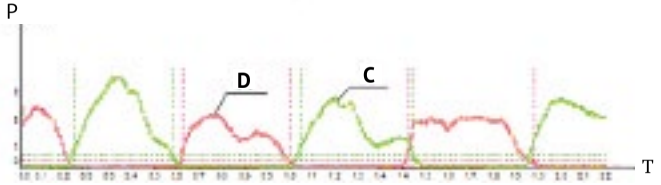
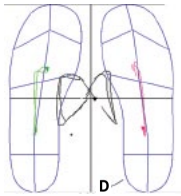
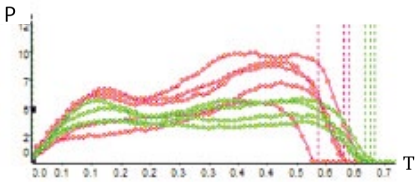
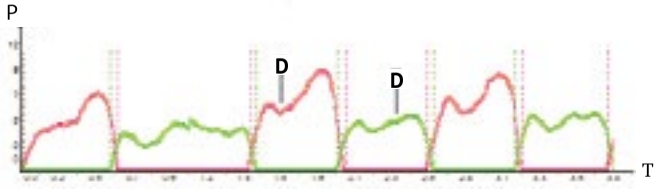
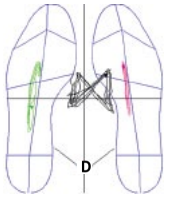
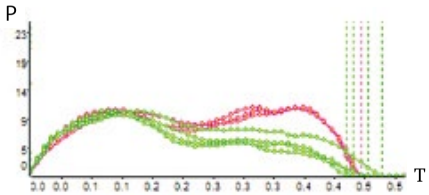
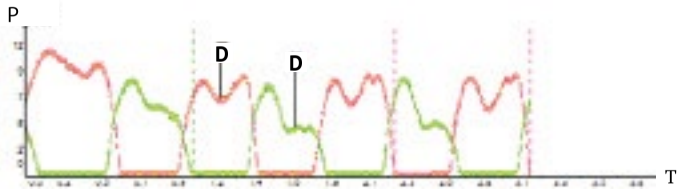
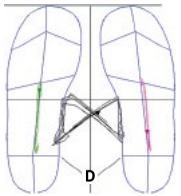
In reliance on the literature available, we conducted a study of the state of the donor feet in patients in the long-term period postoperatively after the harvesting of non-vascularized phalanges.

*Table 5*

**Results of barodynamic and plantographic examination of 7 patients aged 6–13 y.o.**

| No. | Age at the time of examination | Time after surgery | Graphs of the integral load in the superposition mode by steps | Change in the total load on the feet when walking | Migration of the pressure center trajectory |
|---|---|---|---|---|---|
| 1 | 13 years | 2 years |  |  |  |
| 2 | 9 years | 3 years |  |  |  |
| 3 | 6 years | 4 years |  |  |  |
| 4 | 7 years | 7.5 years |  |  |  |

*End of the table 5*

| No. | Age at the time of examination | Time after surgery | Graphs of the integral load in the superposition mode by steps | Change in the total load on the feet when walking | Migration of the pressure center trajectory |
|---|---|---|---|---|---|
| 5 | 10 years | 9 years |   |   |   |
| 6 | 9 years | One year on the left foot, 6 months on the right foot |   |   |   |
| 7 | 7 years | 3 years on the right foot, 2 years on the left foot |   |   |   |

D — donor foot; C — contralateral foot; P — pressure under the feet, conventional units; T — duration of rolling over the foot, sec.

A survey of patients and their legal representatives using the Oxford Ankle Foot Questionnaire did not reveal complaints about impaired support and gait, pain, limitations in wearing shoes, and emotional problems due to the appearance of toes although our clinical and radiological examination confirms the authors' findings on the linear shortening of the donor toes (more significant shortening was detected in those pediatric patients whose proximal phalanx was harvested). Our study was supplemented by an instrumental biomechanical assessment of donor and contralateral feet and revealed no significant changes in their shape and statodynamic function in the long-term period after harvesting the toe phalanges for autografting to the hand.

## Study limitations

The result interpretation of the biomechanical examination of the patients' feet was small sample size. Also, limited data availability (four reported studies) determined the relevance of further studies of this issue.

## CONCLUSION

The computer plantography and podometry results showed that the data obtained on the effects of non-vascularized phalanx transplantation of the toes on pathological changes in the longitudinal arch, adduction/abduction of the middle or anterior segments, flattening of the anterior segment, or valgus/varus angulation of the posterior segment of the operated foot were not statistically significant. Additionally, no significant changes were revealed in the statodynamic function of the operated foot in the long-term period after harvesting the toe phalanges for transplantation to the hand, according to the barodynamic and plantographic examination results.

The method for autografting of non-vascularized toe phalanges can be used for finger reconstruction without the risk of pronounced impairment in the statodynamic function of the donor zones. However, the data array available for examination, which is less due to the low incidence of pathology and its surgical treatment using the study method, makes it expedient to further follow-up the condition of the feet in a larger number of patients and for longer periods postoperatively.

## DISCLAIMERS

### *Author contribution*

*Matveev P.A.* — research conception and design, literature review, the collection and processing of data, data statistical processing, text writing and editing.

*Shvedovchenko I.V.* — the collection and processing of material, text writing and editing.

*Smirnova L.M.* — research conception and design, processing of data, text writing and editing.

*Koltsov A.A.* — the collection and processing of data, text writing and editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Competing interests.*** The authors declare that they have no competing interests.

***Ethics approval.*** The study was approved by the local ethics committee of Federal Scientific Center of Rehabilitation of the Disabled named after G.A. Albrecht, protocol No 1, 02.06.2022.

***Consent for publication.*** Written consent was obtained from legal representatives of children for publication of relevant medical information and all of accompanying images within the manuscript.

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## Authors' information

✉ *Pavel A. Matveev*
Address: 50, Bestuzhevskaya str., St. Petersburg, 195067, Russia
https://orcid.org/0000-0002-0455-740X
e-mail: p-matveyev@narod.ru

*Igor V. Shvedovchenko* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0003-4618-328X
e-mail: schwed.i@mail.ru

*Lyudmila M. Smirnova* — Dr. Sci. (Tech.)
https://orcid.org/0000-0003-4373-9342
e-mail: info@diaserv.ru

*Andrey A. Koltsov* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-0862-8826
e-mail: katandr2007@yandex.ru

Case Report
https://doi.org/10.17816/2311-2905-1804



# Ceramic Liner Fracture in Total Hip Arthroplasty: A Case Report

Baikozho R. Tashtanov [1], Andrey A. Korytkin [1], Vitalii V. Pavlov [1], Igor I. Shubnyakov [2]

[1] *Tsivyan Novosibirsk Research Institute of Traumatology and Orthopaedics, Novosibirsk, Russia*

[2] *Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russia*

***Background.*** Ceramic component fracture is a severe complication of primary and revision total hip arthroplasty, leading to multiple revision surgeries.

***Case report.*** This report of rare clinical case of ceramic liner fracture. Fifteen months after a planned left hip replacement, the patient experienced anterior surface pain in the area of the operated joint accompanied by creaking, so the patient went for a consultation. Based on the results of the consultation, the patient was urgently hospitalized and underwent a delayed surgery for revision arthroplasty. Radiologically, there was varus position of the femoral component, dislocation of the bearings. MSCT showed ceramic liner fracture and fragment dislocation. Intraoperatively, the multifragmentary fracture of the liner, significant damage to the head, and retroversion of the acetabular component (retroversion was detected on the preoperative CT scan) were identified. All components of the endoprosthesis and tribologic bearings were replaced with identical ones, total synovectomy was performed, and the wound was cleaned and sanitized.

***Conclusion.*** The presented case report demonstrates the danger of incorrect positioning of the components when using a ceramic bearings. In this case, retroversion of the acetabular component and varus position of the femoral component resulted in a reduced contact area between the head and the liner, which caused the ceramic to fracture. The described observation confirms the need for further in-depth study of the ceramic bearings in order to prevent ceramic component fracture, as it leads to severe complications and significant economic costs.

**Keywords:** total hip arthroplasty, ceramic bearings, ceramic liner fracture, acetabular component retroversion, revision hip arthroplasty.

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✉ Baikozho R. Tashtanov; e-mail: b.tashtanov95@gmail.com

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# Раскол керамического вкладыша эндопротеза тазобедренного сустава: клинический случай

Б.Р. Таштанов [1], А.А. Корыткин [1], В.В. Павлов [1], И.И. Шубняков [2]

[1] *ФГБУ «Новосибирский научно-исследовательский институт травматологии и ортопедии им. Я.Л. Цивьяна» Минздрава России, г. Новосибирск, Россия*

[2] *ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

***Актуальность.*** Раскол керамических компонентов является тяжелым осложнением первичного и ревизионного тотального эндопротезирования тазобедренного сустава, приводящим к многократным ревизионным операциям.

***Описание клинического наблюдения.*** Представляем редкий клинический случай раскола керамического вкладыша. Через 15 мес. после проведения планового эндопротезирования левого тазобедренного сустава у пациента появились боли по передней поверхности в области оперированного сустава, сопровождающиеся скрипами, вследствие чего пациент обратился за медицинской помощью. По результатам консультации пациент был экстренно госпитализирован и прооперирован в отсроченном порядке в объеме ревизионного эндопротезирования. Рентгенологически отмечались варусное положение бедренного компонента, дислокация пары трения. По данным МСКТ выявлены раскол керамического вкладыша и дислокация фрагментов. Интраоперационно обнаружены мультифрагментарный раскол вкладыша, значительное повреждение головки. На дооперационной КТ была выявлена ретроверсия вертлужного компонента. Выполнены замена всех компонентов эндопротеза и трибологической пары на идентичную, тотальная синовэктомия, рана промыта и санирована.

***Заключение.*** Представленный клинический случай демонстрирует опасность неправильного положения компонентов при использовании керамической пары трения. В приведенном наблюдении ретроверсия вертлужного компонента и варусное положение бедренного компонента привели к уменьшению площади контакта головки и вкладыша, что повлияло на раскол керамики. Описанное наблюдение подтверждает необходимость дальнейшего изучения керамической пары трения с целью профилактики раскола керамических компонентов, так как это приводит к тяжелым осложнениям и значительным экономическим затратам.

**Ключевые слова:** эндопротезирование тазобедренного сустава, керамическая пара трения, раскол керамического вкладыша, ретроверсия вертлужного компонента, ревизионное эндопротезирование тазобедренного сустава.

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*Таштанов Байкожо Рустамович*; e-mail: b.tashtanov95@gmail.com

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## BACKGROUND

Total hip arthroplasty (THA) is currently one of the most frequent surgical interventions in orthopedics. THA has proven as the most effective treatment method in the final stages of hip pathology. One of the main problems of THA is the choice of bearings because the chosen bearings determine the long-term surgical efficiency. At the moment, we have a wide variety of bearings, such as metal-polyethylene (Met-Pe), metal-metal (Met-Met), ceramic-polyethylene (Ce-Pe), ceramic-ceramic (Ce-Ce), and ceramized metal-polyethylene (CerMe-Pe). Met-Pe and Met-Met bearings did not show the best long-term results and manifested themselves as osteolysis due to the presence of friction products thus, in 1970, Boutin et al. proposed Ce-Ce bearings as an alternative to reduce wear and their consequences [1]. The advantages of ceramics are their high wear resistance and optimal biocompatibility, which determines their potential advantages in the long-term when used in young and active patients [2, 3]. However, these bearings were easily fractured due to their fragility, thereby requiring their improvement [4, 5]. The third-generation aluminum ceramics (Forte) are continuously used to date, and the use of fourth-generation aluminum-zirconium composite ceramics has markedly increased (Biolox Delta, CeramTec). The third-generation ceramics showed good serviceability of 95-98% in the long-term follow-up, but their component fragility remained the main problem, as fractures accounted for up to 0.2% of all cases of installed prostheses with ceramics [6]. Biolox Delta ceramics are characterized by a significant increase in tool life and, according to the national registers of England, South Korea, and Norway, the head has become more resistant to fractures, but the destruction rates of the liner remain at the same level, averaging 0.2%, which is 1-2 cases per 1000 [7, 8, 9].

According to the Vreden Center of Traumatology and Orthopedics, in the Russian Federation in 2019, more than 88.5 thousand primary and revision hip arthroplasties were performed, which amounted to 61.3 per 100 thousand population. Concurrently, the share of the Ce-Ce bearings in primary hip arthroplasty is relatively small. The number of cases of its use significantly fluctuated from 2008 to 2020, ranging from 0.5% to 8.2% of the total number of surgeries in different years, but reached 30% in the age group under 30 years [10].

The available Russian literature revealed no reports or descriptions of cases of ceramic liner fracture. The ratio of these complications to survival rate may seem insignificant, but the consequences can be disastrous in the case of improper therapy approach to patients with a fracture. A ceramic liner fracture is often asymptomatic and is not associated with trauma, or it manifests itself only as a creak [11].

This study aimed to describe a rare case in our practice, namely a fracture of a ceramic liner Biolox Delta.

## Case report

A 46-year-old patient, with a weight of 115 kg, height of 184 cm, and body mass index of 34, was admitted on February 4, 2022, to the consultative and diagnostic department of Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics with complaints of noise (crepitus), soreness, and movement limitation in the left HIP, which have been persisting for a week.

In January 2020, the patient was operated on for a road traffic injury, which resulted in a closed fracture of the left proximal femoral metaepiphysis without type A1 displacement. Osteosynthesis was performed with a dynamic hip screw (DHS). In October 2020, primary THA was performed with a proximal fixation endoprosthesis using ceramic bearings due to the avascular necrosis of the left femoral head. The femoral component of Zimmer ML Taper 13.5, an acetabular component of Zimmer Continuum of 60 mm, ceramic head of 36 mm, and ceramic liner of 60/36 mm were implanted in the patient.

On January 27, 2022, a week before visiting the consultative and diagnostic department, the patient stumbled on the left lower limb and felt crepitus in the left hip area. Concurrently, he experienced short-term pain and movement limitation in the prosthetic left hip. The pain decreased during the day spent at rest. However, the symptoms began to increase as the patient became more active within 4 days (from 01/29/2022 to 02/01/2022). Noises (creaking) in the hip during movement appeared in addition to the general symptoms, accompanied by pain (according to the patient, “crepitus during movements”).

An in-depth history taking revealed that the patient noticed the appearance of noises shortly after the left hip arthroplasty before the injury, but did not contact the operating surgeon.

The inguinal and gluteal region examination and palpation revealed no pain or edema. The patient moved using additional support with a limp on his left leg. Relative shortening of 1 cm was observed. Flexion and extension were 0°; abduction was 20°; adduction was 0°; inward rotation was 0°; outward rotation was 0°. The patient felt pain during rotation, abduction, and flexion. Hence, the clinical algorithm recommended by CeramTec for noise interpretation was followed [12].

Sequential X-ray methods of research using plain pelvic radiography in the antero-posterior view revealed a satisfactory inclination of the acetabular component, a varus position of the femoral component of 10°, and a distortion of the endoprosthesis contours in the lower region of the acetabular component and the femoral neck component, which was regarded as a fracture of the ceramic liner or head that make up the bearings. Signs of a previously installed DHS surgical hardware, as well as channels from previously inserted cortical and dynamic screws, were visualized in the cortical area in the upper third of the diaphysis of the left femoral bone after removal in the diaphyseal and subtrochanteric regions (Fig. 1, 2).

Multi-slice computed tomography (MSCT) revealed head decentration. Its correct shape was visualized, which only enabled us to assume its integrity; and a freely lying fragment of a ceramic liner in the neck area of the femoral component was noted. The retroversion was 23° with acetabular component malposition (Fig. 3).

A fracture of the acetabular liner on the left was diagnosed (Fig. 4). A histological examination of the puncture sample was not performed since radiological diagnostic methods were sufficient.

The diagnosis of ceramic liner destruction of the left hip endoprosthesis replaced due to left-sided avascular necrosis of the left femoral head was established based on the obtained data. Following the diagnosis, indications for revision surgery were determined to replace and adjust the positions of all prosthetic components. On the same day, the patient was hospitalized, with strict bed confinement, and his left lower limb was located on a roll under the knee. The patient stayed in a forcedly limited position until surgery.

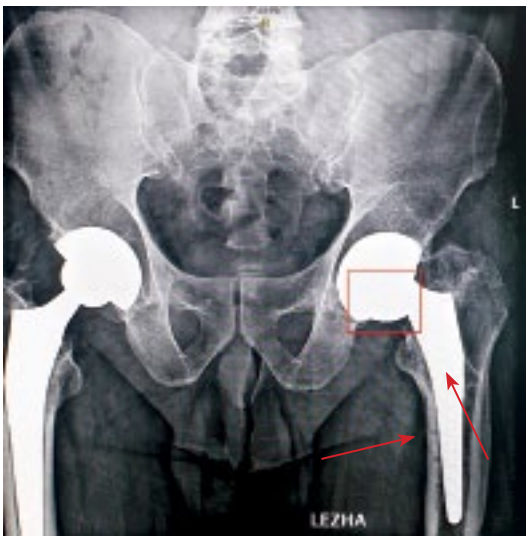


**Fig. 1.** Overview X-ray of the hip joints:
on the right — a total hip replacement with a cementless proximal fixation (2019); jn the left — a total hip replacement with a cementless proximal fixation. Dislocation of the elements of the bearing (highlighted in red). The arrows indicate the canals after removal of the screws

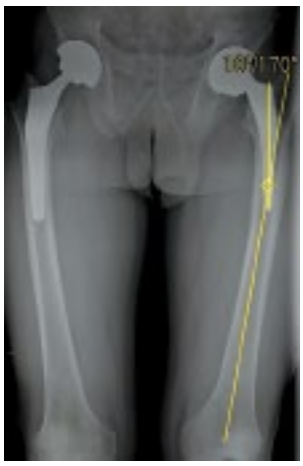

**Fig. 2.** Overview X-ray of the hip joints with full femoral capture. On the left is a 10° varus placement of the femoral component

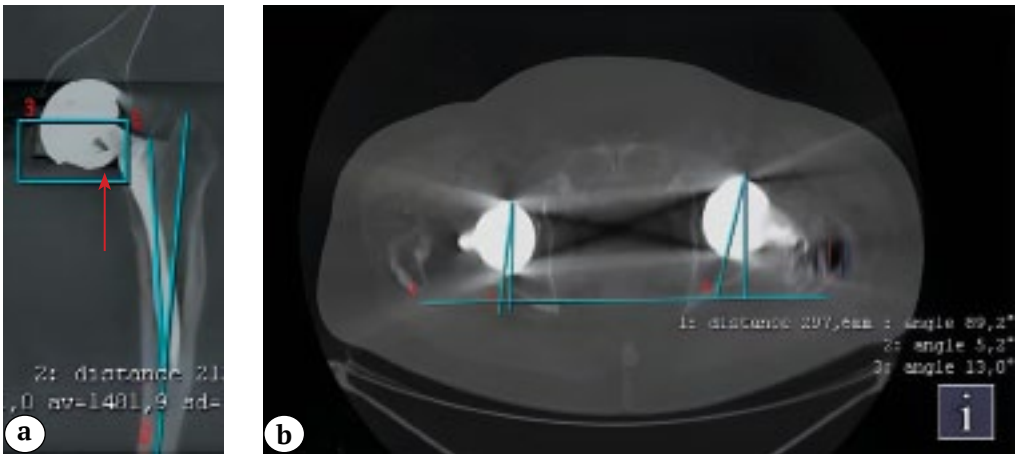


**Fig. 3.** MSCT:
a — frontal projection: decentration of the femoral component head, its correct shape and a fragment of the ceramic liner in the area of the femoral component neck (arrow) are visualized;
b — axial projection: malposition of the acetabular component on the left — 23° retroversion

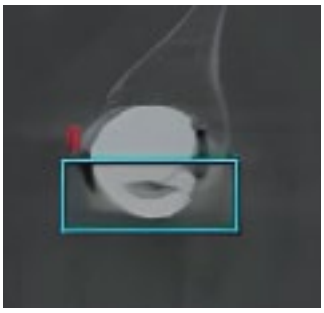

**Fig. 4.** MSCT, sagittal projection: fracture of the ceramic liner

Revision surgery was performed on February 5, 2022. All actions were performed in the presence of a medical representative of the manufacturer of the fractured component.

The skin, subcutaneous tissue, and fascia were dissected along the previous postoperative scar on the outer surface in the proximal third of the left thigh with the Hardinge approach in the patient's right lateral position under combined anesthesia (spinal and inhalation anesthesia). Cicatrices were mobilized in the greater trochanter area. Approximately 50 ml of odorless hemorrhagic fluid without fibrin was released when the joint capsule was opened. Multifragmentary destruction of the acetabular ceramic liner was visually registered after capsular dissection and femoral component dislocation after the Hohmann retractor installation behind the anterior and posterior columns. All seven visible ceramic liner fragments were removed, and their sizes ranged from 2×3 mm$^2$ to 20×20 mm$^2$. Repeating notch-shaped defects were visible along the edges of the preserved large fragments of the liner (marginal zones of the liner). The head was intact. The proximal femur was mobilized, and the endoprosthesis head was removed (Fig. 5).

The femoral component was stable, without signs of bone lysis. The component was extracted by traction with a minor effort using an extractor with preliminary use of osteotomes to mobilize it in the proximal part. Its neutral position was registered when assessing the component torsion. Its installation in the retroversion position was revealed during the acetabular component revision, which corresponded to the preoperative X-ray examination findings. The acetabular component was mobilized using an acetabular gouge and removed. The acetabular contours were preserved, without wall defects. The repeated maximum total synovectomy was performed, followed by the use of the Pulsavac (Zimmer) pulse system to remove ceramic fragments using a water jet. Hemostasis control was performed. A mixed fixation femoral component (Alloclassic) and an acetabular press-fit fixation component (Continuum), as well as Ce-Ce tribological bearings (Biolox Delta), were chosen for the revision replacement of the femoral component. A 62-mm continuum acetabular component due to revision arthroplasty, which was fixed with three screws after impaction, and a 62/36 mm ceramic liner, were installed. The femoral component No. 9 (Alloclassic) was installed, con-

sidering the correction of the varus position of the previous component with installation along the medullary canal axis. The 36 mm + 7 XL ceramic head was chosen for limb length correction. The femoral component was repositioned into the endoprosthesis cup after the head was installed. Their sufficient volume was revealed when testing movements in the left hip joint. Additionally, the surgical wound was sanitized using the Pulsavac system with 1 L of normal saline solution. Finally, the wound was sutured in layers with Vicryl. Staples on the skin and an aseptic dressing were used. The wound healed by primary intention. The patient was discharged on day 10. The plain radiography of the pelvis in the antero-posterior view determined that the acetabular component inclination was 35°, the femoral component was in the correct position when conducting control 3 months postoperatively, and no valgus or varus angulation was noted (Fig. 6). MSCT in the axial projection revealed that the acetabular component was implanted in the anteversion position of 17° (Fig. 7).


**Fig. 5.** The appearance of the ceramic liner fragments:
a — a large ceramic liner fragment (central) 20×20 mm with signs of metal contact (black);
b — medium (15×6 mm) and small fragments (2×3 mm) with excised surrounding tissues;
c — femoral head with signs of metal contact (black)

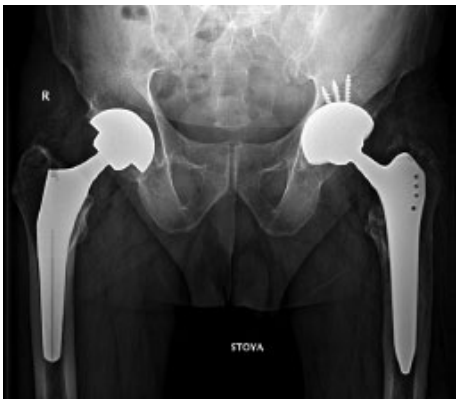


**Fig. 6.** Anteroposterior X-ray view of the pelvis 3 months after surgery: on the right — a total hip replacement with a cementless proximal fixation (2019); jn the left — a total hip replacement with a cementless proximal fixation

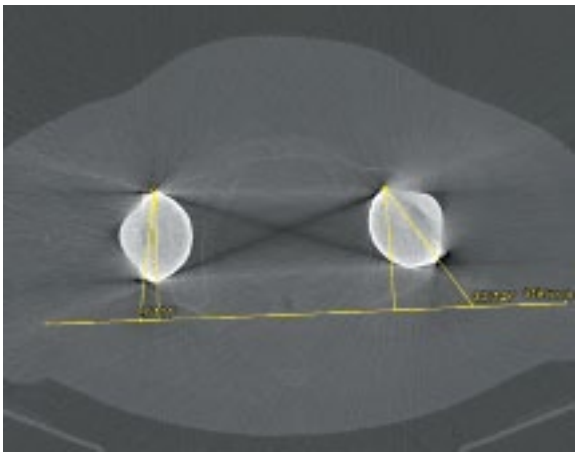

**Fig. 7.** MSCT of pelvis in axial projection: anteversion of acetabular component 17°

## DISCUSSION

Various clinical studies demonstrate a rather high survival rate of endoprostheses with Ce-Ce bearings, namely 97.9–99.6% in the follow-up period of 2–10 years [13, 14, 15, 16, 17], and an insignificant decrease to 95.7% with longer follow-up [18]. Concurrently, only a small share of cases of revision is due to the fracture of ceramic elements, accounting for 0.3%, and <0.2% of them are due to the liner fracture. Untimely and incorrect approaches in this situation can lead to severe consequences for the patient although such complications are rare [19, 20, 21, 22, 23]. Therefore, the main issue is determining the risk factors for ceramic liner destruction. Notably, trauma is rarely the cause of a fracture based on available literature analysis. On the contrary, most of the presented clinical cases do not have a traumatic origin [8, 9, 13, 18, 22, 24, 25, 26]. According to various authors, the incorrect position of the liner and the acetabular component leads to an uneven distribution of the load on the articulating surfaces, which leads to microcrack formation [9, 27, 28], and their accumulation can lead to structural macrodestructions [6]. Malposition of the components can also contribute to the development of impingement of the femoral component neck and the liner edge, or lead to uneven marginal loading of the contralateral side [3, 9, 26, 29].

Some authors revealed the importance of the patient's weight and height [29, 30]. However, Traina et al. revealed that differences in weight and height in the group of patients with a fracture and absence of noise were not significantly different from the comparison group, and concluded that the liner fracture has a multifactorial origin [24]. The same study revealed that the angle of anteversion of the acetabular component was greater in patients with fractures than in those without fractures.

The area with undercoverage has a significant effect. High-strength polyethylene can mitigate the effect of weight redistribution in case of undercoverage of the acetabular component due to its flexibility. The ceramic liner does not cushion the maldistribution of weight due to its hardness [3, 9, 24, 31, 32, 33].

Patient risk factors also remain debatable. There is no approved protocol for working with Ce-Ce bearings, although most orthopedists believe that these bearings can be installed in all young and active patients [3, 6, 34]. The question of the pelvic sagittal balance remains even with the correct placement of the components according to the X-ray data in the antero-posterior view. Additionally, the majority of younger patients are operated on for dysplastic coxarthrosis, that is, with significant anatomical disorders of the joint structure, which entails a shift in the center of rotation, thereby increasing the risk of uneven load on the articulating surfaces [25, 35]. The installation inaccuracy of the same 5°–10° can be significant for the Ce-Ce bearings if Ce-Pe bearings conditionally allow the error of 5°–10° of the angle of inclination or anteversion due to its damping properties [33, 36].

Ceramic debris is bioinert to the body, but studies demonstrated osteolysis due to exposure to ceramic debris. The effect of the influence of a third body should not also be disregarded, because it can significantly reduce the service life of Ce-Ce bearings [6]. Cases of a ceramic bearing fracture due to the third body effect have no exact facts and information, but there are theoretical justifications that the formation of debris between the bearing elements can lead to a violation of the uniform distribution of head pressure on the liner, thereby creating conditions for excessive friction of a certain section and subsequently lead to ceramic destruction [34]. Moreover, there is evidence that coarse debris fragments make scratches and microcracks on the bearing surfaces [28, 37].

Koo et al. revealed that the size of the head in the Ce-Ce bearings plays an important role because bearings with a head of ≤32 mm have a higher risk of component fracture than those with heads of ≥36 mm [38]. Additionally, the head size affects the range of motion in the joint (jumping distance), accordingly, the larger the size, the greater the range of motion [6]. However, an increased head size results in the use of a thinner liner, which directly increases the risk of a fracture and reduces the shelf life of the bearings, or requires an equal increase in the acetabular component diameter. Therefore, installing liners with an anti-luxation tilt with a metal rim or using components with pre-installed liners is recommended to reduce the risk of marginal chipping as the head diameter increases [8, 14, 39].

The surgical approach of revision arthroplasty in case of ceramic destruction is described in the operating procedure from CeramTec [12]. A diagnostic search should be conducted at the first detection of creaking in a Ce-Ce bearing for early ceramic fracture diagnostics. The literature repeatedly indicates that creaking may result from a fracture [40, 41]; however, acoustic phenomena are multifactorial [41, 42], thereby requiring a comprehensive evaluation [12].

Many authors recommend the use of CT for reliable fracture diagnostics. This method is effective in diagnosing fractures without dislocation and malposition of fragments. This is sufficient if fragmentation and dislocation are detected by radiography [18, 38, 43, 44]. Lee et al. proposed the following damage classification [14]:

– marginal splits, which are cases caused by impingement of the neck of the femoral component and the liner from the inner or outer surface, may be indicated by abrasions on the neck surface during revision;

– central fractures (often multifragmentary), where the mechanism is a disproportionate load on the articulating surfaces due to incorrect installation (non-compliance with the parameters of inclination and anteversion, errors during impaction) or loosening of the component.

Histological examination of aspirate from the hip with complaints of creaking may reveal the presence of ceramic fragments. Revision surgery should be performed if a patient complains of creaking accompanied by pain, and ceramic fragments of >5 μm are detected in the synovial fluid [18, 43]. Concurrently, a pre- and intraoperative biopsy of periarticular tissues is recommended for histological diagnostics of the number of macro- and microparticles of debris. The sizes of macroparticles can be 1–22 microns.

The third body effect is the main problem of the consequences of ceramic fracture. Many authors state that approximately 20% of residual debris remains even after total synovectomy and careful treatment of the periarticular space [38, 43, 45]. Accordingly, the choice of bearings during revision is an important component. The Met-Pe bearings are avoided in case of bearing replacement during revision due to ceramic fracture. Complications that occur during short-term follow-up have been repeatedly reported in the literature [38, 41, 45], including a massive metallosis of periprosthetic tissues, induced by residual ceramic debris, which precedes systemic intoxication with cobalt and chromium ions. Patients with a lethal outcome in the medium term after revision with a replacement for Met-Pe bearings were also reported [23]. The best option for revision due to ceramic fracture is the use of similar Ce-Ce bearings, although a hypothesis reported that residual debris can lead to microcracks, and subsequently to repeated fracture [38, 45].

## CONCLUSION

The probable cause of the ceramic acetabular liner destruction in our case was the malposition of the acetabular and femoral components. A passive treatment approach after destruction could lead to significant damage to surrounding tissues. A timely revision, according to the CeramTec algorithm, prevented further wear and possible soft tissue disorders. Therefore, introducing a standard protocol for working with these patients in the Russian Federation is advisable because an increased number of primary surgeries with ceramic bearings will undoubtedly increase the number of such complications despite the rarity of ceramic fractures. Clinical cases associated with noises in the hip after hip arthroplasty should be analyzed with great deliberation for early fracture diagnostics. The noise phenomenon, which is divided by the algorithm into frequent noise and intermittent noise, and is not associated with ceramic fractures, requires further study. MSCT is currently considered the best diagnostic method. A histological examination of periprosthetic tissues and punctate can be a significant addition to justify the revision of the bearings in the absence of malposition of the components. Only the Ce-Ce bearings are necessary bearings for the revision of endoprostheses with a ceramic fracture because small particles of ceramics cannot be completely removed by synovectomy, and there will always be a possibility of third body particles entering the friction unit with the development of extremely gross wear.

## DISCLAIMERS

### *Author contribution*

*Tashtanov B.R.* — the collection and processing of data, literature review, writing the draft.

*Korytkin A.A.* — research conception, data analysis, text editing.

*Pavlov V.V.* — the treatment of patient, research conception and design, collection and processing of material, data analysis, text editing.

*Shubnyakov I.I.* — literature review, data analysis, text editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Competing interests.*** The authors declare that they have no competing interests.

***Ethics approval.*** Not applicable.

***Consent for publication.*** Written consent was obtained from the patient for publication of relevant medical information and all of accompanying images within the manuscript.

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## Authors' information

✉*Baikozho R. Tashtanov*
Address: 17, Frunze str., Novosibirsk, 630091, Russia
https://orcid.org/0000-0002-8553-9712
e-mail: b.tashtanov95@gmail.com

*Andrey A. Korytkin* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-9231-5891
e-mail: andrey.korytkin@gmail.com

*Vitalii V. Pavlov* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-8997-7330
e-mail: pavlovdoc@mail.ru

*Igor I. Shubnyakov* — Dr. Sci. (Med.)
https://orcid.org/0000-0003-0218-3106
e-mail: shubnyakov@mail.ru

Case report
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# Reverse Shoulder Arthroplasty After Communited Humerus Fracture: A Case Report

Aleksandr V. Frolov [1,2], Aleksey N. Logvinov [1], Mikhail E. Burtsev [1], Musa N. Maysigov [1], Aleksandr A. Olchev [3], Pavel M. Kadantsev [1], Andrey V. Korolev [1,2]

[1] *European Clinic of Sports Traumatology and Orthopedics (ECSTO), Moscow, Russia*

[2] *RUDN University, Moscow, Russia*

[3] *City Clinical Emergency Hospital, Ryazan, Russia*

***Background.*** Fractures of the proximal humerus are common injury, especially among older age group patients. For the treatment of most cases, conservative tactics are required, some require surgery: osteosynthesis, arthroplasty. Proximal humerus fractures with extension to the metadiaphyseal and diaphyseal zones uncommon, and treatment of this type of injuries is complex for trauma surgeons.
***The aim of the study*** is to demonstrate successful experience of two-stage treatment of the proximal humerus fracture with extension to the diaphysis middle third in an older age group patient.
***Case presentation.*** The case report presents successful two-stage treatment of the proximal humerus fracture with extension to the middle third of the diaphysis in an older age group patient. The first stage was performed osteosynthesis of the humerus with the PHILOS Long plate, the second stage — reverse shoulder arthroplasty.
***Conclusion.*** Consistent performing of osteosynthesis and total reverse shoulder arthroplasty allows to achieve satisfactory treatment results with restoration of the injured limb function and relief of pain syndrome.

**Keywords:** humerus fracture, plate osteosynthesis, shoulder arthroplasty, humerus head avascular necrosis.

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✉ *Aleksey N. Logvinov*; e-mail: logvinov09@gmail.com

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# Реверсивное эндопротезирование плечевого сустава после оскольчатого перелома плечевой кости: клинический случай

А.В. Фролов [1,2], А.Н. Логвинов [1], М.Е. Бурцев [1], М.Н. Майсигов [1], А.А. Ольчев [3], П.М. Каданцев [1], А.В. Королев [1,2]

[1] *Европейская клиника спортивной травматологии и ортопедии (ECSTO), г. Москва, Россия*

[2] *ФГАОУ ВО «Российский университет дружбы народов», г. Москва, Россия*

[3] *ГБУ РО «Городская клиническая больница скорой медицинской помощи», г. Рязань, Россия*

***Актуальность.*** Переломы проксимального отдела плечевой кости — распространенная травма, особенно среди пациентов старшей возрастной группы. Для лечения большинства данных повреждений применяется консервативная тактика, однако некоторым пациентам требуется хирургическое лечение: остеосинтез, эндопротезирование. Переломы проксимального отдела плечевой кости с распространением на метадиафизарную и диафизарную зоны встречаются значительно реже, и их лечение представляет сложную задачу для травматологов.

***Описание случая.*** Представлен успешный опыт двухэтапного лечения перелома проксимального отдела плечевой кости с распространением до средней трети диафиза у пациентки старшей возрастной группы. Первым этапом выполнен остеосинтез плечевой кости пластиной PHILOS Long, вторым этапом — реверсивное эндопротезирование плечевого сустава.

***Заключение.*** Последовательное применение остеосинтеза и тотального реверсивного эндопротезирования плечевого сустава позволяет добиться удовлетворительных результатов лечения с восстановлением функции травмированной конечности и купированием болевого синдрома.

**Ключевые слова:** перелом плечевой кости, остеосинтез пластиной, эндопротезирование плечевого сустава, аваскулярный некроз головки плечевой кости.

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*Логвинов Алексей Николаевич*; e-mail: logvinov09@gmail.com

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## BACKGROUND

Proximal humerus fractures (PH) represent the third most common injury among geriatric patients [1, 2]. Generally, such fractures are associated with osteoporosis, and low-energy injuries can lead to complex types of fractures in this area [3]. In most cases, a conservative approach is used to treat such fractures, but surgical stabilization is required in some cases according to classical indications using intramedullary or plate osteosynthesis [3]. The main treatment objectives geriatric patients with PH fractures are early rehabilitation and rapid daily activity resumption [4]. However, PH fractures with extension to the metadiaphyseal and diaphyseal zones are much less common and can lead to a major decrease in upper limb function and quality of life in older patients [5]. The distal spread of this fracture type the success of conservative treatment with various types of dressings and braces, as well as complicates the use of intramedullary osteosynthesis [6]. The method of choice for the treatment of these types of fractures is locking plate osteosynthesis [7, 8]. Concurrently, the low quality of bone tissue, the risk of reposition loss, the occurrence of varus collapse, and avascular necrosis of the humeral head cause a great number of complications.

We present a rare clinical case of staged surgical treatment of an older female patient with a PH fracture with extension to the diaphyseal zone.

## Case report

A 73-year-old patient applied to the European Clinic of Sports Traumatology and Orthopaedics (Mocow) 4 days after the injury resulting from a fall on the left upper limb. An X-ray examination was performed on admission, a multi-fragment fracture of the proximal and middle thirds of the humerus was diagnosed (Fig. 1). Additionally, signs of neuropathy of the left radial nerve and secondary anemia due to blood loss (hemoglobin of 110.0 g/L, erythrocytes of $3.53\times10^{12}$/L, and hematocrit of 32.10%) were detected.

After patient examenation and preparing for surgical treatment open direct repositioning and plate osteosynthesis were performed through the deltoid-pectoral approach with an additional lateral approach. Surgical treatment was performed in the beach-chair position.

The first step was passing the lag screws through the diaphyseal part of the fracture; however, satisfactory repositioning was not achieved. The lag screws were removed and two cerclage sutures were applied (Fig. 2). Then osteosynthesis was performed with a long PHILOS plate (Synthes) (Fig. 3).

Postoperatively, the patient retained paresis of the radial nerve, and therapy with special neurological therapy was started. Additionally, immobilization in a shoulder brace was performed for 6 weeks, followed by active rehabilitation therapy and staged radiography. Radial nerve paresis resolved 9 months postoperatively with complete radial nerve function restoration.

The control X-rays showed a consolidated fracture of the humeral diaphysis 9 months postoperatively, as well as the development of avascular necrosis of the left humeral head, nonunion, and migration of the greater tubercle into the subacromial space (Fig. 4). The shoulder function was limited, and the pain syndrome up to 5 VAS points persisted during movements, as well as a pronounced limitation of the amplitude of active movements with the abduction of up to 70°, flexion of up to 90°, external rotation of up to 0°, and internal rotation at the L5 level. However, the patient was fully adapted to daily activities.

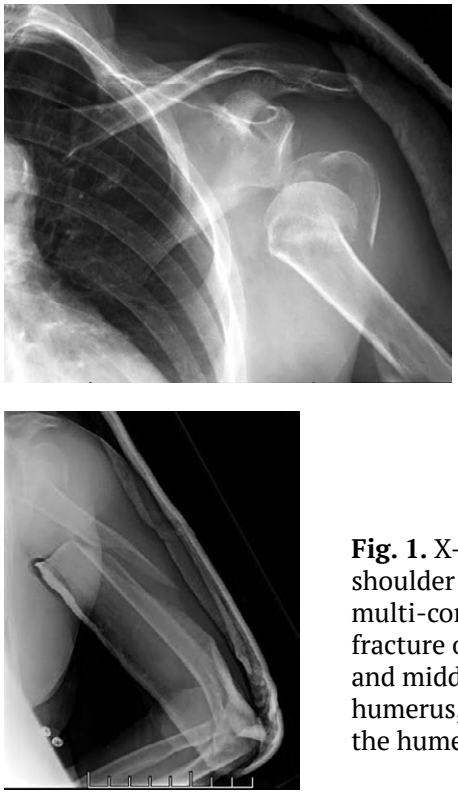

**Fig. 1.** X-rays of the left shoulder at admission: multi-comminuted fracture of the proximal and middle thirds of the humerus, dislocation of the humeral head

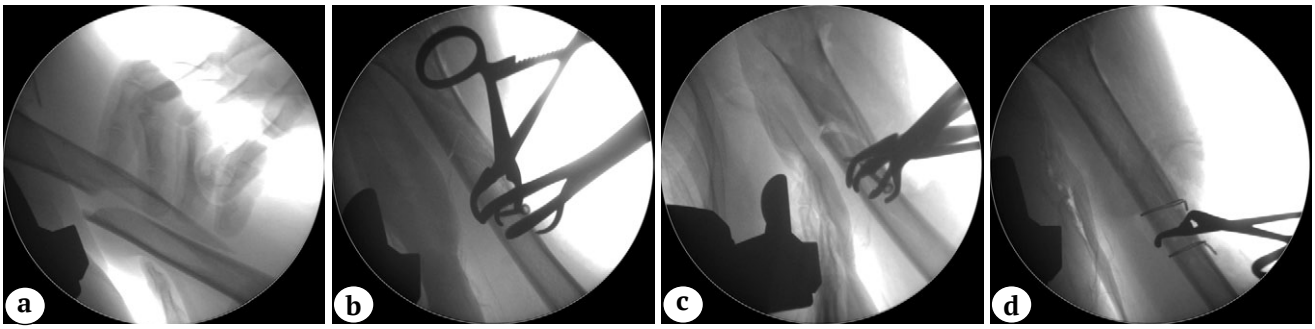


**Fig. 2.** Intraoperative X-rays:
a — humerus diaphysis fragments displacement; b — reposition of the humerus shaft, lag screws insertion; c — loss of reposition; d — removal of lag screws, cerclages ostheosynthesis

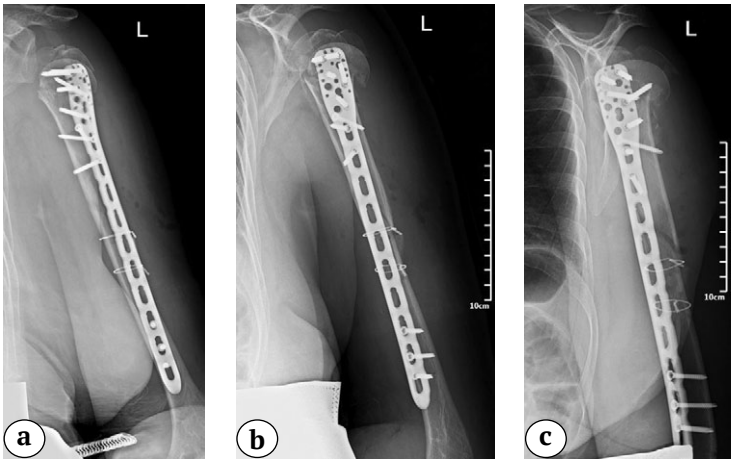


**Fig. 3.** Postoperative X-ray's after osteosynthesis of the humerus with a PHILOS Long plate and cerclages: a — frontal view; b — lateral view; c — oblique view

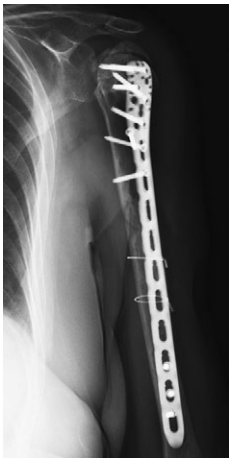

**Fig. 4.** Shoulder control X-ray after 9 months since surgery: consolidation of the diaphyseal part, nonunion, secondary displacement of the greater tubercle and avascular necrosis of the humeral head

After 20 months, stage 2 of the surgical treatment, including removal of metal fixators and total reverse arthroplasty of the left shoulder, was decided together with the patient due to the persistent pain syndrome. A deltoid-pectoral approach was performed, and the metal fixators were removed. Then, tenotomy of the subscapular muscle tendon and long head biceps tendon was performed, and access to the shoulder joint was provided. The remaining nonviable fragments of the humeral head were removed, cementless metaglene was placed with fixation by three screws, and a 38-mm glenosphere was placed.

A decision was made to install a cemented endoprosthesis stem (size 1, diameter 10) because of the reduced bone quality, thin cortical walls, the risk of low integration, and the risk of endoprosthesis stem instability. The height of the shoulder component was determined by the most intact medial bone edge of the humerus. The 38/+3 cup was installed after fitting. The final radiographs are presented in Figure 5.

The pain syndrome was not registered and the patient was discharged on day 5 after the surgery. Additionally, immobilization in a shoulder brace was performed, and rehabilitation therapy was started.

Subjective assessment of the left shoulder joint function according to the American Shoulder and Elbow Surgeons score (ASES) scale was performed at stage control examinations (Fig. 6).

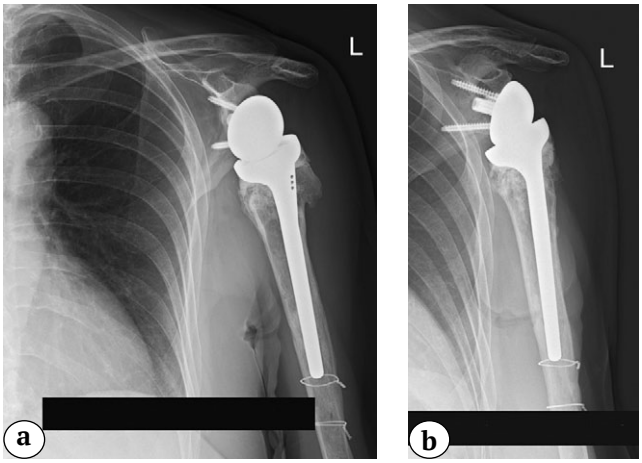


**Fig. 5.** Shoulder X-rays in the early postoperative period after left shoulder arthroplasty: a — Y-shaped view; b — direct view

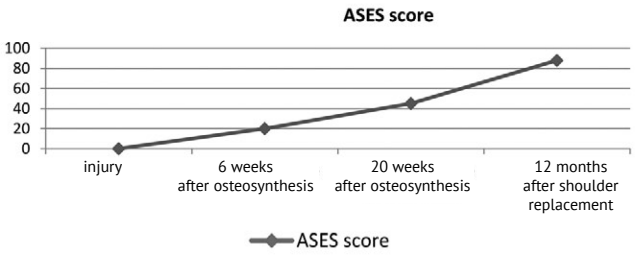


**Fig. 6.** Dynamics of ASES scores

The patient had no pain syndrome (VAS score of 0), the subjective assessment of the left shoulder function was 90%, and the ASES score was 88 at the final follow-up examination. The patient achieved a complete painless range of motion, while the external rotation deficit persisted, and a lag-sign positive test was noted, when the patient was unable to retain the arm in maximum external rotation.

## DISCUSSION

The PH fracture with extension to the diaphysis in geriatric patients is a relatively rare injury and can lead to a sharp decrease in limb function and quality of life. Internal fixation with the long PHILOS plate (Synthes) provides stable fixation due to the anatomical shape of the plate [9].

According to the literature, surgical treatment of PH isolated fractures is associated with a large number of complications (17-32%) [10, 11], among which avascular necrosis of the humeral head is up to 5% [12, 13, 14]. Brunner et al. revealed that geriatric patients have a 2-3 times higher risk of complications compared to young people [10].

The treatment results of patients with PH fractures with extension to the diaphyseal zone vary in the literature. Arumilli et al. revealed that only 2 out of 12 patients with 13 fractures developed postoperative complications (mini-

mal varus collapse in a 73-year-old patient and screw migration in a 53-year-old patient) [6]. James et al. revealed that only 1 of 18 patients had a postoperative complication in the form of transient radial nerve paresis; while no cases of avascular necrosis, nonunion, or delayed union were identified [5]. In our case, aseptic necrosis of the humeral head and nonunion of the humeral tubercles were diagnosed, which may be associated with the fracture severity, the nature of fragment displacements, and the use of open direct reposition.

The nature of complications in our clinical case can be classified as type 1 (aseptic necrosis of the head) and type 4 (nonunion of the humeral tubercles) based on Boileau classification of PH isolated fractures [15]. Schliemann et al. revealed satisfactory results from the total reverse shoulder arthroplasty after osteosynthesis of the PH with the development of aseptic necrosis [16]. Grubhofer et al. revealed satisfactory results in the use of total reverse arthroplasty of the shoulder joint after complications of primary osteosynthesis. Patients with intracapsular fracture complications (types 1 and 2) had a statistically significantly better outcome than patients with extracapsular fracture complications (types 3 and 4) [17]. All studies registered a significant improvement in the values of the orthopedic scales in the postoperative period. Similar results were also obtained in our clinical case (88 points on the ASES scale) at the final follow-up examination.

The use of one-stage total reverse shoulder arthroplasty for PH fracture treatment in older patients provides better clinical results than unipolar arthroplasty or osteosynthesis [18]. A cohort study by E. Sebastia-Forcada et al. compared the results of primary and revision total reverse shoulder arthroplasty. Both groups showed better functional results and fewer complications in the group of primary total reverse shoulder arthroplasty despite a significant improvement in function [19]. Similar results were obtained by Shannon et al. [20].

One of the treatment methods for three- and four-fragment PH fractures is one-stage unipolar arthroplasty. According to some authors, this method effectively reduces the pain level; however, shoulder joint dysfunction often persists due to damage to the rotator cuff of the shoulder joint or nonunion of the humeral tubercles [21, 22]. Thus, Radzhabov et al. described the successful surgical treatment of severe PH fractures using unipolar shoulder arthroplasty [23]. Notably, unipolar arthroplasty in this work was performed in patients without damage to the rotator cuff and signs of omarthrosis. Bonns et al. did not reveal a statistically significant difference in the treatment results of patients over 65 years of age with four-fragment PH fractures using conservative treatment or a unipolar endoprosthesis [24].

A systematic review by Austin et al. revealed significantly superior results using total reverse shoulder arthroplasty (421 patients) than unipolar arthroplasty (492 patients) in terms of postoperative pain syndrome and range of motion levels [25]. Additionally, Gallinet et al. revealed that patients achieved better clinical results and flexion amplitude after reverse shoulder arthroplasty, but patients had a greater amplitude of external and internal rotation after unipolar arthroplasty. Moreover, they established that the incidence of complications and repeated surgeries is higher in patients after total reverse shoulder arthroplasty and the percentage of revisions is higher in patients after unipolar arthroplasty [26].

In our opinion, the use of one-stage unipolar arthroplasty in presented case is inappropriate due to the comminuted nature of the fracture of the humeral tubercles and the proximal metaphysis.

Greiner et al. analyzed 50 cases of shoulder reverse arthroplasty in patients with PH fractures after conservative treatment, osteosynthesis, or unipolar arthroplasty and revealed that the metaphyseal bone defect of >3 cm and atrophy or avulsion of the teres minor muscle are statistically significant negative prognostic factors that affect the clinical treatment results. The authors noted that the fixation of the endoprosthesis humerus component depends on the diaphyseal fixation in case of metaphyseal defects of the humerus, which can often be inconsistent. Insufficiency of tension in the musculus deltoideus is often noted in combination with difficulties in reconstructing the anterior and posterior parts of the rotator cuff [27].

A defect in the metaphyseal zone leads to rotational and axial instability, difficulties in installation due to the lack of bone markers, and an increased risk of instability of the shoulder component of the endoprosthesis, dislocations, weakness of the upper limb, and functional impairment in PH fractures.

Our clinical case revealed no formed metaphyseal defect at the time of the primary surgery; however, the intermediate fragment was significantly larger than 3 cm and extended to the middle third of the humeral diaphysis, which could adversely affect the stability of fixation of the shoulder component of the endoprosthesis during a one-stage surgery and the deltoid muscle function (tension). However, in our opinion, the use of shoulder reverse arthroplasty in combination with diaphysis cerclage osteosynthesisis possible in this case but is associated with certain risks.

## CONCLUSION

The presented clinical case shows that the use of sequential osteosynthesis and total shoulder reverse arthroplasty achieves satisfactory results with injured limb function restoration and pain elimination. Damage to the rotator cuff or tubercles of the humerus, the degree of metaphyseal defect of the humerus, age, and comorbidities are important factors to consider during surgical treatment planning.

## DISCLAIMERS

### *Author contribution*

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Aleksey N. Logvinov* — Cand. Sci. (Med.)
Address: 7, Orlovskii str., Moscow, 129110, Russia
https://orcid.org/0000-0003-3235-5407
e-mail: logvinov09@gmail.com

*Aleksandr V. Frolov* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-2973-8303
e-mail: a.frolov1980@gmail.com

*Mikhail E. Burtsev* — Cand. Sci. (Med.)
https://orcid.org/0000-0003-1614-1695
e-mail: mburtsev@emcmos.ru

*Musa N. Maysigov*
https://orcid.org/0000-0002-2096-5876
e-mail: mmaysigov@emcmos.ru

*Aleksandr A. Olchev*
https://orcid.org/0000-0001-5081-8319
e-mail: olchevshoulder@gmail.com

*Pavel M. Kadantsev*
https://orcid.org/0000-0002-8027-3898
e-mail: pkadantsev@emcmos.ru

*Andrey V. Korolev* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0002-8769-9963
e-mail: akorolev@emcmos.ru

Review Article
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# Surgical Treatment of Congenital Radioulnar Synostosis in Children: Systematic Review

Yulia A. Fedorova, Sergei V. Vissarionov, Yaroslav N. Proschenko, Sofia A. Gevorgiz, Ekaterina A. Zakharyan

*H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, St. Petersburg, Russia*

***Background.*** Congenital radioulnar synostosis (CRUS) may have a negative impact on the function of the upper limb and cause disability. The main aim of the surgical treatment is to correct the forearm position for diminishing functional limitations.
***The study aimed*** to analyze the variety of surgical methods for correction of the pronation forearm deformity in children with CRUS based on the literature data.
***Methods.*** We have searched publications in eLIBRARY, PubMed (MEDLINE), Ovid, ScienceDirect, Google Scholar databases. The analysis has included the age at surgery, indications for surgery, the target functional forearm position, the time of consolidation of the forearm bones, the frequency of neurovascular complications.
***Results.*** Most authors considered subjective complaints as the main indication for surgical treatment, while some researchers recommended taking into account the forearm hyperpronation position. The median age of the surgical treatment was 5.17 years (3.25-9.46). The medians of the recommended forearm positions for unilateral CRUS were 0-10° of pronation for the dominant, and 0-12.5° of supination for the non-dominant limb; with bilateral cases — 0-17.5° pronation for the dominant and 0-12° supination for the non-dominant limb. Median of the osteotomy consolidation time varied from 6 to 8 weeks. The maximal time of forearm bone consolidation was significantly higher ($p = 0.024$) in the group with osteotomies through the synostosis site. Though the target forearm position was achieved in all cases, the number of complications in the proximal osteotomy group was statistically significantly different ($p<0.01$). The chances of neurovascular complications were 20.5 times higher in the group of patients who underwent osteotomy through the synostosis (95% CI: 2.7-155.6).
***Conclusions.*** The problem of surgical treatment of children with CRUS in the world medical practice remains relevant despite the wide range of proposed methods. The development of an algorithm regarding the need for surgical treatment and its methodology requires further high-quality research.

**Keywords:** congenital radioulnar synostosis, derotation, rotation, forearm osteotomy, surgical treatment, child.

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✉ *Yulia A. Fedorova*; e-mail: julsigareva@gmail.com

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# Хирургическая коррекция положения предплечья у детей с врожденным радиоульнарным синостозом: систематический обзор литературы

Ю.А. Федорова, С.В. Виссарионов, Я.Н. Прощенко, С.А. Геворгиз, Е.А. Захарьян

*ФГБУ «Национальный медицинский исследовательский центр детской травматологии и ортопедии им. Г.И. Турнера» Минздрава России, г. Санкт-Петербург, Россия*

***Актуальность.*** Врожденный радиоульнарный синостоз (ВРУС), будучи редкой аномалией развития, может оказывать существенное негативное влияние на функцию верхней конечности, затруднять самообслуживание. Основная задача хирургического лечения — коррекция положения предплечья с целью расширения функциональных возможностей.

***Цель*** — анализ данных литературы о хирургических методах коррекции пронационной деформации предплечья у детей с ВРУС.

***Материал и методы.*** Поиск публикаций выполнен в базах данных eLIBRARY, PubMed (MEDLINE), Ovid, ScienceDirect, Google Scholar. Проанализированы сроки консолидации костей предплечья, возраст хирургического лечения, показания к операции, целевое функциональное положение предплечья, частота нейроваскулярных осложнений в зависимости от варианта операции.

***Результаты.*** Большинством авторов рекомендовано выполнение хирургического вмешательства при наличии субъективных жалоб, некоторые исследователи рекомендуют учитывать степень гиперпронационного положения предплечья. Медиана возраста хирургического лечения составила 5,17 лет (3,25–9,46). Медианы рекомендуемых целевых функциональных положений при одностороннем ВРУС составили для доминантной конечности 0–10° пронации, для субдоминантной — 0–12,5° супинации; при двустороннем поражении — 0–17,5° пронации для доминантной и 0–12° супинации для субдоминантной конечностей. Медианы сроков консолидации зон остеотомии варьируют от 6 до 8 нед. Максимальные сроки консолидации костей предплечья в группе остеотомий через зону синостоза статистически значимо ($p$ = 0,024) выше в сравнении с группой остеотомий обеих костей предплечья. Несмотря на то, что целевое положение предплечья достигнуто во всех случаях, количество осложнений в группе проксимальных остеотомий статистически значимо отличалось ($p$<0,01). Шансы развития нейроваскулярных осложнений в 20,5 раз выше в группе пациентов, которым выполняли остеотомию через зону синостоза (95% ДИ: 2,7–155,6).

***Заключение.*** Проблема хирургического лечения детей с ВРУС в мировой медицинской практике, несмотря на широкий спектр предложенных методик, остается актуальной. Разработка алгоритма определения необходимости хирургического лечения и его методики требует дальнейшего проведения исследований высокого качества.

**Ключевые слова:** врожденный радиоульнарный синостоз, врожденный лучелоктевой синостоз, остеотомия костей предплечья, хирургическое лечение, дети.

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*Федорова Юлия Андреевна*; e-mail: julsigareva@gmail.com

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## BACKGROUND

Congenital radioulnar synostosis (CRUS) is a rare anomaly of the development of the upper limb that occurs in the early stages of embryogenesis as a result of a violation of differentiation from the common perichondria of the proximal parts of the radius and ulna [1]. Despite the fact that a single clinical case of idiopathic distal radioulnarl synostosis has been described in the literature [2], the authors suggest that the etiology of this condition is different.

The frequency of occurrence of CRUS in some regions of the European part of Russia is 0.47-1.29 per 100,000 population [3]. The world statistics of this disease are unknown.

Despite the relatively low frequency of occurrence, this anomaly has a significant impact on the function of the upper limb, especially in cases of severe pronation deformity and bilateral lesion. The existing congenital pathology significantly complicates the child's self-care: eating, holding objects and hygiene procedures, which is due to the absence or sharp restriction of the possibility of positioning the brush in the supination position. It should be noted that this pathology manifests and becomes pronounced with the acquisition of complex manual skills by the child [4]. These limitations become most obvious from the age of three [1], however, the anomaly may remain unnoticed until adolescence or even in an adult, especially with a unilateral lesion, a small synostosis and a forearm position close to the average physiological [5].

There are a number of studies in the modern literature devoted to attempts to restore active rotational movements in patients with congenital radioulnar synostosis [6-10]. The main task as a result of surgical treatment remains the correction of the forearm position in order to expand the functionality of the upper limb.

To date, more than 20 different options have been described for surgical correction of the hyperpronation position of the forearm in children with CRUS, but questions about the optimal age of surgery, indications for it, the most optimal and safe variant of derotation osteotomy, as well as alternative surgical treatment options aimed at restoring active rotational movements of the forearm are still being discussed.

The aim of this study was to analyze the literature data on surgical methods of correction of pronational deformity of the forearm in children with congenital radioulnar synostosis.

## METHODS

### Search and selection of publications

This systematic review was carried out in accordance with the international requirements of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The search for literary sources was carried out independently by two researchers (F.Y.A. and G.S.A.) in the electronic databases eLIBRARY, PubMed (MEDLINE), Ovid, ScienceDirect, Google Scholar using combinations of OR, AND operators and keywords for English-language papers "congenital radioulnar synostosis", "derotation", "rotation", "osteotomy", "surgical treatment", "children", "congenital radioulnar synostosis", "osteotomy", "children". The search query in the PubMed (MEDLINE) database included the following keywords: (congenital AND radioulnar AND synostosis) AND (surgical treatment OR derotation OR osteotomy) AND (child) NOT (trauma). Retrospectively, the search was not restricted, the date of the last request was January 31, 2022.

*The criteria for inclusion*:

1. A series of cases with more than 3 patients.
2. The age of patients at the time of surgical treatment is less than 18 years.
3. The use of surgical techniques for correcting the hyperpronation of the forearm in children with CRUS.

Due to the small number of analytical studies and the predominance of descriptions of clinical case report, studies with incomplete data presentation were included for analysis.

## RESULTS

The initial search included 365 sources. After excluding duplicate papers, conference abstracts, book chapters, and comments, 283 studies were selected for screening. After analyzing the headings and abstracts of the articles, checking for compliance with the inclusion criteria, 26 articles directly met the goal of the study. The design of the articles was a description of a series of clinical observations, with the exception of the cohort study of Hwang et al. (2015) [11]. The research selection process is described in more detail in Figure 1.

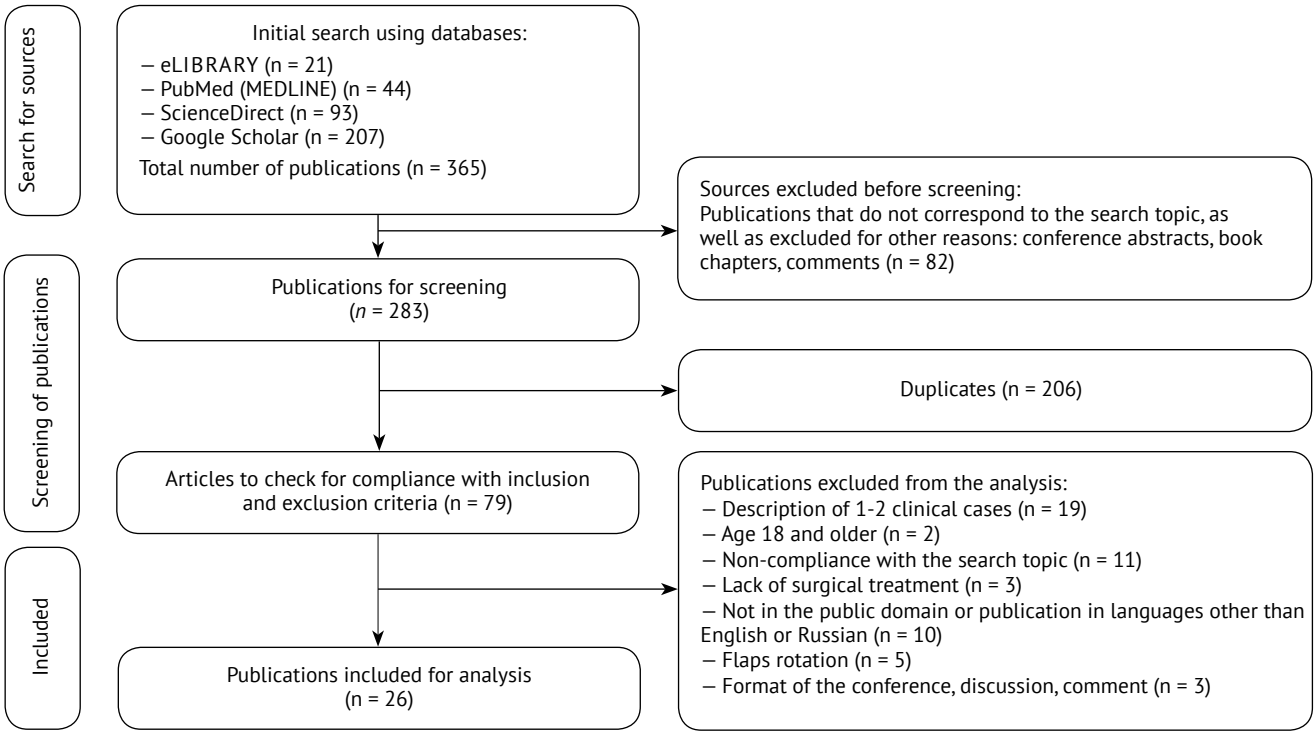
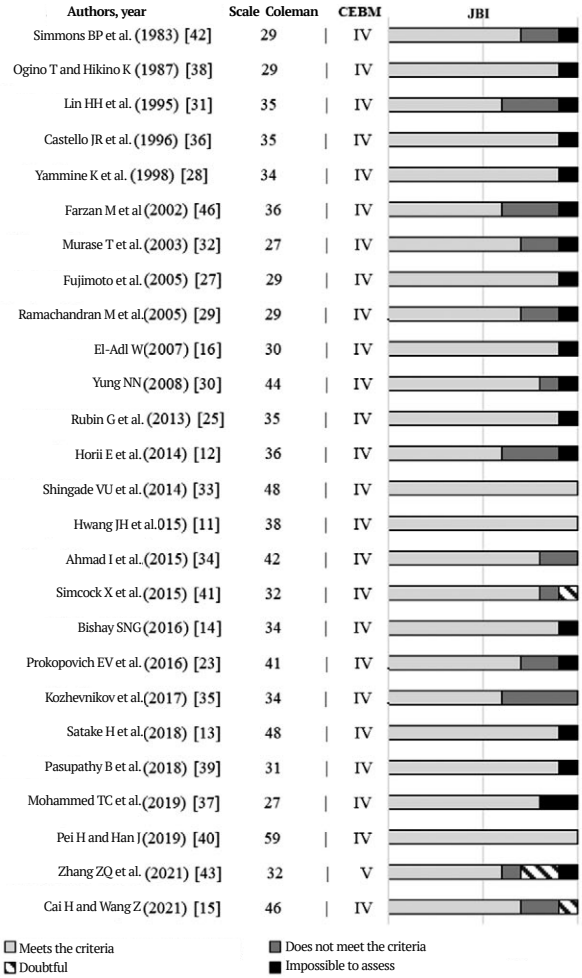



**Fig. 1.** Flowchart of the study




## Risk of systematic error

The methodological quality of the selected studies was assessed in accordance with the criteria of the CEBM (Oxford Center for Evidence-Based Medicine) to determine the level of research, the JBI (Joanna Briggs Institute Critical Appraisal tools) and the Modified Coleman Scale (Modified Coleman Methodology Score) were used to assess the quality of the description of a series of clinical cases. Due to the fact that the overwhelming number of studies is a description of clinical cases series, an assessment on the Newcastle-Ottaw scale was not carried out. The results of the assessment are presented in Fig. 2.

## Statistical analysis

The analysis of the extracted quantitative data (age at the time of surgery, the period of bone consolidation in the osteotomy area, the target functional position of the forearm) was performed using descriptive statistics methods after a preliminary check for the normality of the distribution according to the Shapiro-Wilk criterion.

**Fig. 2.** Results of the quality assessment of the included studies

To assess the frequency of neurovascular complications, the analysis of four-field tables was used. The comparison of consolidation periods in different osteotomy variants was performed using the Mann-Whitney U-test. Statistical processing was carried out in the IBM SPSS Statistics 26 program.

## RESULTS AND DISCUSSION

### Surgical options

Methods of surgical treatment of patients with congenital radioulnar synostosis can be divided into two main groups:

• surgery aimed at giving the forearm a functionally advantageous position (variants of derotation osteotomies) [12, 13, 14, 15, 16];

• surgery, the purpose of which was an attempt to improve rotational movements by resection of the synostosis zone with or without interposition of biological or synthetic materials [7, 8, 17, 18].

Historically, surgical separation of the synostosis zone and reconstructive techniques with an attempt to restore rotational movements seemed to be an ideal treatment option, but the final results according to most studies were not satisfactory.

Already in 1912, Dawson asked the question: "will it be possible to restore rotational movements when dividing the bone fusion zone?" [19]. A relapse of synostosis within 18 months after separation attempts was noted by a number of researchers [20, 21, 22, 23]. In 1998, Kanaya et al. [8] suggested filling the resection zone of synostosis with a blood-supplied fat graft. In this study, during 3.7 years of follow-up, none of the 7 patients relapsed, and the rotational function was preserved. In 2016, the 10-year long-term results of this technique were analyzed [9], which revealed a decrease in the amplitude of rotational movements, to a greater extent supination, the rate of extinction of rotation was about 16° per year. Sakamoto et al. in 2013 analyzed the results of treatment of 14 patients using the Kanaya method with an average follow-up period of 58 months [10]. Despite the fact that there was no recurrence of synostosis, rotational movements tended to fade [10]. In 2020, Dong et al. was retrospectively investigated the effectiveness of placing a blood-supplied flap in the radius resection zone in a large sample (36 patients). The authors claimed to improve the rotational function with the achievement of pronation of 30.1° (15-45°), supination – 22,6° (10-40°) [6].

It should be kept in mind that more than half of the cases of CRUS belong to type III according to the Cleary-Omer classification, that is, they are accompanied by an arcuate deformation of the radius, hypoplasia of the head of the radius. Consequently, the restoration of the rotational function of the forearm may be hindered by the pathological form of bone structures. Sakamoto (2013) et al. The emphasis was placed on the fact that in their study, a smaller rotation amplitude was achieved in patients with a larger arcuate deformity of the radius [10].

Thus, despite the good immediate results of attempts to restore the rotational function of the forearm, either an insufficiently long observation period is described, or a gradual extinction of rotation is noted.

At the moment, the leading methods of surgical treatment of CRUS are precisely the variants of forearm derotation osteotomies to achieve functionally advantageous position [24]. Conditionally, they can be divided as follows:

• surgery with gradual correction of pronation deformation using external fixation devices [25, 26];

• surgery consisting in performing a single-level osteotomy of the radius [12, 13, 23, 27];

• surgery accompanied by osteotomy of both forearm bones at different levels [11, 14, 15, 28, 29, 30, 31, 32, 33];

• surgery involving osteotomy through the synostosis zone [34, 35, 36, 37, 38, 39, 40, 41, 42, 43].

Most authors recommend performing surgery only in the presence of subjective complaints of the patient about the restriction of daily activity [4, 11, 33, 43, 44]. Some researchers recommend taking into account the severity and magnitude of the hyperpronation position of the forearm [28, 42]. When choosing a patient's treatment tactics and indications for surgical treatment, it is necessary to remember that the need for complex manual skills and the development of fine motor skills increase with the age of the child. In young children, even severe pronational deformities may not cause difficulties in providing self-service functions. A comparison of indications for surgical treatment is presented in Table 1.

*Table 1*

**Comparative characteristics of indications for surgical treatment**

| Name | Osteotomy level | Surgery indications | Target functional position of the forearm |
|---|---|---|---|
| Green WT and Mital MA (1979) [45] | Through the synostosis zone | No information | With bilateral CRUS With 30-45° pronation for the dominant limb, 20-35° supination for the subdominant. With a one-sided CRUS of 10-20° supination |
| Simmons BP et al. (1983) [42] | Through the synostosis zone Distal radius | Forearm position ≥60° pronation – absolute indication, 15-60° – relative indication in the presence of subjective complaints; ≤15° – does not cause functional limitations | With a one-sided PRUS of 15° pronation, it is impractical to position the hand in the supination position. With a bilateral CRUS of 10-20 ° pronation for dominant, neutral for subdominant or taking into account the wishes of the patient |
| Ogino T and Hikino K (1987) [38] | Through the synostosis zone | Functional limitations, the presence of subjective complaints. There is no indication of the degree of pronation position of the forearm in degrees | With unilateral CRUS 0-20 ° supination. With a bilateral CRUS, 0-20° pronation for the dominant limb and 0-20° supination for the subdominant |
| Lin HH et al. (1995) [31] | Proximal ulna, distal radius | Functional limitations, the presence of subjective complaints. Unilateral pronation deformity ≥60° of the subdominant limb | 20-30° pronation for the dominant limb, 0-20° supination for the subdominant |
| Castello JR et al. (1996) [36] | Through the synostosis zone | The position of the forearm ≥60° pronation with the presence of complaints is an absolute indication, 30-60° is a relative indication in the presence of complaints | 0-15° of pronation |
| Yammine K et al. (1998) [28] | Ulna and radius diaphysis | The position of the forearm >900 or the restriction of daily activity with bilateral CRUS without specifying the degree of pronation position of the forearm in degrees | 20° of pronation |
| Farzan M et al. (2002) [46] | Proximal ulna | Hyper-pronation position of the forearm without specifying degrees and bilateral lesion with functional limitations. In the absence of difficulties in daily activity, surgical treatment is not indicated | 15° of supination |
| Murase T et al. (2003) [32] | Proximal ulna, distal radius | Functional limitations, the presence of subjective complaints. There is no indication of the degree of pronation position of the forearm in degrees | 0-30° pronation for dominant limb, 0° for subdominant |
| Fujimoto M et al. (2005) [27] | Radius diaphysis | No information | 10° pronation for dominant limb, 0° for subdominant |
| Ramachandran M et al. (2005) [29] | Ulna diaphysis, distal radius | The presence of subjective complaints, difficulty in self-service and daily activity, taking into account the severity of pronation deformation without specifying the degree in degrees | 10° of supination |
| El-Adl W (2007) [16] | Proximal ulna, distal radius | Functional limitations, the presence of subjective complaints. There is no indication of the degree of pronation position of the forearm in degrees | 30° pronation for dominant, 20° supination for subdominant |
| Hung NN (2008) [30] | Distal ulna, proximal radius | The presence of subjective complaints, difficulty in self-service and daily activity | 0-30° pronation for dominant, neutral for subdominant with 70-100% correction of the initial deformation |
| Rubin G et al. (2013) [25] | Through the synostosis zone | Bilateral lesion with forearm position ≥90° pronation | 0-30° supination, and for the subdominant limb more supinated |
| Horii E et al. (2014) [12] | Radius diaphysis | Forearm position ≤30° pronation does not require surgical correction | Neutral without specifying degrees |
| Shingade VU et al. (2014) [33] | Proximal ulna, distal radius | The presence of subjective complaints, objective functional limitations on the Failla or Jebsen-Taylor scale, regardless of the severity of the hyperpronation position | 20-30° of supination |
| Hwang JH et al. (2015) [11] | Proximal ulna, distal radius | The presence of subjective complaints, difficulty in self-service and daily activity | 0-30° of supination |
| Ahmad I et al. (2015) [34] | Through the synostosis zone | Functional limitations, the presence of subjective complaints, deformity >60°, taking into account a single or bilateral lesion | 10-20° of supination |

*End of Table 1*

| Name | Osteotomy level | Surgery indications | Target functional position of the forearm |
|---|---|---|---|
| Simcock X et al. (2015) [41] | Through the synostosis zone | Forearm position >60° with significant limitation of daily activity | 10-20° of pronation |
| Bishay SNG (2016) [14] | Proximal ulna, distal radius | No information | 20-30° pronation for the dominant limb, 20° supination for the subdominant |
| Prokopovich E.V. et al. (2016) [23] | Proximal radius | Forearm position >60° pronation | 0-10° of pronation |
| Kozhevnikov O.V. and Kralina S.E. (2017) [35] | Through the synostosis zone | Functional limitations without a detailed description | Average physiological without specifying degrees |
| Satake H et al. (2018) [13] | Radius diaphysis | Forearm position ≥60° pronation | A position that allows for 90 ° supination of the hand, taking into account compensatory rotation at the level of the wrist joint |
| Pasupathy B et al. (2018) [39] | Two levels through the synostosis zone | Bilateral lesion with severe hyperpronation without specifying degrees, in other cases, the decision on surgical treatment is made individually | 15-25° of supination |
| Mohammed TC et al. (2019) [37] | Through the synostosis zone | Forearm position =600 pronation with unilateral lesion with the presence of complaints, bilateral CRUS regardless of the degree of pronation position in degrees | 0-30° of pronation |
| Pei X and Han J (2019) [40] | Through the synostosis zone | Forearm position ≥55° pronation, ≤ 10 points on the Failla scale | 10° of pronation - 20° of supination |
| Zhang ZQ et al. (2021) [43] | Through the synostosis zone | The presence of subjective complaints, difficulty in self-service and daily activity | No information |
| Cai H and Wang Z (2021) [15] | Proximal ulna, distal radius | Forearm position >60° pronation, <8 points on the ADL scale | 20° pronation for dominant limb, neutral for subdominant without specifying degrees |

## Optimal age for surgical treatment

A consensus on the optimal age for surgery according to the literature has not been formed at the moment. It is recommended to start surgical treatment no earlier than the age of two [47]. The youngest age of the operation for a child with CRUS, according to literary, was 1.5 y.o. [35]. It was found that surgical treatment at the age of over 7 years is associated with a high risk and a higher incidence of neurovascular complications compared to patients who underwent surgery at an early age [24]. According to the results of the analysis of the extracted data, the median age of surgical treatment was 5.17 years (3.25-9.46) (Table 2).

## Assessment of upper limb function

The analysis of the functional results of surgical treatment using objective scales was carried out only in 23% of the publications (6 out of 26 papers) included in the analysis. Objective scales for assessing the function of the upper limb have been used since 2005, among them – ADL (activity of daily living) [13, 15, 27, 33], qDASH [13], Failla [33, 40], Jabson-Taylor [33], Liverpool Elbow Score [11]. In another 9 papers (35%), the authors either offer their own scale without its detailed description, or assess the subjective satisfaction of patients with the result of surgical treatment. The most complete assessment of the function of the upper extremities is described in the paper of Shingade et al. (2014) [33].

## Terms of consolidation and the option of fixing

Various ways of fixing the bones of the forearm are proposed – from the absence of internal fixation [12, 16, 26, 27, 31, 33] prior to the application of the external fixation device [25], osteosynthesis with K-wires is most common [14, 23, 29, 30, 32, 34, 35, 36, 37, 39, 41, 43]. Additionally, in all cases, the limb was immobilized with a posterior plaster splint from the upper third of the shoulder to the metacarpophalangeal joints when the elbow joint was bent at an angle of 90°. Hwang et

al. (2015) compared the groups with internal fixation and the absence of such, without revealing statistically significant differences in the terms of consolidation, the angle of correction, the postoperative position of the forearm, the magnitude of the loss of correction after surgery and the function of the upper limb according to the Liverpool scale [11]. Median periods of consolidation of osteotomy zones vary from 6 to 8 weeks (Table 2). A comparative analysis of the minimum and average consolidation periods in the groups that underwent osteotomy through the synostosis zone and osteotomy of both forearm bones revealed no statistically significant differences (Table 3).

When comparing the terms of consolidation after different variants of osteotomies, statistically significant differences were found in the maximum terms of consolidation (p=0.024). The maximum periods of consolidation in the osteotomy group through the synostosis zone were higher in comparison with the osteotomy group of both forearm bones. The differences in the minimum and average consolidation periods were not statistically significant.

## Forearm position and safe degree of correction

The optimal position of the forearm remains an actively discussed issue. Hwang et al. (2015) indicate that the position of excessive supination may limit the daily activity of the child due to global computerization and widespread use of the keyboard [11]. Shingade et al. (2014) are of the opinion that the peculiarities of hygienic procedures of the inguinal region require almost complete supination [3]. Many groups of authors, mainly from Asian

*Table 2*

**The results of the analysis of the extracted quantitative data from the articles**

| Extracted data | | | Min, Me [IQR] | Average, Me [IQR] | Max, Me [IQR] |
|---|---|---|---|---|---|
| Age at the time of surgery, full years | | | 3,25 [2,20-4,00] | 5,17 [4,74-6,90] | 9,46 [8,25-13,00] |
| Consolidation period, weeks | | | 6,0 [5,5-7,0] | 7,0 [6,0-8,0] | 8,0 [9,0-14,0] |
| Target position of the forearm, degrees | One-sided CRUS | Dominant limb | 0 [-20,0-12,5] | - | 10,0 [-5,0-25,0] |
| | | Subdominant limb | -12,5 [20,0-0,0] | - | 0 [-10,0-10,0] |
| | Two-sided CRUS | Dominant limb | 0 [-17,5-15,0] | - | 17,5 [0,0-30,0] |
| | | Subdominant limb | -12,5 [-20,0-0,0] | - | 0 [-12,5-5,0] |

The supination position is represented by negative values.

*Table 3*

**The results of a comparative analysis of the terms of consolidation in various variants of rotational osteotomies of the forearm bones**

| Parameter, weeks | Surgery option | | *p* |
|---|---|---|---|
| | Osteotomy through the synostosis zone | Osteotomy of both forearm bones at different levels | |
| | Me [IQR] | Me [IQR] | |
| Minimum consolidation period | 8,0 [5,0-8,6] | 6,0 [5,0-6,9] | 0,381 |
| Average consolidation period | 9,4 [7,0-12,0] | 6,95 [5,9-7,5] | 0,142 |
| Maximum consolidation period | 12,0 [10,1-16,0] | 7,95 [7,0-9,0] | 0,024* |

* - differences in parameters are statistically significant (p<0.05)

countries, emphasize the need to take into account the socio-cultural environment – for example, eating with chopsticks requires holding the bowl in the supination position [13, 38, 40]. A number of researchers have indicated that a small supination can be well compensated by shoulder retraction [11, 29, 33], in contrast to the pronation [12]. Other groups of authors emphasize the need to position the subdominant limb in a more "supination" position [14, 27, 31, 32, 38, 42]. The results of the Pei study et al. (2019) demonstrated the highest score on the Failla functional scale in patients with a forearm position of 0-20° supination, both for dominant and subdominant limbs [40]. A detailed comparison of the target positions of the forearm after derotation osteotomy is presented in Table 2. The medians of the recommended target functional positions for unilateral CRUS were 0-10° pronation for the dominant limb, 0-12.5° supination for the subdominant limb; for bilateral lesions – 0-17.5° pronation for the dominant and 0-12° supination for the subdominant limb (Table 2).

Despite the fact that the target position of the forearm was achieved in all cases, the number of complications differed depending on the level of osteotomy – the highest frequency of neurovascular complications was associated with osteotomy through the synostosis zone (Table 4).

When comparing the frequency of neurovascular complications depending on the surgical intervention option (through the zone of synostosis and both forearm bones at different levels), statistically significant differences were obtained ($p<0.01$). The chances of developing neurovascular complications increased in the group of patients who underwent osteotomy through the synostosis zone by 20.5 times (95% CI: 2.7-155.6). There was an average strength relationship between the compared signs ($V = 0.235$).

Other variants of possible complications, as well as more detailed characteristics of the surgical options used are described in Table 5.

## CONCLUSION

According to the literature data, the problem of surgical treatment of children with congenital radioulnar synostosis in world medical practice remains relevant due to the lack of a unified approach, decision-making algorithm and clear indications for surgery. Based on the information presented and analyzed by us, we can summarize:

1. Many authors recommend performing surgical treatment of children with radioulnar synostosis before starting school, at the age of 5 years (3-9 years).

2. Insufficient attention is paid to an objective assessment of the function of the upper extremities when determining indications for surgical treatment using point scales and questionnaires.

3. The target functional position of the forearm differs depending on the leading limb and in the case of a bilateral lesion, more supination is preferable for the subdominant limb.

4. The terms of consolidation of the forearm bones in various variants of osteotomies vary from 6 to 8 weeks. There were no statistically significant differences in the minimum and average terms of consolidation in the group of osteotomies through the zone of synostosis and osteotomies of both forearm bones. At the same time, the maximum consolidation periods differ statistically significantly ($p=0.024$), averaging 12 weeks after osteotomy through the synostosis zone and 7.95 weeks with osteotomy of both forearm bones.

5. Despite the fact that the target functional position of the forearm was achieved in all variants of surgery, osteotomies through the zone of synostosis, as well as proximal osteotomies of the radius are accompanied by a higher frequency of neurovascular complications.

Thus, the development of a decision-making algorithm regarding the need for surgical treatment and its methodology remains an unsolved task to the end and requires further research.

*Table 4*

**Comparative characteristics of rotational osteotomies**

| Author | Osteotomy level | The fixation option | Age at the time of surgery, full years | Consolidation period, weeks | Forearm position before surgery, degrees of pronation | Forearm position after surgery, degrees | Correction angle, degrees | Observation period, months | Complications |
|---|---|---|---|---|---|---|---|---|---|
| Simmons BP et al. (1983) [42] | Through the synostosis zone. Distal radius | Steinmann pin + K-wires/ brackets | 8 (2,5-17,5) | No information | 82 (45-120) | In pronation | 67 (25-90) | 150 (12-312) | Neurocirculatory 4/20<br>Infectious 1/20<br>Loss of correction 3/20 |
| Ogino T and Hikino K (1987) [38] | Through the synostosis zone | K-wires + pin | 7 (4-13) | No information | 65,8 (30-110) | 4.2 of supination<br>(10 of pronation - 20 of supination) | 70 (30-110) | >24 | Neurocirculatory 2/11 |
| Lin HH et al. (1995) [31] | Proximal ulna, distal radius | No fixation | 4,5 (2-14,33) | No information | 81,7 (60-90) | 20 of pronation<br>(30 of pronation - 20 of supination) | No information | 69 (20-165) | No |
| Castello JR et al. (1996) [36] | Through the synostosis zone | K-wires | 7,33 (4-9) | No information | 80-100 | 0-15 of pronation | In 1 case, a two-stage correction due to derotation by 100 degrees | 96 (36-120) | No |
| Yammine K et al. (1998) [28] | Ulna and radius diaphysis | Plate / ex-fix | 4-12 | There is no indication of deadlines | 85 (30-110) | 19 of pronation<br>(30 of supination - 45 of pronation) | 66 (40-90) | 228,8 (12-264) | Loss of correction 3/6<br>Slow consolidation 1/6 |
| Farzan M et al. (2002) [46] | Proximal ulna | K-wires | 4,6 (3-6) | No information | 113,3 (110-120) | 13,3 of supination<br>(10-15 of supination) | No information | 40 (12-60) | Neurocirculatory 1/3 |
| Murase T et al. (2003) [32] | Proximal ulna, distal radius | K-wires | 3,9 (2,2-5) | 7,5 (6,9-7,9) | 78 (70-80) | 7,5 of pronation<br>(0-20 of pronation) | 65 (60-80) | 45,8 (14-73) | Loss of correction 1/4 |
| Fujimoto M et al. (2005) [27] | Radius diaphysis | No fixation | 4,42 (3,92-4,92) | 12,0-20,0 | 75 (70-85) | 2,6 of pronation<br>(10 of pronation - 10 of supination) | No information | 21 (12-36) | No |
| Ramachandran M et al. (2005) [29] | Ulna diaphysis, distal radius. | K-wires | 4,9 (3,5-8,25) | 6,3 (6-9) | 68 (40-80) | 10 of supination | 78 (50-90) | 29 (18-43) | Neurocirculatory 1/5<br>Angular deformation 1/5 |
| El-Adl W (2007) [16] | Proximal ulna, distal radius | No fixation | 5,5 (3,75-8,25) | 5,9 (5-7) | 76 (65-85) | 25 (20-30) of pronation for dominant, 25 (25-30) supination for subdominant limb | 58,6 (35-110) | 26,4 (13-38) | Neurocirculatory 1/5<br>Angular deformation 1/5 |
| Hung NN (2008) [30] | Proximal radius, distal ulna | K-wires | 6,25 (3,75-9,92) | 7,2 (6,6-7,4) | 82 for the dominant and 74 for the subdominant limb (65-85) | 6 of pronation for dominant, 10 of pronation for subdominant (0-30 of pronation) | No information | 64 (30-129) | Loss of correction 5/34 |
| Rubin G et al. (2013) [25] | Through the synostosis zone | Ex-fix | 11 (9-13) | 9,4 (8,6-10,1) | 100 (90-110) | 15 of supination (0-30) | 60 гр + 4 гр/мес | 99,6 (84-120) | Neurocirculatory 2/4<br>Infectious 1/4 |
| Horii E et al. (2014) [12] | Radius diaphysis | No fixation | 5,1 (2,5-8,75) | No information | 72 (40-100) | Neutral (except 2 cases) | No information | 60 (12-132) | No |
| Shingade VU et al. (2014) [33] | Proximal ulna, distal radius | No fixation | 8,6 ± 3,7 | 5 | 56,3 +- 13,7 (30-86) | 27,2±4,1 (20-30) of supination | No information | 54±13 (36-84) | Slow consolidation 1/36 |

*End of Table 4*

| Author | Osteotomy level | The fixation option | Age at the time of surgery, full years | Consolidation period, weeks | Forearm position before surgery, degrees of pronation | Forearm position after surgery, degrees | Correction angle, degrees | Observation period, months | Complications |
|---|---|---|---|---|---|---|---|---|---|
| Hwang JH et al. (2015) [11] | Proximal ulna, distal radius | 2 groups – with and without axial fixation with spokes | 7 (4-16) | 7 (6-8) | 47 (30-65) | 27 of supination (25-30) | 74 (55-90) | 33 (12-72) | No |
| Ahmad I et al. (2015) [34] | Through the synostosis zone | K-wires | 5,16 (3-11) | 7 (5-12) | 68,75 (45-90) | 14,58 of supination (10-20 of supination) | 77,91 (45-100) | 62,28 (48-132) | Neurocirculatory 3/12 |
| Simcock X et al. (2015) [41] | Through the synostosis zone | K-wires | 6,8 (3,0-18,8) | 8 | 85 (60-100) | 8 (0-30) | 78 (40 - 95) | 46 (6-148) | Neurocirculatory 3/26 |
| Bishay SNG (2016) [14] | Proximal ulna, distal radius | K-wires | 5,17 (4,83 - 6,42) | 6,9 (6-8) | 70,7 (60–85) | No information | 59,8 (30–90) | 30,4 (24–36) | No |
| Prokopovich E.V. et al. (2016) [23] | Proximal radius | K-wires, 1 patient – Plate | No information | No information | No information | No information | No information | 6-120 | Neurocirculatory - 4 cases (8,9%) Fracture of the osteosynthesis zone - 2 cases |
| Kozhevnikov O.V. and Kralina S.E. (2017) [35] | Through the synostosis zone | K-wires | 1,5-9 | No information | 50-90 | No information | 45-60 | 12 | Neurocirculatory 1/6 |
| Satake H et al. (2018) [13] | Radius diaphysis | No fixation | 4,5-10,0 | 6 | 51,3 (30-90) | 4 of supination (20 of pronation - 30 of supination) | 55 (30-90) | 163,2 (120-230,4) | No |
| Pasupathy B et al. (2018) [39] | Through the synostosis zone | K-wires | 3,8 (2-9) | No information | 72,25 (55-85) | 22 of supination (12-35) | No information | 26,4 (7-48) | Infectious 1/20 |
| Mohammed TC et al. (2019) [37] | Through the synostosis zone | K-wires | 5 (3-9) | 12 (8-16) | 62 (45-85) | 0-30 of pronation | 54 (30-75) | No information | Neurocirculatory 1/10 |
| Pei X and Han J (2019) [40] | Through the synostosis zone | Plate | 4,87 ± 3,06 (2-13) | 8 | 62,92±7,11 (55-80) | 7,94 ± 7,25 of supination | 70,86 ± 9,58 (50-90) | 55,19 ± 27,10 (24 - 123) | Neurocirculatory 4/31 |
| Zhang ZQ et al. (2021) [43] | Through the synostosis zone | K-wires | 5,2 (4,3-6,0) | 5 | 98 (95-100) | No information | 60 (fixed value) | No information | No |
| Cai H end Wang Z (2021) [15] | Proximal ulna, distal radius | No fixation | 6,25 (4-9) | 8 | 75,31 (45-90) | 15 of pronation | No information | 27,4 (24-36) | No |

## DISCLAIMERS

### *Author contribution*

*Fedorova Yu.A.* — concept and design of the study; the collection and processing of material, evaluation and interpretation of the data and the preparation of the text.

*Vissarionov S.V.* — study design; interpretation of the data, preparation and editing of the text.

*Proschenko Ya.N.* — analysis and interpretation of the data; preparation and editing of the text.

*Gevorgiz S.A.* — collection and processing of material; preparation of the text.

*Zakharyan E.A.* — data analysis; editing of the text.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Yulia A. Fedorova*
Address: 64-68, Parkovaya str., St. Petersburg, Pushkin, 196603, Russia
https://orcid.org/0000-0003-3842-2113
e-mail: julsigareva@gmail.com

*Sergei V. Vissarionov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0003-4235-5048
e-mail: vissarionovs@gmail.com

*Yaroslav N. Proschenko* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-3328-2070
e-mail: yar-2011@list.ru

*Sofia A. Gevorgiz*
https://orcid.org/0000-0002-3489-3658
e-mail: sofiagevorgiz@gmail.com

*Ekaterina A. Zakharyan* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-6544-1657
e-mail: zax-2008@mail.ru

Review Article
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# Leg Length Measurement: Review

Daria A. Petrova [1], Vladimir M. Kenis [1,2]

[1] *H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, St. Petersburg, Russia*

[2] *Mechnikov North-Western State Medical University, St. Petersburg, Russia*

***Background.*** Measurement of the length of the lower extremities is an important part of the assessment of the musculoskeletal system. If there is a discrepancy in the length of the legs, the accuracy of the measurement technique will determine the choice of further tactics for treating the patient. However, to date, there is no consensus among experts regarding the optimal and accurate method for assessing this clinical condition.
***The aim*** is to analyze foreign and domestic researches about measurement of LLD and to determine the optimal method for measuring the lengths of the lower extremities.
***Methods.*** More than 70 scientific articles were selected from 1983 to 2021 in the PubMed/MEDLINE and eLIBRARY databases in Russian and English languages.
***Results.*** An analysis of the literature data did not reveal the optimal method for measuring the length of the lower extremities. Clinical evaluation procedures have demonstrated poor reproducibility and high measurement errors. Radiation imaging techniques also have measurement errors, additionally exerting radiation exposure on the patient. Imaging techniques such as ultrasound and MRI are described in several studies, which does not allow to fully determine all the advantages and disadvantages of these methods when measuring the lengths of the lower extremities.
***Conclusion.*** The study and development of new methods for diagnostics different lengths of the lower extremities, as well as the improvement of existing methods, will improve the quality of diagnosis of this pathological condition, and therefore affect the quality of the treatment for its correction.

**Keywords:** LLD, measurement limb length discrepancy, limb length inequality.

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✉ *Daria A. Petrova*; e-mail: radd.arr@mail.ru

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# Измерение длины нижних конечностей: обзор литературы

Д.А. Петрова [1], В.М. Кенис [1,2]

[1] *ФГБУ «Национальный медицинский исследовательский центр детской травматологии и ортопедии им. Г.И. Турнера» Минздрава России, г. Санкт-Петербург, Россия*

[2] *ФГБОУ ВО «Северо-Западный государственный медицинский университет им. И.И. Мечникова» Минздрава России, г. Санкт-Петербург, Россия*

***Введение.*** Измерение длины нижних конечностей является важным элементом оценки состояния опорно-двигательного аппарата. При выявлении несоответствия в длине ног точность методики измерения будет обуславливать выбор дальнейшей тактики лечения пациента. Однако на сегодняшний день не существует единого мнения специалистов относительно оптимальной и точной методики измерения длины нижних конечностей.
***Цель обзора*** — на основании анализа зарубежной и отечественной литературы определить оптимальную методику измерения длины нижних конечностей.
***Материал и методы.*** Было отобрано более 70 научных статей с 1983 по 2021 г. в базах данных PubMed (MEDLINE) и eLIBRARY на русском и английском языках.
***Результаты.*** Анализ литературных данных не выявил оптимальной методики измерения длины нижних конечностей. Клинические методики оценки продемонстрировали плохую воспроизводимость и высокие погрешности измерений. Лучевые методики визуализации также не лишены погрешностей измерений, дополнительно оказывают на пациента лучевую нагрузку. Методики визуализации, такие как УЗИ и МРТ, описаны лишь в нескольких исследованиях, что не позволяет полноценно определить все их достоинства и недостатки при измерении длины нижних конечностей.
***Заключение.*** Изучение и разработка новых методик определения разной длины нижних конечностей, а также усовершенствование уже существующих методик позволят улучшить качество диагностики данного патологического состояния, а следовательно, повлиять на качество проводимого лечения.

**Ключевые слова:** разновеликость нижних конечностей, измерение длины нижних конечностей, разная длина нижних конечностей.

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*Петрова Дарья Александровна*; e-mail: radd.arr@mail.ru

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## BACKGROUND

Determining the lower extremity (LEL) is an important point in assessing the pathology of the lower extremities. According to the literature, almost 90% of the population suffer from LEL discrepancy up to 1 cm [1, 2]. Anatomical and functional differences are distinguished [3]. Anatomical length discrepancy occurs when the total length of bones and the thickness of cartilage differ significantly between the limbs. The main causes of anatomical length discrepancy are congenital and acquired [4]. The most common congenital causes are hip dislocations, hemihypertrophy with injury to the skeleton of the lower extremities, unilateral clubfoot. Acquired causes may develop due to infections, paralysis, tumors, surgery such as total hip or knee arthroplasty [4]. Functional length discrepancy can be caused by contracture of soft tissues, contractures of the hip or knee joints, pelvic tilt or deformities of the foot [1, 3]. For example, flexion contractures of the knee and hip joints can cause an obvious shortening of the leg, while the hip abduction contracture and equine foot position can functionally lengthen the affected limb.

The assessment of different sizes is a difficult task for researchers and clinicians, since there are still disagreements about the optimal method of measuring the LEL, and data on their reliability and diagnostic accuracy differ. The accuracy of the method is defined as the spread of measurement using the imaging method compared to the actual measurement, whereas the reliability of the method lies in the difference between the measurement results of different researchers and the same researcher when measuring different patients [5]. The choice of the correct surgical method for correcting the LEL discrepancy requires improving the quality of diagnostic techniques for this pathological condition [6, 7, 8, 9, 10].

*The aim of the study* was to determine the optimal method of measuring the LEL based on the analysis of foreign and domestic literature.

## METHODS

The search for scientific articles was carried out from 1983 to 20 in the PubMed (MEDLINE) and eLIBRARY databases. Keywords used for searching: *leg length discretion, limb length discretion, leg length inequality, leg length, limb length, measurement LLD*. The second stage was to look through the literature lists of the found articles for additional selection of publications of a suitable subject.

## RESULTS

Two main categories of methods are used to evaluate the LEL: clinical methods and imaging methods [1, 5, 11].

### Clinical methods for evaluating the LEL

#### *Measuring with a centimeter tape*

The technique is used to measure the length of each lower limb by measuring the distance between the bone landmarks and is called a direct clinical method for measuring the difference in size. In 21 studies, a centimeter tape was used to measure the length of segments [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. In most studies, the values obtained using a centimeter tape were compared with the results of X-ray images as reference [13, 14, 15, 16, 21, 22, 23, 25, 29, 31]. However, only some authors used full-fledged radiographs of the lower extremities, while some researchers estimated the difference in the LEL from targeted radiographs of specific areas, such as hip, knee and ankle joints [12, 16]. In two studies, the reference values were ultrasound diagnostic data [18, 20]. Several authors used CT scans as reference values [23, 26, 27]. One study assessed the distance of the medial and lateral ankles from the floor [29]. Some authors evaluated the inter-expert and intra-expert consistency of the results of the measurements obtained [11, 12, 17]. Another study compared the results obtained using a centimeter tape with the results obtained using a Metrecom device [16]. According to I.T. Batrshin and T.N. Sadovaya, when measuring the LEL and segments using a centimeter tape, 1000 children in 19% of cases had a change in the length of the segments depending on the position in which the measurement was made – standing, sitting and lying [32]. Only a few publications have reported that the measuring method with a centimeter tape is reliable and/or valid [22, 23, 26, 27]. Most of the authors [11, 13, 15, 18, 19, 20, 24, 26, 28, 30] it was concluded that the tape measurement technique is inaccurate: a wide range of results was revealed, weak correlation with other methods and a length discrepancy

with radiography, which may lead to an incorrect calculation of a small difference in the LEL. In addition, there are certain causes of different sizes, such as fibular hemimelia and posttraumatic bone loss involving the foot, where a significant part of the shortening of the limb is more distal in relation to the medial ankle, respectively, is not evaluated when using this assessment technique.

### *The blocks technique*

The alignment of the patient's pelvis position relative to the horizontal plane in a standing position with the placement of blocks of known height under a short limb is called an "indirect" clinical method of measuring the difference in size. This method was used in 11 studies [12, 14, 18, 19, 20, 21, 23, 24, 29, 33, 34]. When evaluating the results, the data obtained during CT [23] and ultrasound [17] were considered the reference value. In all other studies, the reference value was considered to be the results of an X-ray examination. The blocks technique is defined as reliable, accurate and relevant or superior to the measurement technique with a centimeter tape in five studies [12, 21, 23, 24, 29]. However, several studies have revealed low validity and reliability compared to X-ray studies [14, 19, 34]. In addition, J. Edeen et al. identified the blocks technique as less accurate in comparison with ultrasonic measurement [20].

E. Hanada compared the blocks technique with palpation of the iliac crests to determine the magnitude of the difference. The values obtained using this technique were compared with the X-ray data as a reference value. The researchers concluded that the results obtained indicate high reliability and sufficient validity of the proposed methodology, but there are no other references to the use of this technique in the literature [35].

### *Osteopathic techniques*

To determine functional shortening, osteopaths use unique techniques, such as the Derifield-Thompson test, which allows to accurately determine the difference in length of less than 3 mm when assessing interexpert consistency [36, 37, 38]. However, these studies were conducted on small groups of patients, and none of them used a different method for evaluating the the difference in the LEL.

This research design flaw was leveled in a study by D.W. Rhodes et al., in which the osteopathic measurement technique was compared with measurements obtained when assessing the difference in size on radiographs of the lower extremities in the standing position [39]. Despite the positive correlation, the values of the difference in the length of the limbs differed greatly depending on the measurement method, which prompted the researchers to conduct another study aimed at determining the difference in the LEL depending on the patient's position – lying on his stomach and lying on his back [40]. The results obtained were compared with radiographs of the lower extremities in the standing position, which revealed the low validity of the test and less than expected reliability of the study.

The study by H.T. Nguyen et al. is devoted to the assessment of interexpert consistency in measuring the LEL in patients in the supine position, which demonstrated good reproducibility when using the activator method [41].

In another study, the minimum size of the difference was calculated, which can be accurately determined using the osteopathic assessment technique – 3.74 mm. Such accurate data were obtained due to the known size of the pads simulating the different size of the lower extremities in the experiment [42].

Later, the data of the mistake-free determination of the difference in the LEL were increased to 4-6 mm due to the use of modified surgical boots [43].

A number of researchers believe that the inter-expert consistency in assessing the diversity depends on the experience of researchers and decreases when trying to increase the accuracy of measurements. [44, 45, 46, 47]. A modern study by R. Cooperstein and M. Lucente, devoted to assessing the difference in the patient's lying on his back and lying on his stomach, demonstrated low consistency between the measurements obtained [48]. Another study, also conducted by R. Cooperstein et al., was devoted to the evaluation of the compression technique for detecting different sizes and determining the differences between anatomical and functional shortening. The results demonstrated high reliability of intra-expert and inter-expert consistency, however, the authors indicate that radiological measurement methods are more accurate and reliable [49].

Another study by R. Cooperstein et al., devoted to the mathematical modeling of the Allis test, refutes the value of osteopathic assessment methods due to the significant length discrepancy in the results obtained during the measurement process, arising due to the peculiarities of positioning of patients at the time of the procedure [50]. A study by M. Farella et al. aimed at identifying the length discrepancy caused by disorders in the temporomandibular joint did not reveal a correlation between the pathology of the temporomandibular joint and the different LEL [51].

## Visualization methods

Currently available imaging methods include conventional radiography, computer radiography, microdose digital radiography, ultrasound, CT and MRI. The spread of digital radiography served as an incentive for conducting a study on comparing measurements obtained during the evaluation of film and digital images [52].

### *Comparison of the results obtained by measuring film and digital images*

S. Khakharia et al. conducted a study of comparability, accuracy and reproducibility of measurements of the difference between digital images in the PACS system and standard printed radiographs [52]. The measurements were carried out independently by two researchers. For both methods, comparable reliability and excellent consistency of the results obtained were claimed. Therefore, the transition from printed film to digital images was recommended.

### *Radiography of the pelvis to determine the magnitude of the length discrepancy*

In 4 studies, the comparability of the measurement results of the LEL discrepancy obtained by measuring pelvic radiographs in a direct projection was evaluated [53, 54, 55, 56]. The reference studies were panoramic radiographs of the lower extremities in an AP projection in a standing position or CT results. The authors of all studies concluded that caution should be exercised when determining the magnitude of the length discrepancy in pelvic radiographs due to the limitation of their comparability with reference methods.

### *Panoramic radiography of the lower extremities in the standing position*

Panoramic radiography of the lower extremities in the standing position is recognized as the gold standard for assessing the LEL discrepancy[4]. A number of studies have determined the high or almost perfect reliability of the panoramic radiography method [57, 58, 59, 60]. The CT method was the reference method in some of these studies, and in one of them panoramic radiography in an anterior-posterior projection in a standing position surpassed the CT scan in accuracy of the measurements obtained [60]. In addition, the specialists who conducted these studies recommend using the technique not only to determine the LEL discrepancy, but also to assess the axial deformities of the lower extremities. However, the results of a study by M.D. Ahrend et al. have also been published, demonstrating mistakes of up to 6 cm when measuring panoramic radiographs in an AP projection in the same patients during the treatment period. The authors of the article claim that when comparing the measurement results of an intact limb, the values differ by more than 2 cm in 76% of the studied [61].

### *EOS Biplane Imaging System*

The EOS system is an X-ray machine that allows filming in two mutually perpendicular projections [62, 63]. A number of studies have been conducted to assess the accuracy of measurements of the LEL discrepancy [64, 65, 66]. Due to the high accuracy of the results obtained, the reference evaluation method was not used. When comparing the X-ray load A. Clavé et al. concluded that the obtained images of phantoms are comparable to diagnostic ones and can be used for subsequent examination of living patients in order to reduce radiation exposure [64]. In two other studies, 2D and 3D measurements using the EOS system were considered accurate and highly reliable. However, both studies revealed methodological problems [65, 66].

### *Computed tomography*

In their study, V.Poutawera and N.S. Stott evaluated the reliability of measurements of different LEL obtained using CT [67]. The reference standard was not used. Although the intra-expert con-

sistency of repeated measurements was almost perfect, CT scans should be performed more than once and rechecked by the attending physician.

### *Ultrasound examination*

Several studies have been devoted to assessing the reliability of measurement with the LEL discrepancy by ultrasound diagnostics [18, 20, 68, 69]. The reference standard was radiographic measurement. The authors of all the studies came to the conclusion that ultrasound for the assessment of length discrepancy is a simple technique in performance and much more accurate in comparison with clinical methods, regardless of what type of device is used.

### *Magnetic resonance imaging*

Although MRI is traditionally used for soft tissue imaging, this diagnostic method is becoming increasingly popular for assessing bone abnormalities. In a study by J. Riad et al., the magnitude of the difference in limb length was assessed using MRI [70]. On sagittal T1-weighted tomograms of the lower extremities, the length of the pelvis, femur, lower leg and calcaneal bone was measured in the patient's position on the back with fully straightened legs. The measurements were carried out by two experienced experts and repeated two weeks later. The results obtained indicate the high reliability of the technique for estimating the size of the segments of the lower extremities.

## DISCUSSION

Clinical methods are characterized by ease of application in routine practice and poor reproducibility with high inaccuracy rate of the obtained measurement results. Radiological techniques are also not devoid of mistakes, in addition, they have an X-ray load on the patient. That is why, in our opinion, it is impractical to use CT in the daily diagnosis of the LEL discrepancy. The studies devoted to ultrasound diagnostics and magnetic resonance imaging to assess the LEL discrepancy are one single nature and do not allow us to fully assess the advantages and disadvantages of these methods for assessing different limb lengths.

In addition, the difficulty of diagnosing the length discrepancy in the LEL lies in the fact that the results are compared with methods that also have inaccuracy. When directly measuring the bones of people of the Holocene epoch (modern people), the difference in the length of the thigh and lower leg is no more than 1% of the segment length [71], whereas according to studies describing the methods of clinical and visualizing methods for assessing the difference in size, different limb lengths in the population occur up to 90% of the population [1, 2], which indicates rather the high inaccuracy rate of the measurement methods used than the "epidemic" of dicrepancy.

## CONCLUSION

As the analysis of literature sources has shown, there is no universal method for diagnosing dicrepancy today. The development of new diagnostic techniques of different LEL, as well as the improvement of existing ones, will improve the quality of diagnosis of this pathological condition, and therefore the quality of treatment for its correction.

## DISCLAIMERS

### *Author contribution*

*Daria A. Petrova* — the collection and processing of material, writing the draft.

*Vladimir M. Kenis* — research conception, text editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information


✉ *Daria A. Petrova*
Address: 64-68, Parkovaya str., St. Petersburg, Pushkin, 196603, Russia
https://orcid.org/0000-0001-9641-191X
e-mail: radd.arr@mail.ru

*Vladimir M. Kenis* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-7651-8485
e-mail: kenis@mail.ru

Review Article
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# Surgical Approaches for Acetabulum Fracture Treatment: Analytic Review

Alexander I. Kolesnik [1], Sergey V. Donchenko [2], Vladislav V. Surikov [2,3], Dmitry A. Ivanov [4], Evgeniy P. Tarasov [5], Dmitry M. Yarmamedov [6], Ivan M. Solodilov [7]

[1] *Cytoproject LLC, Moscow, Russia*

[2] *Botkin City Clinical Hospital, Moscow, Russia.*

[3] *Russian Medical Academy of Continuing Postgraduate Education, Moscow, Russia*

[4] *Lytkarino City Hospital, Lytkarino, Russia*

[5] *Odintsovo City Hospital, Odintsovo, Russia*

[6] *Kursk State Medical University, Kursk, Russia*

[7] *Kursk City Clinical Hospital No. 4, Kursk, Russia*

***Background.*** The use of classical and modified surgical approaches to acetabulum is accompanied by serious intra- and postoperative complications associated with tissues, vessels, nerves, and lymphatic structures injury. The choice of approach to acetabulum affects the surgical time and the blood loss volume.
***The aim*** of the review was to compare the surgical time and blood loss volume using different surgical approaches to the acetabulum based on the relevant literature analysis.
***Methods.*** The search was carried out in PubMed/MEDLINE and Scopus databases from 1964 to 2022. When conducting a search for the phrases acetabular fractures, surgical approach to the acetabulum, 4368 articles were found. As a result of the selection, 12 publications containing the most complete information on the studied indicators were included in the quantitative analysis.
***Results.*** The data of surgical treatment of 540 patients with acetabulum fractures were analyzed. The average age of the patients was 45.2±11.6 years. Among the causes of pelvic and acetabulum fractures, road accident (70.4%) and falls from height (21.3%) largely prevailed. The blood loss depended on the use of specific approaches or their combination, and the surgical time. The shortest surgical time (101.0±27.0 min.) was required using pararectal approach, the longest (264±56.4 min.) — with the use of ilio-inguinal approach. The largest volume of blood loss was observed with Pfannenstiel approach — 1057.1±377.9 ml. No statistically significant differences were found when comparing the Kocher-Langenbeck (793±328 ml), ilio-inguinal (828±64 ml) and pararectal (798±322 ml) approach. Performing the Kocher-Langenbeck approach in the patient's lateral position reduces the surgical time by 16.8% and reduces blood loss by 12.4% compared to the patient's prone position.
***Conclusion.*** Comparative clinical studies are required to determine the safest surgical approaches to the acetabulum, depending on the type of fracture, the mechanism of injury and the age of the patient.

**Keywords:** surgical approaches to the acetabulum, acetabulum fractures, surgical time, blood loss volume.

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✉ *Alexander I. Kolesnik*; e-mail: ko-lesnik@mail.ru

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# Хирургические доступы при лечении переломов вертлужной впадины: аналитический обзор литературы

А.И. Колесник [1], С.В. Донченко [2], В.В. Суриков [2,3], Д.А. Иванов [4], Е.П. Тарасов [5], Д.М. Ярмамедов [6], И.М. Солодилов [7]

[1] *ООО «ЦИТОпроект», г. Москва, Россия*

[2] *ГБУЗ «Городская клиническая больница им. С.П. Боткина» Департамента здравоохранения г. Москвы, г. Москва, Россия*

[3] *ФГБОУ ДПО «Российская медицинская академия непрерывного профессионального образования» Минздрава России, г. Москва, Россия*

[4] *ГБУЗ МО «Лыткаринская городская больница», г. Лыткарино, Россия*

[5] *ГБУЗ МО «Одинцовская областная больница», г. Одинцово, Россия*

[6] *ФГБОУ ВО «Курский государственный медицинский университет» Минздрава России, г. Курск, Россия*

[7] *ОБУЗ «Курская городская клиническая больница № 4», г. Курск, Россия*

***Актуальность.*** Применение классических и модифицированных хирургических доступов к вертлужной впадине (ВВ) сопровождается серьезными интра- и послеоперационными осложнениями, связанными с травматизацией тканей, сосудов, нервов, лимфатических структур. Выбор доступа к ВВ влияет на длительность оперативного вмешательства и объем кровопотери.

***Цель обзора*** — на основе анализа литературы сравнить длительность оперативного вмешательства и объем кровопотери при использовании разных хирургических доступов к вертлужной впадине.

***Материал и методы.*** Поиск проводили в базах данных PubMed (MEDLINE) и Scopus с 1964 по 2022 г. При проведении поиска по словосочетаниям acetabular fractures, surgical approach to the acetabulum было найдено 4368 статьи. В результате отбора было включено в анализ 12 публикаций, содержащих наиболее полную информацию по изучаемым показателям.

***Результаты.*** Проанализированы данные оперативного лечения 540 пациентов с переломами ВВ. Средний возраст пациентов составил 45,2±11,6 лет. Среди причин травм таза и ВВ в значительной степени преобладали автодорожная травма (70,4%) и кататравма (21,3%). Объем кровопотери зависел от применения конкретных доступов или их комбинации и продолжительности оперативного вмешательства. Наименьшее количество времени (101,0±27,0 мин.) потребовалось для выполнения операций с использованием параректального доступа, наибольшее (264±56,4 мин.) — с применением подвздошно-пахового доступа. Наибольший объем кровопотери отмечен при доступе Пфанненштиля — 1057,1±377,9 мл. При сравнении доступов Кохера–Лангенбека (793±328 мл), подвздошно-пахового (828±64 мл) и параректального (798±322 мл) доступов не выявлено статистически значимых отличий. Выполнение доступа Кохера–Лангенбека в положении пациента лежа на боку позволяет сократить время операции на 16,8% и сократить объем кровопотери на 12,4% в сравнении с положением пациента лежа на животе.

***Заключение.*** Требуется проведение сравнительных клинических исследований для определения наиболее безопасных хирургических доступов к вертлужной впадине в зависимости от типа перелома, механизма травмы и возраста пациента.

**Ключевые слова**: хирургические доступы к вертлужной впадине, переломы вертлужной впадины, длительность операции, объем кровопотери.

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*Колесник Александр Иванович*; e-mail: ko-lesnik@mail.ru

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## BACKGROUND

The problem of surgical treatment of acetabular fractures remains relevant [1, 2, 3, 4, 5, 6]. The incidence of acetabular fractures ranges from 2% to 22% with an upward trend [1, 3, 7]. Classical and modified surgical approaches to the acetabulum are accompanied by serious intra- and postoperative complications in 8-59% of cases [3]. Complications are associated primarily with the traumatization of tissues, vessels, nerves, and lymphatic structures, operative time up to ≥3 h, and significant blood loss [1, 7, 8, 9, 10, 11], which become serious deterrents to the widespread use of approaches in the acute period of injury [12, 13, 14, 15, 16].

The review aimed to compare the operative time and blood loss volume when using different surgical approaches to the acetabulum based on the literature analysis.

## METHODS

The search was performed in PubMed (MEDLINE) and Scopus for the period from 1964 to 2022.

*The selection criteria*: full-text versions of articles and abstracts containing complete information on the most commonly used standard and modified surgical approaches to the acetabulum, age of the patients, mechanism of injury, operative time, blood loss volume, and patient's position on the operating table. The language of publications was English.

*The exclusion criteria*: experimental studies, clinical cases, and literature reviews.

When searching for the keywords "acetabular fractures" and "surgical approach to the acetabulum," 4368 articles were found, of which 12 publications that contained the most complete information on the studied parameters were selected [1, 11, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26].

### Statistical analysis

Data comparison was performed using SPSS Statistics for Windows, version 11.0 (SPSS Inc., Chicago, USA). Parametric and nonparametric data were compared using unpaired Student's t-test, Mann-Whitney U-test, and $\chi^2$ test. Differences were considered significant at $p < 0.05$.

## RESULTS

We analyzed the results of the surgical treatment of 540 patients with acetabular fractures, whose data are presented in the 12 publications selected for analysis (Table 1).

### Age of patients

The mean age of the patients in all studies was 45.2 ± 11.6 years. The youngest patients were registered in the studies by Khira et al. (32.9 [21.0-58.0] years) [17], Li et al. (32.1 ± 14.6 years) [18], and Salameh et al. (34.8 [18.0-60.0] years) [21]. Older patients were enrolled in the studies by Lont et al. (70 [56-92] years) [19] and T. Borg et al. (76.5 [64.0–89.0] years using the use of the Kocher-Langenbeck approach and 68.2 [50.0–83.0] years using the ilioinguinal approach) [1].

### Mechanism of injury and surgical approaches

Most patients were injured in traffic accidents (n = 184) [1, 16, 17, 19, 20, 22, 23, 24, 25]. A fall from a height of >3 m caused a fracture in 108 patients [1, 16, 17, 19, 20, 22, 23, 24, 25], whereas a fall from a height of <3 m caused a fracture in 65 patients [1, 19, 23, 24, 25]. In 11 patients, the injury resulted from falling heavy objects [21, 23]. Sports injury has been reported in nine patients [21]. Figure 1 presents a diagram of the approach to the acetabulum, taking into account the mechanism of injury. The graph presents data from nine sources because the mechanism of injury is not mentioned in other works.

### Classification of fractures and surgical approaches

In 11 studies, the nature of acetabular fractures was classified according to Judet-Letournel. Fracture of both columns was noted in four studies [1, 16, 22, 25]. Borg et al. and Ozturk et al. used Kocher-Langenbeck and ilioinguinal approaches [1, 25], Xue et al. used Kocher-Langenbeck and Pfannenstiel approaches [16], and Wang et al. used the pararectal approach to the anterior column [22] (Fig. 2).

*Table 1*

**The use of surgical approaches and indications for surgery**

| Author | Observation period | Surgical approach | Number of patients | Age, years | Operative time, min. | Blood loss, ml |
|---|---|---|---|---|---|---|
| Borg T. [1] | 2003–2014 | Kocher-Langenbeck | 16 | 76,5 (64–89) | 188 (175–321) | 800 (400–1700) |
| | | Ilio-inguinal | 10 | 68,2 (50–83) | 166 (95–354) | 675 (300–2600) |
| Harris A. [11] | 1990–1998 | Kocher-Langenbeck | 51 | 34,9 (16–64) | 320 (140–503) | 1735 (300–4000) |
| Xue Z. [16] | 2011–2012 | Pfannenstiel | 7 | 37 (18–53) | 158,57±28,54 | 1057,14±377,96 |
| | | Kocher-Langenbeck | 8 | 37 (18–53) | 278,12±62,33 | 937,50±362,28 |
| Khira Y. [17] | 2009–2017 | Kocher-Langenbeck | 20 | 32,9 (21–58) | 135±20 (120–160) | 780±350 (500–1500) |
| Li Y. [18] | 2013–2017 | Kocher-Langenbeck | 9 | 37±17,09 | 71,28±9,69 | 742,22±228,68 |
| Lont T. [19] | 2000–2017 | Kocher-Langenbeck | 34 | 70 (56–92) | 169 | 1100 |
| Kashyap S. [20] | 2012–2015 | Kocher-Langenbeck | 30 | 48±24 | 215±55 | 570±160 |
| Salameh M. [21] | 2010–2017 | Kocher-Langenbeck (decubitus) | 47 | 36,6 (20–67) | 184,2±57,5 | 551±299 |
| | | Kocher-Langenbeck (prone) | 26 | 34,8 (18–60) | 241,4±106,7 | 584±365 |
| Wang C. [22] | 2016–2017 | prone | 50 | 45,1±12,6 | 170,7±40,6 | 1177,1±691,6 |
| Wang P. [23] | 2013–2016 | Ilio-inguinal | 47 | 41,5±11,7 | 264,0±56,4 | 873,8±535,6 |
| Yang Y. [24] | 2014–2018 | Ilio-inguinal | 44 | 41,89±14,19 | 156,18±27,54 | 784,09±277,70 |
| | | Ilio-inguinal + Stoppa | 32 | 39,94±15,21 | 126,53±29,56 | 625,31±193,39 |
| Ozturk A. [25] | 2017–2018 | Kocher-Langenbeck | 12 | 41,9 | 199,16±24,75 | 511,66±127,33 |
| | | Ilio-inguinal | 5 | 46,2 | 200,00±25,49 | 488,00±111,89 |

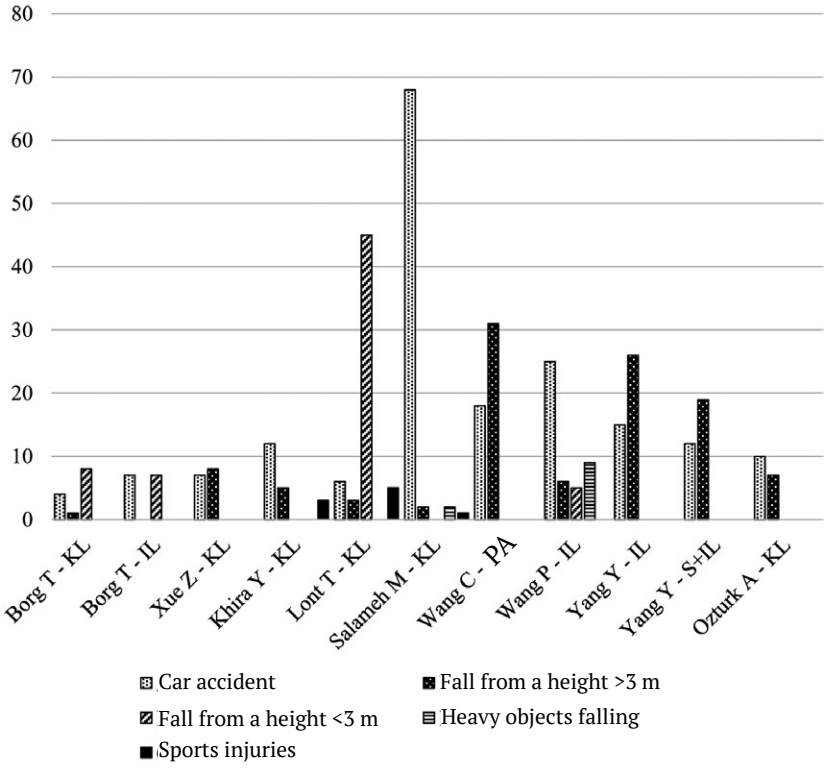


**Fig. 1.** The choice of approach to acetabulum depending on the mechanism of injury. *Abbreviations hereafter*: KL — Kocher-Langenbeck approach; IL — iliac-inguinal approach; S — Stoppa approach; PA — pararectal approach

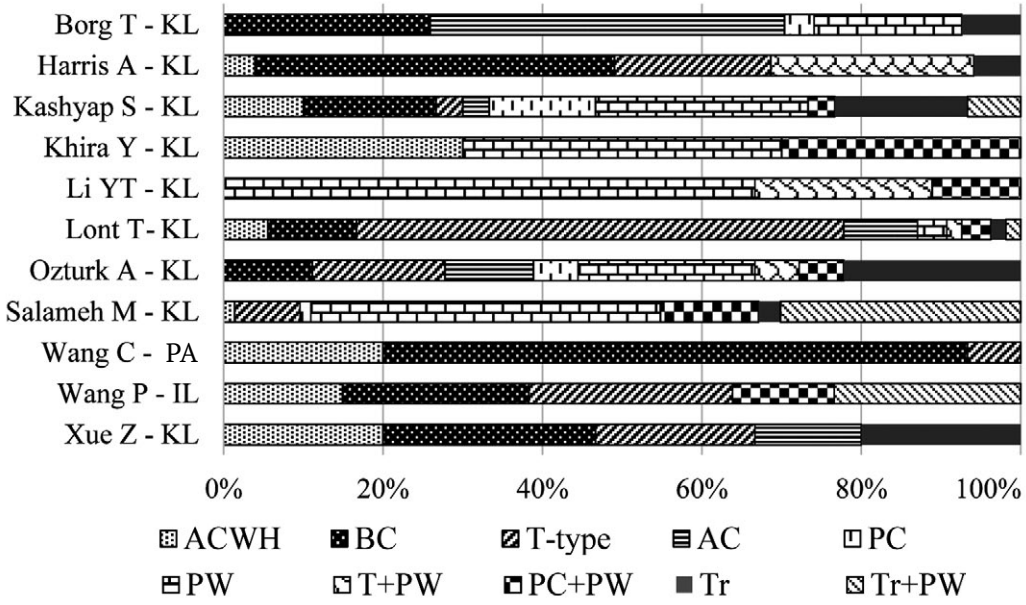


**Fig. 2.** Classification of acetabulum fractures according to Judet-Letournel in the cited sources. Percentages indicate the proportion of acetabulum fractures types from their total number

ACWH — fractures of the anterior column and hemitransverse fracture of the acetabulum posterior column; BC — fracture of both columns; T-type — T-shaped fracture; AC — fracture of the anterior column; PC — fracture of the posterior column; PW — fracture of the posterior wall; Tr — transverse acetabulum fracture

Fractures of the anterior column in combination with a semitransverse fracture of the posterior column of the acetabulum were recorded in 65 patients [1, 16, 19, 22, 23]. Fractures of the posterior wall were detected in 56 patients [1, 16, 17, 19, 21, 25]. A transverse fracture combined with a fracture of the posterior wall was found in 45 patients [1, 17, 19, 21, 23, 25], and a T-shaped fracture was registered in 36 patients [16, 19, 21, 22, 23, 25].

## Operative time and blood loss depending on the surgical approach to the acetabulum

The indicators of operative time and blood loss during surgical intervention using various approaches in patients with acetabular fractures were analyzed in all 12 publications (Fig. 3).

Wang et al. performed surgery on 50 patients using the pararectal approach. A comparative analysis revealed that the pararectal approach required the shortest time (101.0±27.0 min) to perform surgery [22]. The longest time to perform the surgery using the ilioinguinal approach was noted in the study by Wang et al. (264.0±56.4 min) [23].

Wang et al. recorded blood loss of 1177.1± 691.6 mL when using the pararectal approach [22]. The average blood loss volume was 844.8±368.8 mL in multiauthored publications using the Kocher-Langenbeck approach [1, 11, 16, 17, 18, 19, 20, 21]. When using the ilioinguinal approach, the average blood loss was 689.2±148.2 mL [1, 23, 24, 25].

## Results of surgical treatment using the Kocher-Langenbeck approach in the prone and lateral positions

The authors of the cited sources analyzed the operative time and blood loss in 106 patients aged between 36.6 (20–67) and 47.2 (24–69) years [16, 18, 20, 21, 25] and 97 patients aged 32.9 between (21–58) and 34.9 (16–64) years [11, 18, 22] when performing the Kocher-Langenbeck surgical approach with the patients in the prone and lateral positions (Fig. 4). The surgical intervention with the patient in the lateral position allows the reduction of the operative time by 16.8% and blood loss by 12.4% in comparison with the prone position [17, 18, 19, 20, 21] (Fig. 4).

## Results of the classic ilioinguinal and Stoppa's ilioinguinal approaches

Several authors analyzed the results of using the classic ilioinguinal approach (n=96, 128 cases) [23, 24, 25] and Stoppa's ilioinguinal approach (n=32) [24]. The mean age of the patients was 42.7±3.4 years (Fig. 5). The use of the modified Stoppa approach allows the reduction of the operative time by 40%. The blood loss volume was the greatest when using the classic ilioinguinal approach (828.9±63.4 mL). Less blood loss was recorded when using the modified Stoppa approach (625.3 mL).

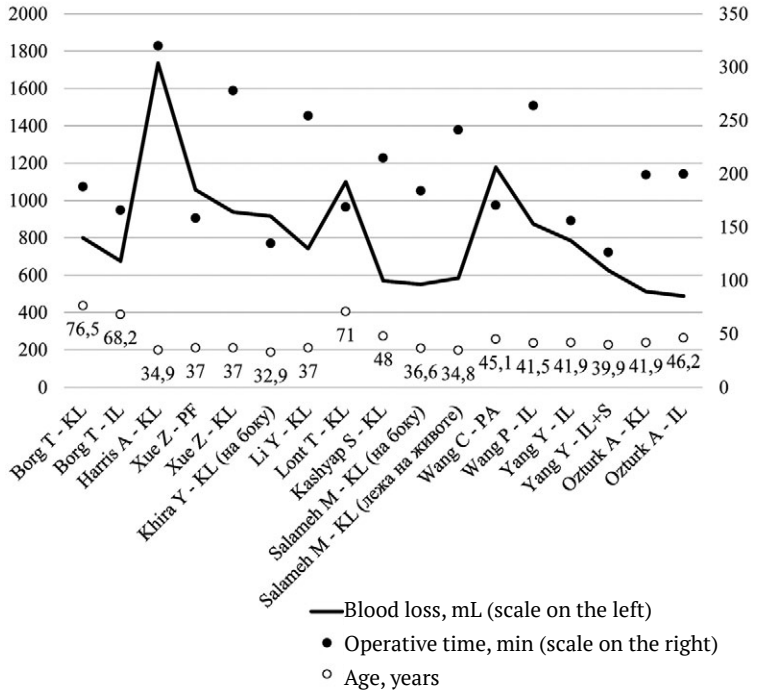


**Fig. 3.** Operative time, blood loss and the age of patients with various surgical approaches to the acetabulum

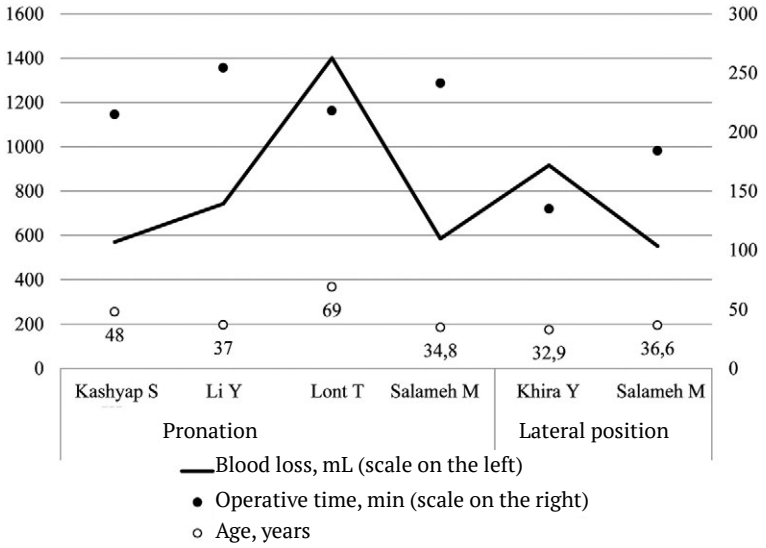


**Fig. 4.** Operative time, blood loss and the age of the patients during the surgery using the Kocher-Langenbeck approach in the supine position and lateral position

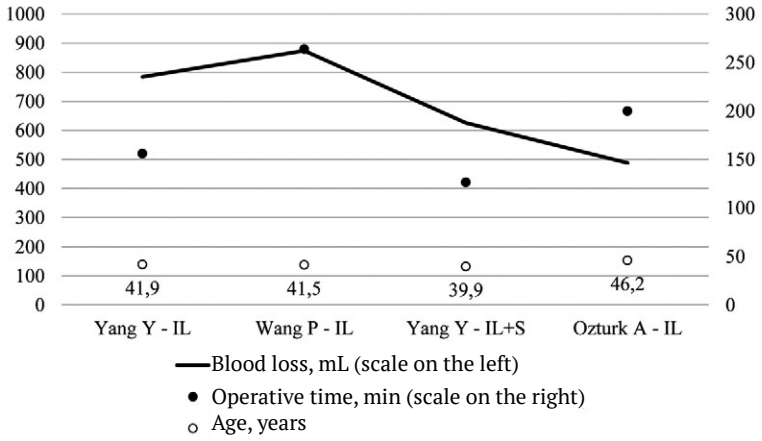


**Fig. 5.** Operative time, blood loss and the age of patients during surgery through the classical iliac-inguinal approach and iliac-inguinal approach in the Stoppa modification

## DISCUSSION

As noted above, the choice of approach in the surgical treatment of acetabular fractures affects the operative time, blood loss, and treatment outcomes. In turn, the choice of approach is determined by various factors, such as the patient's age, fracture type, mechanism of injury, etc.

According to Giannoudis et al., the mean age of patients who underwent surgery for acetabular fractures was 38.6±4.6 years, with men accounting for 69.4% [26]. Goyal et al. included patients with acetabular fractures aged >55 years, with a mean age of 72.5 years [14].

Acetabular fractures with a low-energy injury mechanism mainly occur in older patients. In young patients, a high-energy mechanism of injury is noted [6, 27, 28, 29, 30, 31, 32, 33].

In all publications the authors used the classification of acetabular fractures [developed by Judet and Letournel [33, 34]. Butler et al. indicated the fundamental significance and latent potentialities of this classification [35]. Letournel, the author of the classification, highlighted that the classification of acetabular fractures can be modified in relation to older patients [33, 34]. Some authors believe that the complexity of treatment of acetabular fractures in older patients is attributed to their fracture types, namely, more frequent fractures of the anterior acetabular column, quadrangular surface, and compression of the cartilage of the articular surface [6, 36, 37]. Goyal et al. noted that fractures of both columns are the most common fractures in their patients (19.03%), fractures of the anterior column in combination with a semitransverse fracture of the posterior wall were less common (17.23%), fractures of the anterior column were registered in 541 of 3157 (17.13%) cases, and posterior wall fractures were noted in 425 of 3157 (13.46%) patients [14]. In younger patients, fractures of the posterior wall are more common, whereas transverse fractures of the acetabulum in combination with a fracture of the posterior wall and T-shaped fractures are less common [38, 39].

A literature analysis revealed that the blood loss depends on the approach, i.e., alone or in combination, and accordingly on operative time. The operative time between the Kocher-Langenbeck approach and the modified Stoppa approach was not significantly different. Moreover, the direct dependence of the blood loss on the operative time is expected as confirmed by other authors [26, 40, 41, 42].

Among 203 patients with acetabular fractures who underwent surgery using the Kocher–Langenbeck approach, surgeries were performed in 52.2% (n = 106) of cases with the patient in the lateral position, which reduced the operative time by 16.8% and blood loss by 12.4% in comparison with that in the prone position [17, 18, 20, 21]. In our opinion, the question of using the Kocher-Langenbeck approach in various positions on the operating table requires further study.

The ilioinguinal approach was used in 75% (n = 96) of cases, and the Stoppa ilioinguinal approach — in 25% (n = 32) of cases. According to the data obtained, Stoppa approach allows the reduction of operative time by 40% and blood loss by 11% compared with the classical ilioinguinal approach.

The authors of the analyzed publications used surgical approaches initially taking into account fractures of the acetabular columns (isolated and simultaneous fractures of the anterior and posterior columns) [43, 44, 45, 46]. In principle, in fractures of the anterior column and anterior wall of the acetabulum, the authors used the ilioinguinal or Stoppa approach [46, 47, 48, 49, 50, 51].

## CONCLUSION

Comparative clinical studies are needed to determine the safest surgical approaches to the acetabulum depending on the fracture type, injury mechanism, and patient age.

## DISCLAIMERS

### *Author contribution*

*Kolesnik A.I.* — research concept and design, the collection and processing of material, writing the draft, editing.

*Donchenko S.V.* — research concept and design, the collection and processing of material, writing the draft, editing.

*Surikov V.V.* — the collection and processing of material, writing the draft, editing.

*Ivanov D.A.* — the collection and processing of material, writing the draft, editing.

*Tarasov E.P.* — the collection and processing of material, writing the draft, editing.

*Yarmamedov D.M.* — the collection and processing of material, writing the draft, editing.

*Solodilov I.M.* — the collection and processing of material, writing the draft, editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Competing interests.*** The authors declare that they have no competing interests.

***Ethics approval.*** Not applicable.

***Consent for publication.*** Not required.

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## Authors' information

✉ *Alexander I. Kolesnik* — Dr. Sci. (Med.), Professor
Address: 24, Onezhskaya str., Moscow, 125413, Russia
https://orcid.org/0000-0003-1435-8743
e-mail: ko-lesnik@mail.ru

*Sergey V. Donchenko* — Cand. Sci. (Med.)
https://orcid.org/0000-0003-3341-7446
e-mail: Don_03@mail.ru

*Vladislav V. Surikov*
https://orcid.org/0000-0003-3668-2376
e-mail : Airbag366@yandex.ru

*Dmitry A. Ivanov*
https://orcid.org/0000-0002-5821-6774
e-mail : Ivanovda2001@mail.ru

*Evgeniy P. Tarasov*
https://orcid.org/ 0000-0002-3960-0148
e-mail: t.john@mail.ru

*Dmitry M. Yarmamedov*
https://orcid.org/0000-0002-4580-5502
e-mail: D-yarmamedov@mail.ru

*Ivan M. Solodilov* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-8219-5582
e-mail: Ivan_s_007@mail.ru

Letter
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# Dissection and Permissible Levels of Proximal Mobilization of Anterior Tibial Vessels During Island Flaps Transfer

Aleksandr Yu. Kochish [1], Andrei A. Ostapchenko [2]

[1] *Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian*
[2] *Health Technologies, St. Petersburg, Russia*

The article presents a discussion with the authors of a previously published article (Zelyanin D.A. et al. Features of the Extraction of the Anterior Tibial Vessels in the Formation of Vascularized Bone Grafts. Traumatology and Orthopedics of Russia. 2022. Vol. 28, No 1. p. 89-99), as well as on the basis of our own topographic and anatomical studies, the information about the details of the topography of the branches of the anterior tibial vascular bundle (ATVB) and the permissible levels of its proximal mobilization during island flaps transfer are justified.

Topographic and anatomical study was performed on 32 non-fixed speciments of the lower extremities for substantiating plastic surgery with island skin flaps isolated on ATVB. The arterial bed of the lower leg was injected with black natural latex Revultex, followed by precision dissection and measurements of all branches of the anterior tibial artery (ATA) with a diameter of 0.3 mm or more using a binocular magnifier with a magnification of 3.3 times. All the studied branches of ATA were identified, the number of which varied from 26 to 49 (on average 38.5–3.2), and 88.7% of them went to the three muscles of the anterior group of the lower leg. At the same time, the average numbers of ATA branches departing in each of the 10% intervals of the length of the lower leg were determined, and the average total values of the cross-sectional area of arterial branches in these intervals were calculated. It was found that from 28% to 39% of the total cross-section of all branches of the ATA are localized in the first and second 10% intervals of the length of the lower leg, which makes it possible to justify the proximal limit of the mobilization of the ATVB. Reasonable criteria for choosing the level of proximal mobilization of the ATVB are: the location of the mobilization border is not higher than the level of the upper 20% of the length of the lower leg, the assignment of this border, at least 6 cm distal from the exit of the anterior tibial vessels into the anterior bone fascial sheath of the lower leg and the preservation of at least four feeding vascular bundles extending from the ATVB to the tibialis anterior muscle (two bundles) and to the extensor digitorum longus muscle (two bundles).

**Keywords:** pedicled flaps transfer, island flaps, lower leg, anterior tibial vascular bundle, topographical anatomy.

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✉ *Aleksandr Yu. Kochish*; e-mail: auk1959@mail.ru

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# Особенности выделения и допустимые уровни проксимальной мобилизации передних большеберцовых сосудов при несвободной пересадке кровоснабжаемых комплексов тканей

А.Ю. Кочиш [1], А.А. Остапченко [2]

[1] *ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*
[2] *ООО «Технологиии здоровья», г. Санкт-Петербург, Россия*

В статье представлена дискуссия с авторами ранее опубликованной статьи (Зелянин Д.А. с соавт. Особенности выделения передних большеберцовых сосудов при формировании костных васкуляризированных трансплантатов. Травматология и ортопедия России. 2022. Т. 28, № 1. с. 89-99).
На основании собственных ранее выполненных топографо-анатомических исследований представлены сведения о деталях топографии ветвей переднего большеберцового сосудистого пучка (ПБСП) и обоснованы допустимые уровни его проксимальной мобилизации при несвободной пересадке кровоснабжаемых комплексов тканей. Прикладное топографо-анатомическое исследование выполнено на 32 нефиксированных препаратах нижних конечностей с целью обоснования операций пластики островковыми кожными лоскутами, выделенными на ПБСП. Артериальное русло голени инъецировали черным натуральным латексом Revultex с последующим прецизионным препарированием и измерениями всех ветвей передней большеберцовой артерии (ПБА) диаметром 0,3 мм и более при помощи бинокулярной лупы с увеличением в 3,3 раза. Были установлены все изученные ветви ПБА, число которых варьировало от 26 до 49 (в среднем 38,5–3,2), а 88,7% из них отходили к трем мышцам передней группы голени. При этом были установлены средние количества ветвей ПБА, отходящих в каждом из 10% интервалов длины голени, а также рассчитаны средние суммарные значения площади поперечного сечений артериальных ветвей в указанных интервалах. Было установлено, что от 28% до 39% суммарного поперечного сечения всех ветвей ПБА локализуются в первом и втором 10% интервалах длины голени, что позволяет обосновать проксимальную границу мобилизации ПБСП. Обоснованными критериями при выборе уровня проксимальной мобилизации ПБСК являются: расположение границы мобилизации не выше уровня верхних 20% длины голени, отнесение этой границы как минимум на 6 см дистальнее места выхода передних большеберцовых сосудов в передний костно-фасциальный футляр голени и сохранение не менее четырех питающих сосудистых пучков, отходящих от ПБСП к передней большеберцовой мышце (два пучка) и к длинному разгибателю пальцев (два пучка).

**Ключевые слова:** несвободная передка кровоснабжаемых комплексов тканей, островковые лоскуты голени, передний большеберцовый сосудистый пучок, топографическая анатомия.

Кочиш А.Ю., Остапченко А.А. Особенности выделения и допустимые уровни проксимальной мобилизации передних большеберцовых сосудов при несвободной пересадке кровоснабжаемых комплексов тканей. *Травматология и ортопедия России*. 2022;28(3):116-122. https://doi.org/10.17816/2311-2905-1806.

*Кочиш Александр Юрьевич*; e-mail: auk1959@mail.ru

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The article is interesting and informative, as it includes materials of our own applied topographic and anatomical research performed to rationalize complex reconstructive techniques involving transfer of vascularized pedicled bone flaps from the foot and lower leg to the hip area [1]. In our opinion, it is precisely anatomical and clinical approach, the traditions of which were founded in our country by N.I. Pirogov, that is often required for the successful integration of new surgical techniques into clinical practice.

However, the focus of the authors attention was focused on clarifying the features of the deep peroneal nerve branches topography, and the main practical direction of the study is related to the possibilities of preserving these branches during dissection of the vascularized pedicled bone flaps on the anterior tibial vascular bundle. At the same time, the actual applied anatomy of these vessels, well studied in other authors articles [2, 3, 4, 5], it has remained insufficiently discussed, which can lead to mistakes and complications after such operations. Therefore, we decided to draw attention to the results of our earlier topographic and anatomical studies performed to justify techniques with fascio-cutaneus island flaps, which were also dissected on the anterior tibial vessels of the lower leg and transferred in pedicled version to replace extensive and deep defects of soft tissues in the foot or knee joint [5, 6]. More than 30 such surgeries were performed in the period from 1988 to 2000 in the clinic of thermal lesions of the Military Medical Academy named after S.M. Kirov by our teacher — professor S.H. Kichemasov [2, 6, 7]. In our opinion, the results of our previously applied topographic and anatomical studies, the experience of participating in these surgeries and observing the patients afterwards can be a valuable addition to this article and will facilitate for specialists the development of complex of vascularized pedicled bone flaps transferred on the anterior tibial vessels.

First of all, authors would like to draw attention to the results of the applied topographic and anatomical study of the anterior tibial vessels [4], which were summarized in 2004 as part of the A.A. Ostapchenko PhD dissertation. In the course of this study, performed on 32 non-fixed preparations of the lower extremities by precision dissection, the topography of the anterior tibial artery (ATA) and all its branches with a diameter of 0.3 mm and larger was thoroughly studied. At the same time, the arterial bed of the lower leg was pre-injected with black natural latex Revultex, and preparation and measurements were performed using binocular loupes, which provided x3.3 magnification.

According to the results of these studies, several possible variants of dissection and pedicled transfer of fascio-cutaneus island flaps of the lower leg, which were formed in the middle third of the lower leg on the branches of the anterior tibial veins and transferrd on a permanent proximal (option 1) or distal (options 2 and 3) vascular pedicle (Fig. 1). The first variant offered the mobilization of the anterior tibial vessels in the anterior bone-fascial bed of the lower leg using a technique almost identical to that described in the article by D.A. Zelyanin et al. [1]. However, the possible limits of the dissection in the proximal direction of the anterior taibial vascular bundle, accompanied by ligation and intersection of all more distal branches of this main vascular bundle of the lower leg, differed, since they took into account the results of their own topographic and anatomical study, the most important applied details of which are presented below.

On the studied anatomical material, ATA penetrated into the anterior bone-fascial sheath of the lower leg through the gap in the interosseous membrane located below the level of the knee joint gap by an average of 4.8 ± 0.9 cm (variability — from 3.6 to 6.1 cm). Its diameter at this point

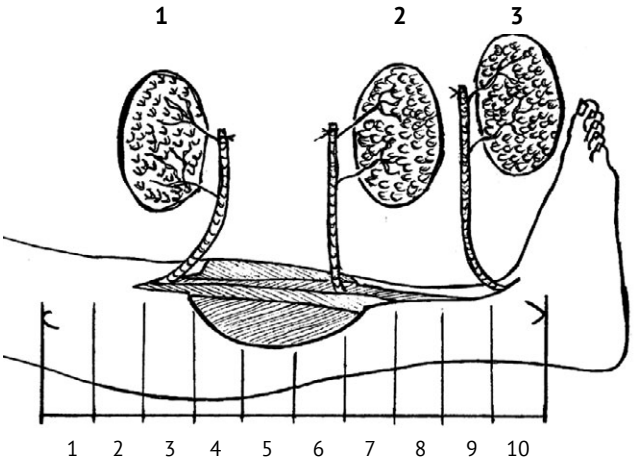


**Fig. 1.** Scheme of possible options for the formation of island complex skin flaps on the anterior tibial vascular bundle in relation to 10% intervals of the lower leg length

varied from 2.7 to 6.1 mm, and averaged 4.5 ± 0.7 mm. Passing further in the indicated compartment, the ATA formed from 26 to 49 (on average 38.5± 3.2) branches with a diameter of 0.3 mm and larger, most of which (88.7%) were muscular and were directed to the tibialis anterior muscle (TAM), the extensor digitorum longus muscle (EDLM) or the extensor hallucis longus muscle (EHLM).

The performed precision dissection of the branches of the ATA revealed the uneven nature of their distribution on the lower leg, which was important in relation to the studied techniques. Therefore, in the future, an analysis was undertaken of the distribution of the identified arterial branches over 10% intervals of the length of the tibia, which was measured from the tip of the fibula head to the tip of the lateral ankle, varied from 30 to 44 cm on the studied anatomical material, and averaged 35.6 ± 3.2 cm. The results of this analysis are presented in the histogram (Fig. 2).

It was found that in the first 10% interval, ATA gave a relatively small number of branches, and on a number of preparations (27% of observations), the place of its exit into the anterior bone-fascial compartment was generally in the second 10% interval. At the same time, the branches of the first two intervals were directed not only to the muscles of the anterior group of the lower leg, but also to the tibia and fibula and to the knee joint. In the third, fourth, fifth, sixth and seventh 10% intervals, the branches of the ATA departed relatively evenly every 4-11 mm and were directed mainly to the TAM, EDLM or EHLM (Fig. 3). In the eighth, ninth and tenth 10% intervals of lower leg length, ATA branches were statistically significantly less common ($p<0.05$) than in the third-seventh intervals. They supplied blood to the EHLM, the tendons of the anterior group muscles of the lower leg, the periosteum of the tibia and the skin, and also participated in the formation of the ankle network of arterial anastomoses.

The performed precision dissection of the ATA branches showed that the largest of them are located with regular constancy in the first and second 10% intervals of the length of the lower leg. This is confirmed by the calculations of the total cross-section of the branches of the ATA for each of these intervals, which was determined by the formula $S = \varpi(D/2)2$ using the results of measurements of the diameters (D) of the studied arterial branches. The average values of the cross-sectional area of these branches for each of the 10% intervals of the lower leg length are shown in Figure 4.

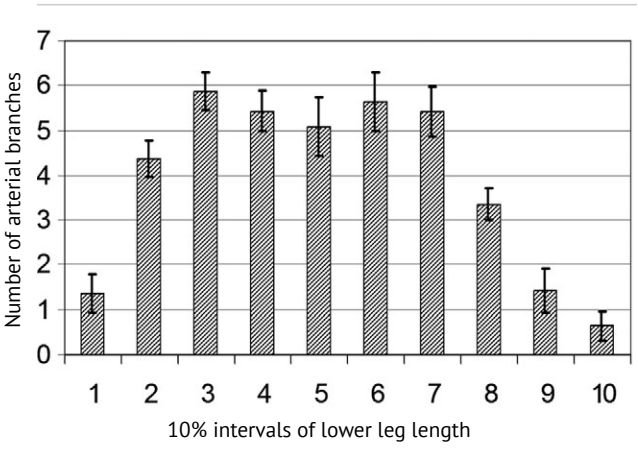


**Fig. 2.** The anterior tibial artery branches distribution over 10% intervals of the lower leg length (here and further, the height of the column reflects the arithmetic mean value on the interval, and the inaccuracy bars are 95% CI)

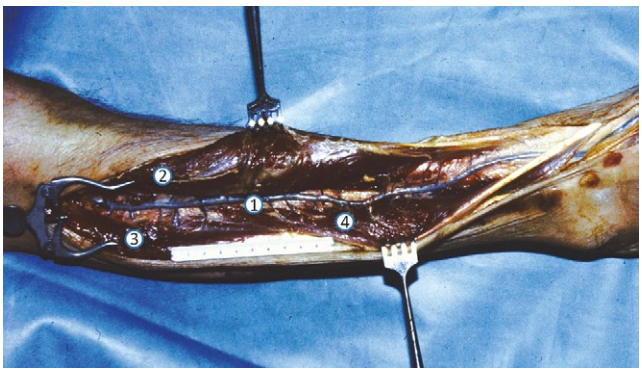


**Fig. 3.** Branches of the anterior tibial artery to the muscles of the anterior group of the right lower leg; injection of arteries with black latex:
1 — arteria tibialis anterior;
2 — musculus tibialis anterior;
3 — musculus extensor digitorum longus;
4 — musculus extensor hallucis longus

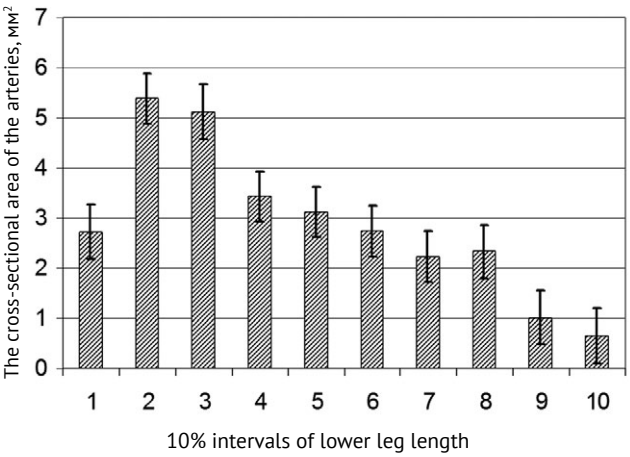


**Fig. 4.** Histogram of the anterior tibial artery branches average total cross sections distribution over 10% intervals of the lower leg length

At the same time, on the studied preparations, the values of the total cross-section of the branches of the ATA in the first and second intervals ranged from 28% to 39% of this indicator for all branches of the ATA. The predominance of the largest branches of anterior tibialis vessels within the most proximal 20% of the length of the lower leg is also clearly visible on the presented preparation (Fig. 5). In our opinion, this pattern has important practical significance for substantiating the surgical technique.

Taking into account the above, we consider it expedient and justified the level of proximal mobilization of anterior tibialis vessels to the lower edge of the second 10% interval of the lower leg length, within which the largest branches of this vascular bundle are localized to TAM and EDLM. Branches to the EHLM in the proximal parts of the lower leg do not depart from the ATA at all, since this muscle begins at the border of the middle and lower thirds of this segment, but its blood supply is also provided by branches of the peroneal artery and veins passing in the anterior intermuscular septum of the lower leg. The point of rotation of the tissue complex isolated on the anterior tibialis vessels will be located with the indicated variant of vascular mobilization 7-8 cm distal to the apex of the fibula head and 9-10 cm below the knee joint gap. A more proximal level of mobilization of anterior tibialis vessels in order to increase the length of the feeding vascular pedicle and the rotation arc of the isolated vascularized bone flaps, in our opinion, is dangerous with undesirable consequences for the function of the two largest muscles of the anterior tibia group - TAM and EDLM due to their ischemic injuries.

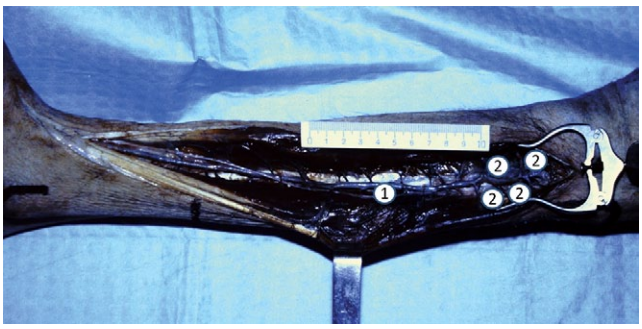


**Fig. 5.** Major branches of the anterior tibial artery extending in the second 10% interval of the lower leg length; injection of arteries with black latex:
1 — arteria tibialis anterior;
2 — major arterial branch

In the course of previously performed surgeries of pedicled fascio-cutaneus flaps into the knee joint area, we have always adhered to the rule to stop the proximal mobilization of anterior tibialis vessels at a level of at least 6 cm from the exit of these vessels into the anterior bone-fascial compartment of the lower leg. At the same time, it was monitored that at least two large (more than 3 mm in diameter) feeding vascular bundles extending from the anterior tibialis vessels entered each of the two muscles — TAM and EDLM — more proximally. In our opinion, it is precisely due to this that in none of our clinical observations in the postoperative period there was a significant loss of the function of the extensors of the foot and its fingers, as well as signs of critical ischemia of the muscles of the anterior group of the lower leg.

It should be noted that the authors of this article recommend a more proximal mobilization of the anterior tibialis vessels — up to a level 4 cm distal to the exit of these vessels into the anterior bone-fascial compartment of the lower leg. This gives a gain in the length of the arc of proximal rotation of bone autografts by 4 cm compared to the level recommended by us — 6 cm more distal than the passage of anterior tibialis vessels through the interosseous membrane on the lower leg. However, with a higher mobilization of an-

terior tibialis vessels, it remains unclear which of its branches are preserved and nourish the functionally important muscles of TAM and EDLM. At the same time, the article does not provide data on ischemic lesions and loss of function of the muscles of the anterior group of the lower leg after such operations in the clinic.

I would also like to express my opinion on the issue of maximum preservation of the branches of the deep peroneal nerve during the mobilization of anterior tibialis vessels, which, of course, should be desired. In this regard, the data on the details of the topography of the branches of this nerve, presented in the article, are significant and useful for surgeons.

However, judging by our observations, the largest branches of the deep fibular nerve to the muscles of the anterior group of the lower leg can always be preserved during the mobilization of anterior tibialis vessels, provided with optical magnification (binocular loupes) and microsurgical instruments. Therefore, a more important condition for the preservation of the function of these muscles, in our opinion, is the sufficiency of their blood supply after the mobilization of the anterior tibial vessels. Ischemic damage to these muscles can undoubtedly cause even more significant violations of their contractile function than partial denervation due to the intersection of several small branches of the deep fibular nerve.

In our opinion, the extensive mobilization of anterior tibialis vessels during the surgery, involving the ligation of all its branches in the distal parts of the lower leg for about 25-30 cm (or about 75% of the segment length), seems to be quite dangerous in terms of maintaining adequate blood supply to the muscles of the anterior group of the lower leg. In the course of our previous interventions, the branches of the anterior tibialis vessels were ligated for a maximum of 15-20 cm (or about 50% of the segment length) and mainly only in the middle third of the lower leg. At the same time, pedicled fascio-cataneus flaps on the distal vascular pedicle transfer was most often performed for the reconstruction of severely damaged feet, when maintaining sufficient function of their extension was not a priority. In patients with the femur non-union, the preservation of the function of the muscles of the anterior group of the lower leg can be very important, and serious ischemic disorders in this area can occur many years later due to atherosclerotic lesions of the arterial bed of the lower extremities. Therefore, taking into account the above, all the advantages and disadvantages of complex techniques with transfer of vascularized pedicled bone flaps isolated on a permanent vascular pedicle, including anterior tibialis vessels, should be carefully weighed in the preoperative period, taking into account the individual characteristics of each individual patient.

The authors of this discussion article hope that the applied anatomical information presented in it and the experience of previously performed transfer of vascularized pedicled bone flaps on the anterior tibialis vessels will be useful for surgeons conducting the complex reconstructions, and the level of proximal mobilization of the anterior tibial vessels chosen by them will continue to take into account the criteria justified by us. These, in our opinion, include the location of the proximal border of the mobilization of the anterior tibial vascular bundle not higher than the level of the upper 20% of the length of the tibia (when measured from the tip of the fibula head to the tip of the lateral malleolus), the assignment of this border is at least 6 cm distal to the exit point of the anterior tibial vessels into the anterior bone-fascial compartment of the tibia and the preservation of at least four sufficiently large (with a diameter of more than 3 mm) feeding vascular bundles, extending from the anterior tibialis vessels to the anterior tibial muscle (at least two bundles) and to the extensor digitorum longus muscle (at least two bundles).

## DISCLAIMERS

***Author contribution***

Authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information


✉ *Aleksandr Yu. Kochish* — Dr. Sci. (Med.), Professor
Address: 8, Akademika Baykova str., St. Petersburg, 195427, Russia
https://orcid.org/0000-0002-2466-7120
e-mail: auk1959@mail.ru
*Andrei A. Ostapchenko* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-2660-9469
e-mail: aostap@gmail.com

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# Diagnosis of Deep Periprosthetic Infection of the Hip

Valery Yu. Murylev[1,2], Alexander I. Rudnev[1], Grigory A. Kukovenko[1,2], Pavel M. Elizarov[1,2], Aleksey V. Muzychenkov[1,2], Semen S. Alekseev[2]

[1] *Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russian*

[2] *Botkin Moscow City Hospital, Moscow, Russian*

Periprosthetic infection (PJI) is one of the most frequent and devastating complications of total hip arthroplasty (THA). Early and accurate diagnosis of PJI allows timely initiation of treatment. Various diagnostic tools and algorithms for hip PJI diagnosis are described. The available serum (ESR, CRP, D-dimer, etc.) and synovial (alpha-defensin, leukocyte esterase, D-lactate) biomarkers are listed, as well as their combinations for the purpose of PJI verification. Combined serum and synovial tests can significantly improve the efficiency of PJI hip diagnosis.

**Keywords:** deep periprosthetic infection of hip, laboratory diagnosis of hip periprosthetic infection, synovial biomarkers, serum biomarkers.

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✉*Valery Yu. Murylev*; e-mail: nmuril@yandex.ru

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# Диагностика глубокой перипротезной инфекции тазобедренного сустава

В.Ю. Мурылев[1,2], А.И. Руднев[1], Г.А. Куковенко[1,2], П.М. Елизаров[1,2], А.В. Музыченков[1,2], С.С. Алексеев[2]

[1] *ФГАОУ ВО «Первый Московский государственный медицинский университет им. И.М. Сеченова (Сеченовский Университет)», Минздрава России, Москва, Россия*

[2] *ГБУЗ «Городская клиническая больница им. С.П. Боткина» Департамента здравоохранения г. Москвы, Москва, Россия*

Перипротезная инфекция (ППИ) является одним из наиболее частых и разрушительных осложнений эндопротезирования тазобедренного сустава (ТБС). Ранняя и точная диагностика ППИ позволяет своевременно начать лечение. Описаны различные диагностические инструменты и алгоритмы диагностики ППИ ТБС. Перечислены имеющиеся сывороточные (СОЭ, СРБ, D-димер и др.) и синовиальные (альфа-дефенсин, лейкоцитарная эстераза, D-лактат) биомаркеры, а также их комбинации с целью верификации ППИ. Объединение сывороточных и синовиальных тестов позволяет значительно повысить эффективность диагностики ППИ ТБС.

**Ключевые слова:** диагностика перипротезной инфекции тазобедренного сустава, синовиальные биомаркеры, сывороточные биомаркеры.

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*Мурылев Валерий Юрьевич*; e-mail: nmuril@yandex.ru

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## BACKGROUND

Annually registers of total hip arthroplasty (THA) reported an increasing number of primary hip arthroplasty surgeries [1, 2, 3, 4]. Hence, the number of complications increases, of which the most dangerous is periprosthetic joint infection (PJI). The same registries of arthroplasty reported that PJI ranks one of the first among the reasons for revision procedures on the hip joint following primary arthroplasty. PJI ranked second in the structure of the causes of revision THA at 40.8%, following the aseptic loosening of the components, according to the Vreden Russian Scientific Center of Traumatology and Orthopedics in 2007-2020 [1].

Ahmed et al. revealed that the need of the population for THA will increase by 400% in 2030. Hence, PJI will rank first among the reasons for revision interventions after primary THA due to a decreased frequency of revisions for aseptic loosening of components and revisions for wear of bearings [2].

Nowadays, PJI is the most life-threatening complication, requiring repeated revision interventions and long courses of systemic antibacterial drugs in some cases, which cause quality of life deterioration in patients, bone and muscle tissue deficiencies, and an extensive cicatricial adhesion in the operated joint area. Postoperatively, patients with PJI require long-term follow-up, as well as prolonged antibacterial, symptomatic, and infusion therapy. hence, the duration of inpatient treatment increases, which entails additional financial treatment and rehabilitation costs. The treatment and rehabilitation process greatly affects the quality of life of patients, often causing mental and psychological disorders. Moreover, a long hospital stay may result in the growth of resistant flora and an increased risk of severe complications, such as systemic inflammatory response syndrome, pulmonary embolism, and sepsis [3, 4, 5]. The mortality rate after two-stage revision intervention for PJI was 4.22% at 1-year follow-up and >21% at 5-year follow-up [6].

To date, several algorithms are used to determine, diagnose, and treat PJI, each of which has its advantages and disadvantages. The search for new diagnostic tools continues, as well as further study of existing ones. However, no single algorithm is generally accepted for diagnosing PJI [7, 8].

The most complete and clear criteria for determining PJI were presented at the Second International Consensus Meeting on Musculoskeletal Infection (ICM) held under the leadership of J. Parvizi in 2018. According to them, a joint with at least one of the proposed main criteria, and/or a joint whose sum of the minor criteria scores is ≥6 is considered infected [9].

Considerably, this definition, as well as all ICM results, exclusively represents recommendations for PJI diagnostics and treatment for healthcare professionals in different countries. Therefore, the use of these recommendations, as a single generally accepted standard for diagnostics and treatment of PJI, cannot guarantee 100% efficiency in all possible clinical cases [9].

Nowadays, the most modern and accurate algorithms for diagnosing and determining PJI are World Association against Infection in Orthopaedics and Trauma, The European Bone and Joint Infection Society (EBJIS) 2018, and ICM 2018. The work by Kazantsev et al. presented the main characteristics of these algorithms [10].

## CLASSIFICATION

According to the PJI classification proposed by Coventry and Tsukayama, the infection has four types depending on the time of manifestation of symptoms and the infection penetration manner in the operated joint area:

type I — early postoperative (up to 4 weeks);

type II — late chronic (4 weeks and more);

type III — acute hematogenous (after 1 year or more);

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type IV — positive intraoperative culture (in case of positive intraoperative inoculation results in 2-6 tissue samples).

The main manifestations of early postoperative infection (type I) may be the emergence of a fistula, edema, local hyperemia, and hyperthermia in the surgical area, as well as systemic reactions, such as an increased leukocytosis in the general blood test, and fever. This type of infection is established within 4 weeks after hip arthroplasty [11].

The DAIR (debridement, antibiotics, implant preservation) algorithm is used for an early postoperative infection [12]. Articular debridement is performed with preservation of endoprosthesis components, mandatory replacement of modular components (head/neck/liner), and microbiological examination of periprosthetic tissues (determining the sensitivity of microorganisms) to prescribe further targeted antibiotic therapy. Empirical antibiotic therapy is prescribed, followed by a transition to drugs according to the inoculation results, before obtaining the microbiological study results [13].

Late chronic infection (type II) has a much less typical clinical presentation and a different period of manifestation; most often, the first symptoms (moderate pain in the area of the operated hip joint with irradiation to the inguinal region, aggravated by axial load) start to manifest themselves in patients on week 4 postoperatively [11]. Treatment for this type of PJI involves one-stage or two-stage revision arthroplasty with prolonged antibiotic therapy. Specialists perform exarticulation of the joint or even amputation of the limb in severe cases [12].

Type III PJI develops in association with bacteriemia after infectious diseases of the urinary system, oral cavity, or respiratory tract in ≥1 year postoperatively [12]. Attention should be paid to existing foci of chronic infection if the diagnostic biomarker levels of inflammation do not decrease after PJI treatment initiation or in cases of acute symptoms of PJI during the rehabilitation phase [14]. The primary foci of acute hematogenous infection can be identified in most cases [15], and the treatment algorithm corresponds to the timing of symptom development postoperatively and is aimed at the sanitation of the focus of infection and prescribing antibacterial drugs for a long time [11].

Type IV PJI is first established in the case of microbial growth in two or more intraoperative samples of periprosthetic tissues during revision surgeries. A course of high-dose antibiotic therapy is prescribed according to the microbiological inoculation results during the revision intervention, considering the sensitivity of the identified pathogen, when type IV infection is detected [12], while specific surgical interventions are not required [11].

## DIAGNOSTICS

The diagnostics include physical examination, instrumental methods (X-ray, computed tomography, etc.), laboratory methods (determination of serum/synovial biomarkers), polymerase chain reaction (PCR) study, and microbiological and cytological studies of the synovial fluid and samples of periprosthetic tissues of the joint under study to rule out the hip joint PJI.

### Physical examination

Clinical evaluation, based on a combination of symptoms and risk factors for infection, is important to determine the most appropriate diagnostic strategy. The diagnosis of PJI can be established already at the initial examination of the patient in some cases. Establishing PJI is not difficult in cases of fistula, erythema, and edema in the investigated hip joint area, as well as in the presence of systemic inflammatory reactions, such as fever, algidity, and general malaise. However, chronic PJI is clinically difficult to distinguish from aseptic loosening of endoprosthesis components because clinical signs of infection may be completely absent [12]. The clinical presentation of PJI depends on the virulence of the involved etiological agent, the nature of the infected tissue, the route of infection, and the illness duration. The possibility of PJI should always be considered even in the absence of obvious evidence of infection [16]. Careful collection and assessment of the patient's history, as well as clinical examination, are important tools to screen for PJI and perform a correct diagnostic search [17].

## Instrumental diagnostic methods

The main method of visualization in diagnosing PJI is standard radiography, namely plain radiographs of the pelvis and the hip joint under study. Plain radiographs are especially useful in the assessment of the pathological process that changes over time, compared to previous images. Signs indicating the development of a pathological process include a radiolucent line (osteolysis) at the cement-bone interface (when using cement fixation) or at the metal-bone interface (uncemented use), which are associated with bone destruction [18]. However, osteolysis and implant migration may be present on patient radiographs and in case of aseptic loosening of endoprosthesis components [19].

Positron emission tomography with intravenous administration of 18F-fluorodeoxyglucose provides a higher spatial resolution of the image zones, which imparts a significant advantage to this method compared with other X-ray diagnostic methods. However, clearly differentiating the pathological process etiology is not possible because neutrophilic granulocytes and tissue macrophages that absorb the contrast agent can be present in both septic and aseptic processes [20].

The use of magnetic resonance imaging (MRI) and computed tomography (CT) in PJI diagnostics is limited due to their high cost and low specificity. However, specialists use MRI to assess the soft tissue condition and the neurovascular formation location and identify fistulous tracts and fluid accumulations in the hip joint area. Additionally, various modes of metal artifact suppression in modern magnetic tomographs enable to further improve the image quality [21]. The obtained data from CT examination of the affected joint can be extremely useful within determining the extent of revision surgery [22].

Notably, imaging diagnostic methods are not included as recommended diagnostic criteria according to ICM (2018) [9, 17].

## Laboratory diagnostics

### *Serum markers*

Serum biomarkers represent a fast and affordable tool for diagnosing PJI both in hospital and outpatient settings [23]. However, the time elapsed from the surgery when interpreting their indicators, and comorbidities should always be considered, as well as other factors affecting the result [24]. Importantly, PJI may exist in cases with normal serological test values [25].

#### *Erythrocyte sedimentation rate and C-reactive protein*

Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) determinations are currently recommended as first-line screening tests for PJI and are part of the diagnostic criteria proposed by ICM (2018). However, CRP and ESR may not be effective in detecting PJI in patients with a history of systemic inflammatory diseases, as well as in the early postoperative period [24]. The level of ESR and CRP reaches a peak value on postoperative days 2-3. CRP values return to normal values 1 month postoperatively, and ESR values become normal only after 3 months [26]. Dugdale et al. determined the optimal threshold values for diagnosing PJI, including a CRP of >100 mg/l and ESR of >46 mm/h up to 6 weeks, and CRP of >33 mg/l and ESR of >47 mm/h from 6 to 12 weeks. The authors note that laboratory studies, conducted from 6 to 12 weeks postoperatively, are more effective and veracious [27].

#### *D-dimer*

D-dimer is a fibrin breakdown product formed when plasmin dissolves a fibrin clot. Thus, the fibrinolytic system is activated in the body with the development of an infectious process, which, in turn, leads to an increase in the blood D-dimer level [28]. D-dimer is promising as a diagnostic serological marker in PJI with a sensitivity of 89% and a specificity of 93% [29]. Blood D-dimer determination is an effective and accurate tool for diagnosing PJI, especially in patients without a history of coagulopathy [30, 31]. Elevated D-dimer levels may indicate the presence of an inflammatory process not associated with infection (thrombosis, oncological diseases, etc.) [28]. Conversely, the diagnostic efficiency of D-dimer determination does not exceed ESR and CRP [32]. Additionally, the absence of a single D-dimer threshold value, different laboratory systems of determination, and other factors require further study of the possibility of using serum D-dimer as a marker for diagnosing PJI [31].

### *Interleukin-6*

Interleukin-6 (IL-6) is produced by immune cells and induces the production of major proteins in the acute phase of inflammation, including CRP and B- and T-lymphocytes, in the presence of bacterial infection [33]. The blood serum IL-6 level reaches its peak values on day 2 after uncomplicated joint arthroplasty and acquires quickly the normal values [34]. Serum IL-6 is a valuable and accurate marker with greater diagnostic accuracy than ESR or CRP in chronic PJI diagnostics. In particular, the diagnostic odds ratio for IL-6 was 314.7 compared to 13.1 and 7.2 for CRP and ESR, respectively [34]. Joint determination of IL-6 and CRP in the blood serum enables PJI detection in 100% of cases [35]. Elgeidi et al. revealed the method sensitivity, specificity, and accuracy as 100%, 90.9%, and 92.5%, respectively, at a threshold value of blood IL-6 of >10.4 pg/ml [36].

Some authors used a combination of serum and synovial IL-6 to more accurately determine PJI [37, 38]. The obtained data revealed a 96.77% accuracy of diagnosing PJI when determining the combination of serum and synovial IL-6, which is higher than when using serum (84.95%) and synovial (93.55) IL-6 separately [37].

The method disadvantages are elevated IL-6 levels in patients with chronic inflammatory diseases of other organs (urinary tract, lungs, and heart), Paget's disease, and immunodeficiency syndromes [38].

## *Synovial markers*

With all their advantages, a significant disadvantage of serum tests is their low specificity. Thus, some biomarkers may increase in response to inflammatory reactions associated with other diseases. Hence, the attention of specialists involved in PJI has recently been focused on the assessment of synovial fluid biomarkers as a possible breakthrough in diagnosing complicated PJI cases [17, 37]. Synovial biomarkers provide high accuracy in diagnosing PJI, including in patients with systemic diseases, as well as in patients taking antibacterial drugs [39].

### *Alpha-defensin*

Alpha-defensin is a pro-inflammatory biomarker secreted by human neutrophils in response to the presence of microbial pathogens [40]. Alpha-defensin is detected using an enzyme-linked immunosorbent assay (ELISA) or a test strip kit for the rapid detection of alpha-defensin in synovial fluid [41]. The rapid test is a convenient and fast alternative to laboratory analysis (ELISA) and allows intraoperative PJI detection. The qualitative result of the rapid test is available in just 10 min, which is noticeably faster than the ELISA test (quantitative result within 24 h). The alpha-defensin rapid test was recently approved in the United States of America and commercialized specifically for diagnosing PJI after large joint endoprosthesis replacement [17]. The undoubted advantage of the method is the possibility of diagnosing PJI in patients with a history of systemic inflammatory diseases, as well as in patients who continue to take antibacterial drugs [42, 43]. However, the probability of false-positive results increases if the aspirated synovial fluid is contaminated with associated blood, as well as in cases of pronounced metallosis or polyethylene debris formation in the periprosthetic tissues [44].

### *Leukocyte esterase*

Leukocyte esterase (LE) is an enzyme that is produced by neutrophils at the bacterial infection site. LE detection has traditionally been used to diagnose urinary tract infections. LE is detected in synovial fluid using inexpensive colorimetric test strips. LE is a fast and inexpensive method for diagnosing PJI with high specificity and sensitivity [45]. Importantly, the assessment and interpretation of the changes in the test strip colors depend on the specialist performing the study. Some experts recommend centrifuging the obtained synovial fluid for 2 min, if it is contaminated with associated blood or metal or polyethylene debris products, to perform a study of pure synovial fluid [46].

### *D-lactate*

D-lactate is a specific marker for the presence of a bacterial infection and is the predominant form of lactic acid produced by various types of

bacteria and fungi. This biomarker has been used by specialists for diagnosing bacterial infections for a long time [47]. The studies by Yermak et al. and Karbysheva et al. are particularly valuable, considering the small number of studies on the use of D-lactate for PJI verification. The presented results revealed that the D-lactate level in the synovial fluid, which enables us to consider the joint as infected, is 1.3 mmol/l with a sensitivity of 94.3% and specificity of 78.4% [48]. Additionally, the method sensitivity and specificity are 86.4% and 80.8%, respectively, at a threshold value of 1.263 mmol/l [49]. Synovial D-lactate determination enables us to verify PJI in a short time (result within 1 h) and with high sensitivity [50].

### *Synovial fluid viscosity*

Some authors propose to determine the synovial fluid viscosity to verify PJI. Fu et al. demonstrated that synovial fluid viscosity determination is a potentially important method for diagnosing PJI. According to their data, the synovial fluid viscosity in patients with PJI is significantly lower (7.93 mPa/s) than in patients with non-infectious loosening of endoprosthesis components (13.11 mPa/s). The obtained results are comparable in terms of the accuracy of diagnosing PJI with the indices of serum biomarkers CRP, ESR, and D-dimer (sensitivity 93.33% and specificity 66.67%). The authors note that their study is currently the only one in the available literature that determines the synovial fluid viscosity as a marker of PJI and states the need for further research on the use of this method for diagnosing PJI [51].

### *Cytological examination of synovial fluid*

An increased synovial fluid of leukocytes of >3000 in 1 μl associated with a neutrophilic shift (>80%) may be a sign of PJI of the joint under study [9]. The study of the cellular composition of the synovial fluid in patients with fistulous tracts communicating with the joint cavity, which is accompanied by profuse discharge, should be considered. The synovial fluid may be completely absent due to an active fistula, and the cytological data validity may be reduced in case of its presence. This fact is confirmed by the guidelines for a rapid test system that determines the presence of alpha-defensin proteins in the aspirate from the joint cavity with a functioning fistula due to the increased risk of false-negative results [10].

Zahar et al. determined the sensitivity and specificity of the method depending on the accepted threshold value. The best diagnostic accuracy was achieved at a level of 2582 leukocytes/μl (sensitivity of 80.6%; specificity of 85.2%) and 66.1% of polymorphonuclear neutrophils (sensitivity of 80.6%; specificity of 83.3%). The indicators have 83.6% sensitivity and 82.2% specificity at a threshold value of 1630 leukocytes/μl, and 80.3% sensitivity and 77.1% specificity with 60.5% of polymorphonuclear neutrophils [52].

## Diagnostic joint aspiration

Diagnostic aspiration of synovial fluid followed by microbiological and cytological analyzes is an invasive method for diagnosing PJI. Its success depends on the specialist performing the study [53]. Various imaging techniques, including ultrasound and fluoroscopic navigation, are used to accurately perform joint cavity aspiration. Duck et al. revealed an 87% accuracy of the method using ultrasound navigation; the method sensitivity and specificity were 83% and 89%, respectively [54]. Kanthawang et al. evaluated the efficiency of fluoroscopic (roentgenoscopic) navigation. The method accuracy in diagnosing PJI was 78.5% and the sensitivity index was 64%, according to the ICM criteria (2018) [55].

Randelli et al. conducted a comparative analysis between ultrasound navigation and fluoroscopic navigation and revealed that ultrasound navigation had higher diagnostic values at a lower cost compared to fluoroscopic navigation, with a sensitivity of 89% compared to 60% and specificity of 94% compared to 81%. Additionally, the cost at the time of the study was 125.30 € versus 343.58 € per study [56].

A specialist may be faced with obtaining only associated blood or with a complete absence of fluid (dry joint) when performing a diagnostic hip joint cavity aspiration. Some authors suggest injecting 10 ml of 0.9% saline solution into the joint cavity and immediately aspirating it in the case of a dry joint, and they recommend diluting the resulting aspirate with 0.9% sa-

line solution when obtaining associated blood [7, 54]. Considerably, distortions in the test results are possible when diluting the punctate [57]. Thus, the accuracy of diagnostics is 69% when obtaining a hemorrhagic aspirate and 60% when rinsing a dry joint compared with 87% in studies with obtaining synovial fluid [54]. Barker et al. analyzed and determined the mean joint aspiration volume for infected and non-infected joints (6 ml [2–36 ml] and 11 ml [1–200 ml], respectively) [58]. An important condition for performing diagnostic aspiration is the abolition of antibiotic therapy at least 14 days before the puncture, because this may contribute to obtaining unveracious results of microbiological examination [59]. The use of bacteriostatic solutions when rinsing the joint and the use of local anesthesia of deep tissues in the joint area under study should also be excluded [54, 55].

## Methods of molecular diagnostics

The PCR technique is a simple and automated method for analyzing a biomaterial sample, which does not require an incubation period. A new generation of multiplex PCR for PJI diagnostic demonstrates a fast and accurate result, making it possible to identify the pathogen within 5 h, which enables us to prescribe timely targeted antibiotic therapy in comparison with the standard microbiological study (5–14 days) [60].

Li et al. demonstrated the combined sensitivity and specificity of the method of 70% and 92%, respectively [61]. Lausmann et al. believe that PCR diagnostics can detect even culture-negative infections, including in patients taking antibacterial drugs [60].

The disadvantages of PCR are related to the type of study, as multiplex PCR enables specific organism identification depending on the primers used, in contrast to broad-spectrum PCR, which can detect DNA from many types of cultures but not microbial associations. The disadvantages also include the high cost of the study (¥1200) [62, 63]. However, PCR diagnostics can become a fast and accurate test that complements traditional microbiological examination [64].

## Microbiological examination

To date, the gold standard for diagnosing PJI is the microbiological examination of the synovial fluid, as well as intraoperative samples of periprosthetic tissues [9]. Qu et al. revealed the method sensitivity and specificity of 70% and 94%, respectively, which indicates a high diagnostic value of the method [65].

Strictly following the rules for collecting, processing, and transporting biomaterial is necessary to obtain accurate microbiological examination results [10]. An important requirement for microbiological examination is the abolition of antibiotic therapy for at least 14 days [66]. The probability of false-positive (contamination during sampling) and false-negative (culture-negative infections/microorganisms in biofilms/low-virulent strains) results, together with the time for obtaining the result up to 14 days, constitute significant disadvantages of this method [67, 68].

## Sonication

Sonication (ultrasound treatment of the removed components of the endoprosthesis) is actively used within the intraoperative diagnostics of PJI, followed by a microbiological examination of the obtained fluid. Some authors revealed that this enabled us to improve the accuracy of diagnosing PJI due to the destruction of biofilms under the action of ultrasonic waves and the dispersion of microorganisms in the sonic fluid and to establish a diagnosis in situations previously treated as aseptic loosening [20]. The sensitivity score for sonication is significantly superior to the standard microbiological examination of tissue samples, namely 97% vs. 57% for synovial fluid and vs. 70% for periprosthetic tissue samples. However, the sonication method specificity is comparable to that of a standard microbiological study (90% and 100%, respectively) [69]. The sensitivity index was 96.3% when combining the methods of sonication and microbiological examination [70].

## Aspects of compliance with the algorithm for preoperative diagnostics of periprosthetic infection

A specialist may encounter some difficulties when performing a diagnostic algorithm. Thus, obtaining liquid during the hip joint aspiration is not always possible. Hence, the use of synovial biomarkers is not possible when diagnosing PJI.

Christensen et al. believe that paying special attention to the result interpretation is necessary when diagnosing PJI in "dry joints" [71].

Strictly adhering to the chosen algorithm for diagnosing and determining PJI is worthy in cases of obtaining ambiguous microbiological study results, as well as serological and synovial tests. Observing the stages of diagnostic measures and performing a comprehensive preoperative diagnostic study, two or even three times with an interval of 14–30 days, is important [7].

Notably, Charette and Melnic revealed that the incidence of culture-negative infections varies from 2% to 18% despite all possible diagnostic measures [72].

## CONCLUSION

PJI diagnostics remain a difficult task, which can be solved using a multidisciplinary approach, as well as additional training of outpatient doctors and hospital specialists to be alert to PJI. Existing scientific studies revealed that the combination of the serum and synovial test results, as well as the use of a multidisciplinary approach, improves the speed and accuracy of diagnosing PJI.

The development and research of new diagnostic methods with greater accuracy, simplicity, convenience, and low cost will increase the efficiency of diagnosing PJI, thereby avoiding possible adverse consequences.

## DISCLAIMERS

### *Author contribution*

*Murylev V.Yu.* — design of the study, literature review, analysis and statistical processing of data, writing the draft, editing.

*Rudnev A.I.* — design of the study, literature review, writing the draft, editing.

*Kukovenko G.A.* — design of the study, literature review, collection and processing of material, writing the draft.

*Elizarov P.M.* — design of the study, analysis and statistical processing of data.

*Muzychenkov A.V.* — collection and processing of material.

*Alekseev S.S.* — collection and processing of material.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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## Authors' information

✉ *Valery Yu. Murylev* — Dr. Sci (Med.), Professor
Address: 8-2, Trubetskaya str., Moscow, 119991, Russia
https://orcid.org/0000-0001-5753-8926
e-mail: nmuril@yandex.ru

*Alexander I. Rudnev*
https://orcid.org/0000-0003-4490-2922
e-mail: ruda310895@gmail.com

*Grigory A. Kukovenko* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-6700-0222
e-mail: gkukovenko@gmail.com

*Pavel M. Elizarov* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-0217-2434
e-mail: elizarov_07@mail.ru

*Aleksey V. Muzychenkov* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-3933-672X
e-mail: amuzychenkov@inbox.ru

*Semen S. Alekseev*
https://orcid.org/0000-0001-7599-7472
e-mail: semen.alekseev.92@mail.ru

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# Профилактика, диагностика и лечение тромбоэмболических осложнений в травматологии и ортопедии: методические рекомендации

## Утверждены на открытом заседании экспертов 25.08.2022

С.А. Божкова [1], Р.М. Тихилов [1], В.В. Андрияшкин [2], И.Ф. Ахтямов [3], М.В. Белов [4,5], С.В. Дианов [6], А.Р. Касимова [1,8], О.А. Каплунов [7], С.С. Копенкин [2], Д.А. Маланин [7], Н.Е. Муштин [8], А.Н. Цед [8]

[1] *ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

[2] *ФГАОУ ВО «Российский национальный исследовательский медицинский университет им. Н.И. Пирогова» Минздрава России, г. Москва, Россия*

[3] *ФГБОУ ВО «Казанский государственный медицинский университет» Минздрава России, г. Казань, Россия*

[4] *ФГБОУ ВО «Ярославский государственный медицинский университет» Минздрава России, г Ярославль, Россия*

[5] *ГАУЗ ЯО «Клиническая больница скорой медицинской помощи им. Н.В. Соловьева», г. Ярославль, Россия*

[6] *ФГБОУ ВО «Астраханский государственный медицинский университет» Минздрава России, г. Астрахань, Россия*

[7] *ФГБОУ ВО «Волгоградский государственный медицинский университет» Минздрава России, г. Волгоград, Россия*

[8] *ФБГОУ ВО «Первый Санкт-Петербургский государственный медицинский университет им. И.П. Павлова» Минздрава России, г. Санкт-Петербург, Россия*

В методических рекомендациях описаны современные подходы к профилактике, диагностике и лечению тромбоэмболических осложнений у пациентов с травмами и операциями на опорно-двигательном аппарате в соответствии с междисциплинарным проектом клинических рекомендаций 2022 г. «Тромбоз глубоких вен конечностей», прошедшим общественные слушания и находящемся на утверждении в Минздраве России. Методические рекомендации рассчитаны на врачей различных специальностей, оказывающих медицинскую помощь профильным пациентам: травматологов-ортопедов, хирургов, анестезиологов-реаниматологов, клинических фармакологов, организаторов здравоохранения, студентов медицинских вузов, ординаторов, аспирантов.

**Ключевые слова:** тромбоз глубоких вен, венозные тромбоэмболические осложнения, тромбоэмболия легочных артерий, осложнения эндопротезирования суставов, осложнения после ортопедических операций.

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*Касимова Алина Рашидовна*; e-mail: kasi-alina@yandex.ru

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# Prevention, Diagnosis and Treatment of Thromboembolic Complications in Traumatology and Orthopedics: Methodological Guidelines

## Guidelines approved at open meeting of experts 25.08.2022

Svetlana A. Bozhkova [1], Rashid M. Tikhilov [1], Vyacheslav V. Andriyashkin [2], Il'dar F. Akhtyamov [3], Mikhail V. Belov [4,5], Sergei V. Dianov [6], Alina R. Kasimova [1,8], Oleg A. Kaplunov [7], Sergei S. Kopenkin [2], Dmitrii A. Malanin [7], Nikita E. Mushtin [8], Alexander N. Tsed [8]

[1] *Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russia*

[2] *Pirogov Russian National Research Medical University, Moscow, Russia*

[3] *Kazan State Medical University, Kazan, Russia*

[4] *Yaroslavl State Medical University, Yaroslavl, Russia*

[5] *Solovyov Clinical Emergency Hospital, Yaroslavl, Russia*

[6] *Astrakhan State Medical University, Astrakhan, Russia*

[7] *Volgograd State Medical University, Volgograd, Russia*

[8] *Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia*

The guidelines describe modern approaches to the prevention, diagnosis, and treatment of thromboembolic complications in patients with injuries and after musculoskeletal surgery, in accordance with the interdisciplinary draft of the Clinical Guidelines (2022) "Deep vein thrombosis of the extremities", which has passed public hearings and is being approved by the Russian Ministry of Health. The guidelines are designed for doctors of various specialties to provide medical care to specialized patients: orthopedic surgeons, anesthesiologists, resuscitators, clinical pharmacologists, health care organizers, medical students, residents, graduate students.

**Keywords:** deep vein thrombosis, venous thromboembolic complications, pulmonary embolism, arthroplasty complications, orthopedic surgery complications.

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✉ *Alina R. Kasimova*; e-mail: kasi-alina@yandex.ru

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## 1. КРАТКАЯ ИНФОРМАЦИЯ ПО ВТЭО ПРИ ТРАВМАХ И ОПЕРАЦИЯХ НА ОПОРНО-ДВИГАТЕЛЬНОМ АППАРАТЕ

### 1.1. Этиология и патогенез

Венозные тромбоэмболические осложнения (ВТЭО) представляют собой сложное (многофакторное) заболевание, включающее взаимодействие между приобретенной или наследственной предрасположенностью к тромбозу и воздействием окружающей среды. В этиопатогенезе ВТЭО при хирургических вмешательствах можно выделить два основных звена — непосредственно хирургическая травма и эндотелиальная дисфункция.

В настоящее время под травматичностью операции понимают большое количество патологических процессов, а не просто повреждение тканей в зоне хирургического вмешательства. Хирургический стресс проявляется многофункциональными изменениями, происходящими в организме пациента под влиянием агрессивных факторов хирургического вмешательства: психоэмоционального возбуждения, боли, повреждения мягких тканей и кровеносных сосудов, патологических рефлексов и массивной кровопотери.

Изменения в организме, происходящие на фоне хирургического вмешательства, представляют собой программируемый стресс, следствием которого являются существенные изменения реологических свойств крови. Совокупность нарушений регуляции в системе гемостаза, приводящих к повышению свертывающей способности, замедление кровотока в конечности и повреждение сосудистой стенки составляют триаду Вирхова, лежащую в основе патогенеза тромбоэмболических осложнений. В патогенезе развития тромбоэмболических осложнений после эндопротезирования крупных суставов пусковым механизмом является массивная травма тканей, повреждение кровеносных сосудов и обнажение сосудистого коллагена [1].

Выброс катехоламинов в ответ на хирургических стресс также увеличивает агрегационные свойства тромбоцитов. При этом активизируется как сосудисто-тромбоцитарное (за счет выброса в кровоток тромбопластических факторов из тромбоцитов), так и коагуляционное (за счет высвобождения тромбопластических веществ из стенки сосудов) звенья гемостаза [2, 3]. Внешний путь коагуляционного гемостаза приводит к образованию первичного сгустка и при массивном повреждении тканей происходит в течение 15 сек. [4]. Повреждение эндотелия сосудов запускает свертывание крови по внутреннему пути. В норме эндотелий секретирует антикоагулянтные факторы, препятствующие адгезии форменных элементов к стенке сосуда. При травме сосуда эта способность теряется, и на месте повреждения формируется сначала тромбоцитарный тромб, а затем фибриновый тромб. Другими причинами повышенного риска тромбообразования являются вынужденное положение конечности, например при эндопротезировании коленного сустава, когда выраженное сгибание в оперированном суставе приводит к компрессии сосудов в подколенной ямке, а также применение турникета, что вызывает стаз крови, перерастяжение и микроразрывы сосудистой стенки. Кроме того, манипуляции в костном канале во время установки эндопротеза, также как и применяемый костный цемент, активируют внешний путь свертывания крови за счет образования большого количества тромбина, что также увеличивает риск тромбообразования.

Таким образом, патогенез тромбообразования при хирургическом вмешательстве представлен в виде сменяющих друг друга процессов: хирургическая агрессия запускает классическую триаду Вирхова: интраоперационная травма сосудов, замедление кровотока из-за вынужденного положения конечности и наложения турникета при эндопротезировании коленного сустава и активация коагуляционного гемостаза. Далее каскад цитокинов и гуморальных медиаторов провоцирует нарушение сосудистого тонуса и миграцию лейкоцитов к месту повреждения сосуда. Вследствие этого на протяжении сосудов образуются конгломераты, состоящие из нитей фибрина и форменных элементов крови. Отрываясь от сосудистой стенки, данные конгломераты могут вызывать тромбоэмболию. Действие факторов продолжается в послеоперационном периоде, причем важную роль играют такие факторы, как послеоперационная боль и вынужденная иммобилизация пациентов.

Отдельную группу составляют пациенты с переломами костей нижних конечностей, костей таза, а также пострадавшие с политравмой. Их особенностью является то, что активация свертывающей системы крови происходит в несколько этапов. Первичная травма сопровождается значительным повреждением тканей, включая эндотелий сосудов, и выделением большого количества тканевого фактора, способствующего активации свертывающей системы крови. Затем в течение короткого промежутка времени этим пациентам выполняется операция остеосинтеза, что является дополнительной травмой и повторно активирует свертывающую систему. Кроме того, пострадавшие с политравмой нередко нуждаются в этапных операциях, которые производятся три и более раз с интервалами в 1–2 нед. При этом каждое хирургическое вмешательство приводит к активации гемостатического каскада. В результате риск развития посттравматических венозных тромбозов

в этой группе пациентов значительно превышает риск подобных осложнений у больных ортопедического профиля, которым обычно выполняется одна операция. Кроме того, если ортопедического пациента можно подготовить к плановому оперативному вмешательству, компенсировав заболевания сердечно-сосудистой системы, явления венозной недостаточности нижних конечностей и другую сопутствующую патологию, способную увеличить риски венозных тромбозов, то пациент с травмой поступает в стационар и оперируется в экстренном или срочном порядке. Соответственно, возможности адекватного воздействия на сопутствующую соматическую патологию у хирургов обычно нет в силу дефицита времени.

### 1.2. Эпидемиология

Большие ортопедические операции сопряжены с высоким риском развития ВТЭО — симптоматического и бессимптомного тромбоза глубоких вен и тромбоэмболии легочной артерии, которые являются потенциально опасными для жизни пациентов [5]. К основным ортопедическим операциям, вызывающим наибольшую озабоченность, относятся операции тотального эндопротезирования коленного и тазобедренного суставов и остеосинтез при переломах бедренной кости.

Частота различных тробоэмболических осложнений различна. Бессимптомные тромбозы глубоких вен (диагностируемые только при скрининговом ультразвуковом ангиосканировании (УЗАС)) встречаются в 12,6–31,1% случаев после первичного эндопротезирования [6, 7]. Клинически значимые тромбозы глубоких вен (ТГВ) развиваются гораздо реже — в 0,75–2,10% случаев [8, 9]. Наиболее тяжелое осложнение — тромбоэмболия легочной артерии (ТЭЛА) регистрируется в 0,41–1,93% случаев. При этом обструкция легочной артерии или ее ветвей не только потенциально опасна для жизни, но и может привести к хроническим осложнениям с плохим прогнозом, таким как тромбоэмболическая легочная гипертензия [10, 11]. Тромбозы глубоких вен являются основным промежуточным процессом, необходимым для развития ТЭЛА, связанной с хирургическим вмешательством, и повышают риск ее развития. Кроме того, приблизительно у 5–10% пациентов с симптоматическими ТГВ в течение последующих 10 лет развивается тяжелый посттромботический синдром, проявляющийся формированием венозных язв, периферических отеков и хронической боли [12].

В настоящее время общепринятой практикой при оценке эффективности тромбопрофилактики является учет только симптоматических тромбоэмболий, что обусловлено отсутствием различий через 2 года после хирургического вмешательства в клинических исходах (смертность от сердечно-сосудистых причин) между пациентами, у которых регистрировались бессимптомные ВТЭО, и пациентами без данных осложнений [13].

### 1.3. Классификация

Венозные тромбозы можно классифицировать по локализации, направлению тромботического процесса, степени фиксации тромба, степени гемодинамических расстройств и наличию осложнений [14, 15].

По локализации венозные тромбозы можно разделить в зависимости от:

– венозной системы: поверхностной или глубокой;

– уровня поражения вен: проксимальный или дистальный тромбоз.

По распространенности тромботического поражения: сегментарное или распространенное, двустороннее, мультифокальное.

По направлению распространения выделяют восходящий или нисходящий тромботическй процесс.

По степени фиксации тромба к венозной стенке:

– окклюзионный;

– неокклюзионный: пристеночный, флотирующий (эмболоопасный).

Выделяют три степени гемодинамических расстройств:

– легкая;

– средней тяжести;

– тяжелая.

По наличию осложнений:

– неосложненный;

– восходящий поверхностный тромбофлебит (верхняя граница тромба на уровне верхней трети бедра) — эмболоопасная форма;

– осложненный: ТЭЛА, венозная гангрена, посттромботическая болезнь (хроническая венозная недостаточность), тромбоз вен нижних конечностей с переходом на нижнюю полую вену.

## 2. ПРОФИЛАКТИКА ВТЭО У ПАЦИЕНТОВ ТРАВМАТОЛОГО-ОРТОПЕДИЧЕСКОГО ПРОФИЛЯ

В настоящее время оптимальным следует признать подход, согласно которому профилактику ВТЭО проводят абсолютно всем пациентам, поступающим в стационар. Характер профилактических мер определяется степенью риска.

### 2.1. Оценка степени риска развития ВТЭО в травматологии и ортопедии

Несмотря на невозможность точного прогнозирования развития ВТЭО, необходимо оценить степень вероятности их развития. Наличие у пациента факторов, предрасполагающих к ВТЭО (табл. 2.1) служит основанием для отнесения его к той или иной группе риска. Одним из наиболее удобных инструментов определения риска ВТЭО в хирургии служит шкала Caprini (табл. 2.2). В зависимости от наличия факторов риска и планируемой операции пациенту присваивают степень риска развития ВТЭО [16]. При отсутствии профилактики у больного с очень низким (0 баллов), низким (1–2 балла), умеренном (3–4 балла) и высоком (≥5 баллов) риске вероятность развития ВТЭО составляет соответственно менее 0,5; 1,5; 3 и 6%. В связи с отсутствием принципиальных различий в частоте ВТЭО и тактике ведения и профилактики пациентов низкого и очень низкого рисков в клинической практике целесообразно объединить в одну группу низкой вероятности ВТЭО.

*Таблица 2.1*

**Вероятность ВТЭО при различных предрасполагающих факторах**

| Факторы, повышающие вероятность ВТЭО более чем в 10 раз |
|---|
| • перелом длинных костей нижней конечности;<br>• эндопротезирование тазобедренного или коленного сустава;<br>• крупная травма;<br>• повреждение спинного мозга;<br>• венозные тромбоэмболические осложнения в анамнезе;<br>• инфаркт миокарда (достаточно обширный) в последующие 3 мес.;<br>• госпитализация с сердечной недостаточностью или фибрилляцией/трепетанием предсердий в предшествующие 3 мес. |
| Факторы, повышающие вероятность ВТЭО в 2–9 раз |
| • артроскопическая операция на коленном суставе с применением турникета;<br>• аутоиммунные заболевания;<br>• переливание крови;<br>• катетер в центральной вене;<br>• химиотерапия;<br>• застойная сердечная или дыхательная недостаточность;<br>• использование стимуляторов эритропоэза;<br>• гормональная заместительная терапия (риск зависит от препарата);<br>• использование пероральных контрацептивов;<br>• искусственное оплодотворение;<br>• инфекция (в частности пневмония, инфекция мочевых путей, СПИД);<br>• воспалительные заболевания толстого кишечника;<br>• злокачественное новообразование (наибольший риск при наличии метастазов);<br>• инсульт с параличом;<br>• послеродовой период;<br>• тромбоз поверхностных вен;<br>• тромбофилия. |
| Факторы, повышающие вероятность ВТЭО менее чем в 2 раза |
| • постельный режим >3 сут.;<br>• сахарный диабет;<br>• артериальная гипертензия;<br>• длительное положение сидя (например при вождении автомобиля, авиаперелетах);<br>• лапароскопические операции (в частности холецистэктомия);<br>• ожирение;<br>• беременность;<br>• варикозное расширение вен нижних конечностей |

*Таблица 2.2*

**Шкала балльной оценки клинических характеристик по Caprini [17]**

| Баллы | Клинические характеристики |
|---|---|
| 1 | 41–60 лет<br>Малая операция<br>ИМТ >25 кг/м$^2$<br>Отек нижних конечностей<br>Варикозное расширение вен<br>Беременность или послеродовый период<br>Невынашивание беременности в анамнезе<br>Прием эстрогенов/гестагенов<br>Сепсис (<1 мес.)<br>Тяжелое заболевание легких, в том числе пневмония (<1 мес.)<br>Нарушение функции дыхания<br>Острый инфаркт миокарда<br>Застойная сердечная недостаточность (<1 мес.)<br>Анамнез воспалительного заболевания кишечника<br>Постельный режим у терапевтического пациента |
| 2 | 61–74 года<br>Артроскопическая операция<br>Большая открытая операция (>5 мин.)<br>Лапароскопическая операция (>45 мин.)<br>Онкология<br>Постельный режим (>3 сут.)<br>Гипсовая повязка<br>Катетер в центральной вене |
| 3 | Старше 74 лет<br>Анамнез ВТЭО<br>Семейный анамнез ВТЭО<br>Лейденская мутация<br>Мутация в гене протромбина<br>Волчаночный антикоагулянт<br>Антитела к кардиолипину<br>Повышение уровня гомоцистеина в плазме<br>Гепарининдуцированная тромбоцитопения<br>Другие тромбофилии |
| 5 | Инсульт (<1 мес. назад)<br>Замена крупного сустава<br>Перелом бедренной кости, костей таза, голени<br>Травма спинного мозга (<1 мес. назад) |

*Общий балл и уровень риска ВТЭО для хирургических пациентов*

| Сумма баллов | Риск ВТЭО | Необходимость профилактики ВТЭО |
|---|---|---|
| 0 | Очень низкий | Нет |
| 1–2 | Низкий | Механическая |
| 3–4 | Умеренный | Фармакологическая и/или механическая |
| ≥5 | Высокий | Фармакологическая и механическая |

## 2.2. Средства профилактики ВТЭО

Для предупреждения ВТЭО у пациента с травмой или операцией на ОДА прежде всего следует минимизировать или устранить действие факторов, способствующих тромбообразованию: восстановить объем циркулирующей крови, нормализовать гемодинамику, применить адекватное обезболивание, предупредить развитие инфекционных осложнений. Необходимо стремиться к возможно более ранней мобилизации больного, восстановлению объема движений в суставах конечностей. При возможности следует стабильно зафиксировать отломки в ранние сроки после перелома. Применение стабильного функционального остеосинтеза, уменьшение травматичности оперативных вмешательств за счет использования современных технологий закрытого остеосинтеза позволяют сократить время ограничения подвижности пациента с повреждениями и заболеваниями опорно-двигательного аппарата.

Профилактика ВТЭО включает следующие методы:

– немедикаментозные — применяют у всех пациентов с ограниченной двигательной активностью (мобильностью):

– максимальная и возможно более ранняя активизация больных после операции, включая методы пассивной нагрузки: вертикализация, механотерапия, кинезотерапия и др.;

– обеспечение максимально возможной активности мышц нижних конечностей пациентов, находящихся на длительном постельном режиме, местные процедуры, увеличивающие объемный поток крови через глубокие вены нижних конечностей (эластическая компрессия нижних конечностей, перемежающаяся пневмокомпрессия, миостимуляция мышц голени и т.д.);

– активные и пассивные нагрузки на верхние конечности, улучшающие циркуляцию крови в целом, стимулирующие антитромботическую активность эндотелия;

– медикаментозные — проведение фармакологической тромбопрофилактики у пациентов с умеренным и высоким риском развития ВТЭО.

### *2.2.1. Немедикаментозные средства профилактики ВТЭО*

К немедикаментозным средствам относят механические способы профилактики, а именно — статическую эластическую компрессию нижних конечностей, последовательную перемежающуюся пневматическую компрессию (ППК), венозную помпу для стопы, миостимуляцию мышц голени и лечебную физкультуру. Основной целью применения немедикаментозных методов является ускорение венозного кровотока, при этом их использование не увеличивает опасность геморрагических осложнений. Механическую профилактику следует начать до операции, продолжать во время и после нее вплоть до восстановления двигательной активности.

***Последовательная перемежающаяся пневматическая компрессия (ППК)*** нижних конечностей величиной 40–50 мм рт. ст. с помощью специальных манжет и аппарата является наиболее эффективным из механических способов профилактики. Ее следует применять в соответствии с инструкцией к аппарату у пациентов, находящихся на постельном режиме.

***Статическую эластическую компрессию*** нижних конечностей с помощью компрессионного трикотажа (чулки, обеспечивающие оптимальное распределение давления на нижние конечности) или эластичных бинтов следует начинать при поступлении больного, поскольку пребывание в стационаре всегда связано с ограничением двигательной активности и замедлением скорости венозного кровотока. Накладывать эластичный бинт должен обученный персонал. Ежедневно следует проверять и при необходимости корректировать состояние бинта. Специальный профилактический компрессионный трикотаж (чулки дозированной компрессии) эффективнее и проще в использовании, самостоятельно поддерживает необходимый градиент давления. Однако он требует предварительного подбора и из-за развивающегося отека не всегда обеспечивает адекватную степень компрессии в ближайшем послеоперационном периоде. Применение компрессионного трикотажа целесообразно при плановых оперативных вмешательствах. Эластическую компрессию продолжают во время операций на нижних конечностях: бинт (чулок) должен находиться на неоперируемой конечности во время оперативного вмешательства, на оперированную конечность бинт (чулок) накладывают на операционном столе непосредственно после завершения операции [18].

***Электронейростимуляция мышц голени (ЭНСМГ)*** — процедура рекомендована всем пациентам ортопедо-травматологического профиля, находящимся на постельном режиме как в стационаре, так и на амбулаторном этапе лечения. Проводится с помощью различного рода электронейростимуляторов (стационарных приборов или индивидуальных переносных) согласно прилагаемой инструкции. Необходимым элементом является наличие электродов, накладываемых на икроножные мышцы пациента. Возможно сочетание метода со статической эластической компрессией и ЛФК. Может рассматриваться как альтернатива методу ППК [19].

***Лечебную физическую культуру*** применяют у всех больных. Особое значение имеют движения в голеностопном суставе и пальцах стопы. Лечебная физкультура не может быть заменой медикаментозным и механическим способам профилактики ВТЭО.

### *2.2.2. Медикаментозные средства, их дозы и режимы применения*

#### *2.2.2.1. Антикоагулянты*

Группа антикоагулянтов включает в себя препараты нефракционированного гепарина (НФГ) и низкомолекулярного гепарина (НМГ), прямых оральных антикоагулянтов (табл. 2.3) и антагонистов витамина К (АВК).

Однако в настоящее время препараты из группы АВК (варфарин) самостоятельно для профилактики ВТЭО в травматологии и ортопедии практически не используются. Единственной группой пациентов, которые нуждаются в их приеме, остаются пациенты, получающие АВК в связи с соматической патологией.

*Таблица 2.3*

**Рекомендуемые дозы и режим введения антикоагулянтов для профилактики ВТЭО при оперативном лечении пациентов[1]**

| Препарат | Рекомендуемые дозы и режим введения | |
|---|---|---|
| | Средняя степень риска развития ВТЭО | Высокая степень риска развития ВТЭО |
| Нефракционированный гепарин (гепарин натрия*) | Подкожно 2500 МЕ за 2–4 ч. до операции, затем 2500 МЕ через 6–8 ч. после операции, далее по 5000 МЕ 2–3 раза/сут.[4] | Подкожно 5000 МЕ за 4–6 ч.[3] до операции, затем 5000 МЕ через 6–8 ч. после операции, далее по 5000 МЕ 3 раза/сут. |
| Бемипарин натрия[2] | Подкожно 2500 МЕ за 2 ч. до операции или через 6 ч. после операции, затем ежедневно по 2500 МЕ 1 раз/сут. [4] | Подкожно 3500 МЕ за 2 ч. до операции или через 6 ч. после операции, затем ежедневно по 3500 МЕ 1 раз/сут. |
| Далтепарин натрия[2] | Подкожно 2500 МЕ за 2 ч. до операции, затем 2500 МЕ 1 раз/сут. [4] | (1) Подкожно 5000 МЕ вечером накануне операции, затем 5000 МЕ каждый вечер;<br>(2) Подкожно 2500 МЕ за 2 ч. до операции, затем 2500 МЕ через 8–12 ч. (но не ранее чем через 4 ч. после окончания операции), затем со следующего дня 5000 МЕ каждое утро;<br>(3) Подкожно 2500 МЕ через 4–8 ч. после операции, затем со следующего дня 5000 МЕ 1 раз/сут. |
| Надропарин кальция[2] | Подкожно 2850 МЕ (0,3 мл) за 2–4 ч. до операции, затем 0,3 мл 1 раз/сут.[4] | Подкожно 38 МЕ/кг за 12 ч. до операции, 38 МЕ/кг через 12 ч. после окончания операции, затем 38 МЕ/кг 1 раз/сут. на 2-е и 3-и сут. после операции, с 4-х сут. после операции доза может быть увеличена до 57 МЕ/кг 1 раз/сут. |
| Парнапарин натрия* | Подкожно 3200 МЕ (0,3 мл) за 2 ч. до операции, затем по 0,3 мл 1 раз/сут. [4] | Подкожно 4250 МЕ (0,4 мл) через 12 ч. после окончания операции, затем 1 раз/сут. |
| Эноксапарин натрия[2]* | Подкожно 20 мг за 2 ч. до операции, затем 20–40 мг 1 раз/сут.[4] | Подкожно 40 мг за 12 ч. до операции или через 12–24 ч. после операции, затем 40 мг 1 раз/сут. |
| Фондапаринукс натрия | Подкожно 2,5 мг через 6–24 ч. после операции, затем 1 раз/сут. | |
| Апиксабан* | Перорально по 2,5 мг 2 раза/сут.; первая доза не ранее чем через 12–24 ч. после завершения операции по достижении гемостаза | |
| Дабигатрана этексилат* | Перорально по 220 мг или по 150 мг (пациентам: старше 75 лет, при умеренном нарушении функции почек — клиренс креатинина 30–50 мл/мин., принимающим амиодарон, верапамил, хинидин) 1 раз/сут.; первый прием — в половинной суточной дозе через 1–4 ч., если гемостаз достигнут | |
| Ривароксабан* | Перорально по 10 мг 1 раз/сут.; первая доза не ранее чем через 6–10 ч. после завершения операции по достижении гемостаза | |

* Препарат включен в Перечень жизненно необходимых и важнейших лекарственных препаратов для медицинского применения на 2020 г. (Приложение № 1 к распоряжению Правительства Российской Федерации от 12 октября 2019 г. № 2406-р).

[1] Препараты сгруппированы в соответствии с фармакологическими свойствами, НМГ и пероральные антикоагулянты перечислены по алфавиту.

[2] У больных с низкой массой тела (менее 50 кг) разумно уменьшить профилактическую дозу НМГ в 2 раза, а у больных с выраженным ожирением (масса тела более 120 кг, индекс массы тела более 50 кг/м$^2$) — увеличить ее на 25%; у таких пациентов оправдана коррекция дозы НМГ по уровню анти-Ха активности в крови.

[3] Время введения НФГ до операции соответствует мнению экспертов с учетом обширности ортопедических операций, связанных с повышенным риском кровопотери.

[4] Данные рекомендации отражают мнение экспертов и основаны на дозах и режиме применения препаратов гепарина в общей хирургии.

Особое внимание во время медикаментозной профилактики ВТЭО следует уделять снижению периоперационной кровопотери. Необходимо добиваться тщательного интраоперационного гемостаза, применять современные гемостатические средства (фибриновый клей и т.п.), использовать технологии кровесбережения и ингибиторы фибринолиза (транексамовую кислоту и др.).

При использовании любых антикоагулянтов необходимо активно мониторировать признаки возможных геморрагических осложнений, исходно определить и регулярно контролировать уровень гемоглобина, гематокрит и клиренс креатинина (см. п. 2.4). При введении препаратов гепарина необходимо дополнительно регулярно контролировать количество тромбоцитов в крови.

Согласно инструкциям по применению препаратов, при назначении и выборе дозы антикоагулянтов прямого действия необходимо учитывать функцию почек. Для этого следует определить уровень креатинина в крови и рассчитать клиренс креатинина с помощью формулы Кокрофта – Голта:

Для мужчин:

$$\text{Клиренс креатинина (мл/мин)} = \frac{(140 - \text{возраст (в годах)}) \times \text{масса тела (кг)}}{72 \times \text{сывороточный креатинин (мг/100 мл)}}.$$

Для женщин:

$$\text{Клиренс креатинина (мл/мин)} = \frac{0{,}85 \times (140 - \text{возраст (в годах)}) \times \text{масса тела (кг)}}{72 \times \text{сывороточный креатинин (мг/100 мл)}}.$$

Если показатель сывороточного креатинина выражен в мкмоль/л, то результат надо умножить на 88.

В настоящее время существует множество онлайн калькуляторов, позволяющих рассчитывать клиренс креатинина автоматически после ввода исходных данных пациента.

В зависимости от расчетного уровня клиренса креатинина проводят выбор антикоагулянта прямого действия и коррекцию его дозы (табл. 2.4).

*2.2.2.2. Антиагреганты*

Группой лекарственных средств, препятствующих тромбообразованию, с принципиально другим механизмом действия являются антиагреганты. В отличие от антикоагулянтов они действуют

*Таблица 2.4*

**Дозирование антикоагулянтов при проведении профилактики ВТЭО у пациентов со сниженной функцией почек**

| Препараты[1] | Клиренс креатинина, мл/мин. | | |
|---|---|---|---|
| | 30–50, в т.ч. у пациентов старше 75 лет | 15–29 | <15 |
| Бемипарин натрия | Применять с осторожностью при почечной недостаточности | | |
| Далтепарин натрия | Не требует коррекции | Не требует коррекции при курсе ТП до 10 сут. | |
| Надропарин кальция | Не требует коррекции | Противопоказан | |
| Парнапарин натрия* | Применять с осторожностью при почечной недостаточности | | |
| Эноксапарин натрия* | Не требует коррекции | Уменьшить профилактическую дозу до 20 мг 1 раз/сут., лечебную дозу – до 1 мг/кг 1 раз/сут. | |
| Фондапаринукс | 1,5 мг 1 раз/сут. | При клиренсе креатинина <20 мл/мин противопоказан | |
| Апиксабан* | Не требует коррекции | С осторожностью | Противопоказан |
| Дабигатрана этексилат* | Сниженная доза 150 мг/сут | Противопоказан | |
| Ривароксабан* | Не требует коррекции | С осторожностью | Противопоказан |

[1] Препараты сгруппированы в соответствии с фармакологическими свойствами, НМГ и пероральные антикоагулянты перечислены по алфавиту

* Препарат включен в Перечень жизненно необходимых и важнейших лекарственных препаратов для медицинского применения на 2020 год (Приложение № 1 к распоряжению Правительства Российской Федерации от 12 октября 2019 г. № 2406-р).

на первом этапе свертывания крови, во время которого происходит агрегация тромбоцитов, блокируя адгезию тромбоцитов к эндотелию сосудов.

Единственным препаратом, который в настоящее время включен в целый ряд национальных рекомендаций по профилактике ВТЭО после планового ЭП ТБС или ЭП КС (см. п. 2.4.1) у пациентов без дополнительных факторов риска развития тромбозов, является ацетилсалициловая кислота★ [20, 21, 22, 23]. Рандомизированные клинические исследования и опубликованные метаанализы показывают, что АСК демонстрирует схожую с антикоагулянтами эффективность в профилактике ВТЭО после эндопротезирования коленного или тазобедренного сустава как при ступенчатой фармакологической профилактике, когда ее назначают после нескольких дней НМГ вне зависимости от дополнительных факторов риска ВТЭО у пациентов [24], так и при приеме с первых суток после операции у пациентов без дополнительных факторов риска [25].

В настоящее время в РФ лекарственной формой ацетилсалициловой кислоты, имеющей зарегистрированные показания к применению — профилактика тромбоза глубоких вен и ТЭЛА (в том числе, при длительной иммобилизации в результате обширного хирургического вмешательства), являются таблетки, покрытые кишечнорастворимой пленочной оболочкой, в дозе 100–200 мг (рег. № П N013722/01, П N015400/01-241109).

Другие препараты данной группы (клопидогрель★, тиклопидин★, тикагрелор★ и ингибиторы гликопротеиновых рецепторов IIb/IIIa) активно применяют при лечении кардиологической патологии. Пациенты, постоянно принимающие антиагреганты или антикоагулянты по терапевтическим показаниям, характеризуется высоким риском развития геморрагических осложнений. Рекомендации по ведению данной категории пациентов изложены в разделе 2.4.10.

#### *2.2.2.3. Препараты для экстренного прерывания эффектов антитромботической терапии при неотложных операциях*

В таблице 2.5 представлены препараты, позволяющие в той или иной степени нейтрализовать эффект антикоагулянтов или антиагрегантов в случаях развития тяжелых кровотечений, необходимости выполнения неотложного хирургического вмешательства у пациента, получающего антитромботическую терапию или профилактику [26, 27].

*Таблица 2.5*

**Препараты для купирования действия антитромботических препаратов**

| Препарат, действие которого необходимо прервать | Препараты, ингибирующие антитромботическое действие |
|---|---|
| НФГ [26] | Протамина сульфат* — медленный в/в болюс (1–3 мин.) в дозе 1 мг / 100 МЕ НФГ, введенного за последние 2–3 ч. При неэффективности (продолжающееся кровотечение) — инфузия протамина сульфата под контролем АЧТВ |
| НМГ [26] | Эффективного антидота нет, протамин сульфат* ингибирует не более 50% активности НМГ. Возможно в/в введение протамин сульфата 1 мг на 100 анти-Ха НМГ; повторно — 0,5 мг/100 анти-Ха НМГ. Концентрат протромбинового комплекса*# — инфузия |
| Варфарин* [26] | Перед экстренной операцией — концентрат протромбинового комплекса* (25 МЕ/кг) и дополнительное введение 5 мг витамина К1 (в/в, п/к или перорально) или фитоменадион (синтетический водорастворимый аналог витамина К) в виде медленной инфузии (1,0–2,5 мг при МНО 5–9 и 5 мг при МНО более 9) |
| Дабигатрана этексилат* [27] | Специфический ингибитор — идаруцизумаб (2 флакона по 2,5 г/50 мл) в виде двух внутривенных последовательных болюсных введений или инфузий длительностью не более 5–10 мин. каждая |
| Ингибиторы Ха фактора [27] (фондапаринукс, апиксабан*, ривароксабан*), Дабигатрана этексилат* (при недоступности идаруцизумаба) | Неактивированный концентрат протромбинового комплекса*# — начальная доза 50 МЕ/кг, возможно последующее введение дозы 25 МЕ/кг или активированный концентрат протромбинового комплекса*# — 50 ЕД/кг (максимальная доза — 200 ЕД/кг), или рекомбинантный фактор VIIa*# — 90 мкг/кг |

★ Препарат включен в Перечень жизненно необходимых и важнейших лекарственных препаратов для медицинского применения на 2020 г. (Приложение № 1 к распоряжению Правительства Российской Федерации от 12 октября 2019 г. № 2406-р).

*Окончание таблицы 2.5.*

| Препарат, действие которого необходимо прервать | Препараты, ингибирующие антитромботическое действие |
|---|---|
| Антиагреганты: клопидогрель*, тиклопидин*, тикагрелор* и ингибиторы гликопротеиновых рецепторов IIb/IIIa [26] | Тромбоконцентрат — 2 дозы/7 кг массы пациента (может быть неэффективен в течение 12 ч. после введения тикагрелора) |

* Препарат включен в Перечень жизненно необходимых и важнейших лекарственных препаратов для медицинского применения на 2020 г. (Приложение № 1 к распоряжению Правительства Российской Федерации от 12 октября 2019 г. № 2406-р).

# В перечне зарегистрированных показаний к применению препарата отсутствует показание — лечение кровотечений, связанных с применением антикоагулянтов, влияющих на II и Xa факторы свертывания.

### 2.3. Общие подходы к профилактике ВТЭО

• Каждому пациенту с травмой или перед плановой ортопедической операцией рекомендуется оценить и задокументировать степень риска развития ВТЭО [16, 28]. УУР А (УДД — 2)

***Комментарий.*** *Для оценки риска развития ВТЭО у пациента перед операцией целесообразно использовать шкалы балльной оценки степени риска развития ВТЭО по Caprini (см. табл. 2.*2).

• Всем пациентам с ограниченной двигательной активностью (мобильностью) вне зависимости от определенной степени риска развития ВТЭО рекомендуется проводить профилактику ВТЭО механическими методами [23]. УУР А (УДД — 2)

• Всем пациентам с повреждением и/или травмой ОДА при умеренном или высоком риске развития ВТЭО рекомендуется проводить профилактику ВТЭО медикаментозными (фармакологическими) методами, как правило, до восстановления обычной или ожидаемой двигательной активности больного (табл. 2.6) [20, 21, 23]. УУР А (УДД — 2)

• Пациентам с умеренным/высоким риском развития ВТЭО, нуждающимся в фармакологической профилактике после травмы или операции на ОДА, при противопоказаниях или отказе от назначения антикоагулянтов, развитии нежелательных явлений на фоне их приема рекомендуется рассмотреть назначение АСК в дозировке 100 мг/сут. в сочетании с механическими видами профилактики [22, 23]. УУР В (УДД — 2)

• Пациентам с умеренным или высоким риском развития ВТЭО, которым противопоказана любая фармакологическая профилактика или которые отказываются от назначения лекарственных препаратов, рекомендуется назначение механических видов профилактики [18, 21, 23, 28, 29]. УУР В (УДД — 2)

• Оптимальным является продолжение профилактики до восстановления обычной или ожидаемой двигательной активности больного [18, 21, 23]. УУР В (УДД — 1)

*Таблица 2.6*

**Лекарственные средства, рекомендуемые для профилактики ВТЭО**

| Планируемое лечение | Рекомендуемые антикоагулянты[1] | Длительность профилактики |
|---|---|---|
| Консервативное лечение повреждений и заболеваний ОДА, сопровождающееся длительным ограничением подвижности пациента | 1. НМГ<br>2. НФГ<br>3. Антагонисты витамина К (варфарин) | До восстановления обычной или ожидаемой двигательной активности |
| Отсроченное оперативное лечение повреждений позвоночника, таза, нижних конечностей (предоперационный период) | 1. НМГ<br>2. НФГ | До дня операции, далее в зависимости от оперативного вмешательства |
| Остеосинтез бедренной кости | 1. Фондапаринукс натрия<br>2. НМГ<br>3. Дабигатрана этексилат[2] или ривароксабан[2] (при их недоступности — апиксабан[3])<br>4. НФГ<br>5. АВК (варфарин) | Не менее 5–6 нед. |

*Окончание таблицы 2.6*

| Планируемое лечение | Рекомендуемые антикоагулянты[1] | Длительность профилактики |
|---|---|---|
| Эндопротезирование | 1. НМГ или фондапаринукс натрия, или дабигатрана этексилат, или ривароксабан, или апиксабан<br>2. НФГ<br>3. АВК (варфарин)<br>4. Ацетилсалициловая кислота[4] | 5 нед.[5] |
| – тазобедренного сустава | | |
| – коленного сустава | | 2 нед.[5] |
| Другие большие ортопедические операции на нижних конечностях | 1. НМГ<br>2. Дабигатрана этексилат[2] или ривароксабан[2]<br>3. НФГ<br>4. АВК (варфарин) | До восстановления обычной или ожидаемой двигательной активности |
| Другие операции на опорно-двигательном аппарате | 1. НМГ<br>2. Дабигатрана этексилат[2]<br>3. НФГ<br>4. АВК (варфарин) | До восстановления обычной или ожидаемой двигательной активности |

[1] Препараты пронумерованы в порядке приоритетности назначения (в соответствии с накопленной доказательной базой и суждением экспертов).

[2] Эти лекарственные средства изучены при эндопротезировании тазобедренного и коленного суставов, однако, согласно регистрации в Российской Федерации, могут использоваться и при указанных ортопедических операциях.

[3] Не имеет зарегистрированных показаний к применению при остеосинтезе бедра, назначение необходимо утвердить врачебной комиссией или возможность назначения прописать в локальном протоколе по проведению ТП в конкретном ЛПУ.

[4] Только в виде таблеток, покрытых кишечнорастворимой пленочной оболочкой.

[5] Возможно сокращение сроков медикаментозной ТП при более раннем восстановлении ожидаемой двигательной активности пациента и отсутствии других факторов риска развития ВТЭО.

## 2.4. Особенности антикоагулянтной профилактики в различных клинических ситуациях

### *2.4.1. Плановое эндопротезирование тазобедренного или коленного сустава*

• Всем пациентам после планового ЭП ТБС или КС рекомендуется фармакологическая профилактика ВТЭО [28]. УУР А (УДД — 1)

• Пациентам перед ЭП ТБС или КС, нуждающимся в фармакологической профилактике ВТЭО в дооперационном периоде, предпочтительнее применять НМГ, при невозможности их назначения — НФГ [18, 28]. УУР А (УДД — 1)

• Пациентам с риском развития геморрагических осложнений после ЭП ТБС или КС целесообразно отсрочить первое введение НМГ, дабигатрана этексилата или ривароксабана до достижения гемостаза (не менее чем на 8–12 ч. после окончания операции). УУР В (УДД — 2)

• Пациентам после планового ЭП ТБС или КС при условии ранней активизации и отсутствия у них других факторов риска развития ВТЭО, помимо операции, рекомендуется наряду с антикоагулянтами рассматривать АСК как средство профилактики ВТЭО [20, 21, 22, 23]. УУР А (УДД — 1)

• Пациентам после ЭП ТБС, выполненного в экстренном или срочном порядке по поводу перелома проксимального отдела или шейки бедренной кости, при отсутствии противопоказаний к назначению антикоагулянтов не рекомендуется применение АСК в качестве единственного средства профилактики ВТЭО. УУР С (УДД — 2)

• Пациентам после ЭП ТБС рекомендуется продолжение профилактики ВТЭО до 5 нед., после ЭП КС — минимум 2 нед. или до восстановления ожидаемой двигательной активности больного в зависимости от того, что наступит раньше [21, 232, 28]. УУР В (УДД — 2)

#### *2.4.1.1. Эндопротезирование тазобедренного или коленного сустава у пациентов с терминальной болезнью почек (ХБП) 5Д стадии, находящихся на гемодиализе*

• Пациентам, находящимся на программном или перитонеальном гемодиализе, с отсутствием спонтанных кровотечений из паренхиматозных органов в анамнезе, рекомендуется проведение медикаментозной и механической профилактики ВТЭО после ЭП ТБС или КС [23, 30, 31]. УУР В (УДД — 2)

• Пациентам, находящимся на программном или перитонеальном гемодиализе, при наличии в анамнезе спонтанных кровотечений из паренхиматозных органов, не рекомендуется проведение медикаментозной профилактики ВТЭО в междиализный день после ЭП ТБС или КС [32]. УУР В (УДД — 2)

• Пациентам с терминальной ХБП 5Д стадии после «больших» ортопедических операций для проведения фармакологической профилактики ВТЭО рекомендуется назначать в междиализный

день НМГ (дальтепарин натрия 2500 ЕД п/к в сут. или эноксапарин натрия в дозе 20 мг п/к в сут.), при их недоступности — НФГ [32, 33, 34, 35, 36]. УУР А (УДД — 2)

• У пациентов с терминальной ХБП 5Д стадии профилактика ВТЭО прямыми пероральными антикоагулянтами в послеоперационном периоде не рекомендуется [37]. УУР В (УДД — 2)

### *2.4.2. Переломы таза и проксимального отдела бедренной кости*

• При невозможности выполнения операции в первые сутки рекомендуется начать медикаментозную профилактику с применением НМГ или НФГ сразу после госпитализации пациента. При высоком риске или продолжающемся кровотечении проводить профилактику следует немедикаментозными средствами [5, 18, 87]. УУР А (УДД — 2)

• В случаях, когда введение антикоагулянтов вынужденно откладывается на 24 ч. и более, рекомендуется проведение ультразвукового ангиосканирования (УЗАС) для исключения ТГВ [17]. УУР С (УДД — 2)

• Пациентам после оперативного вмешательства рекомендуется исходя из клинической ситуации: продолжить парентеральное введение НМГ, НФГ, или назначить фондапаринукс натрия, или выполнить перевод пациента на пероральные препараты: дабигатрана этексилат, ривароксабан; при невозможности их назначения — АВК (варфарин) [8, 11]. УУР А (УДД — 1)

• Не рекомендуется при отсутствии противопоказаний к назначению антикоагулянтов применение АСК у данной категории больных. УУР С (УДД– 3)

• При оперативном и консервативном ведении пациентов с переломами таза и проксимального отдела бедренной кости оптимальным является продолжение фармакологической профилактики до восстановления ожидаемой двигательной активности больного, но не менее 5 нед. после операции [18, 21, 28]. УУР В (УДД — 2)

### *2.4.3. Операции на коленном суставе, за исключением эндопротезирования*

• Пациентам, нуждающимся в артроскопических операциях, не рекомендуется рутинное применение профилактики ВТЭО при отсутствии у них дополнительных факторов риска ВТЭО и при продолжительности использования турникета менее 45 мин., анестезии — менее 90 мин. [18, 21]. УУР В (УДД — 2)

• В случаях выполнения артроскопии с использованием турникета на 45 мин. и более, при продолжительности общего наркоза более 90 мин. или высоком риске ВТЭО у пациента (например, ВТЭО и/или ТЭЛА в анамнезе, ожирение с ИМТ≥40 кг/м$^2$ и др.) целесообразно рассмотреть назначение НМГ через 6–12 ч. после операции с последующим переходом на ПОАК (дабигатрана этексилат или ривароксабан) с продлением курса ТП до 10–14 дней [18, 21]. УУР В (УДД — 2)

• Пациентам, перенесшим остеотомию или остеосинтез перелома костей, формирующих коленный сустав, при отсутствии активного кровотечения рекомендуется фармакологическая профилактика ВТЭО до восстановления обычной или ожидаемой двигательной активности больного [18]. УУР В (УДД — 2)

### *2.4.4. Иммобилизация нижних конечностей*

• Пациентам с иммобилизацией нижних конечностей рекомендуется начать фармакологическую профилактику ВТЭО сразу после исключения продолжающегося кровотечения. Препаратами выбора являются НМГ, при их отсутствии — НФГ, в дальнейшем — с 3–4-х сут. в зависимости от состояния пациента — возможен перевод на АВК (варфарин) при условии адекватного подбора дозы и регулярного контроля МНО [18]. УУР В (УДД — 1)

### *2.4.5. Ортопедические операции на дистальных отделах нижней конечности (лодыжки, голеностопный сустав, стопа)*

• Пациентам, нуждающимся в операциях на дистальных отделах нижней конечности, не рекомендуется рутинное применение профилактики ВТЭО при отсутствии у них дополнительных факторов риска ВТЭО, последующей иммобилизации и продолжительности анестезии менее 90 мин. [38, 39, 40, 41]. УУР В (УДД — 1)

• Рекомендуется рассмотреть возможность назначения фармакологической профилактики ВТЭО пациентам, которым при выполнении операции на стопе или голеностопном суставе требуется иммобилизация (например, артродез, остеосинтез «трехлодыжечного» повреждения или восстановительно-реконструктивные операции на пяточном сухожилии), при продолжительности анестезии больше 90 мин. или при наличии у пациента высокого риска развития ВТЭО [38, 39, 40, 41]. УУР В (УДД — 1)

### *2.4.6. Ортопедические операции на верхней конечности*

• Рутинно при операциях на верхней конечности под местной или региональной анестезией профилактика ВТЭО не рекомендуется [42, 43]. УУР А (УДД — 1)

• В случаях продолжительности общего наркоза или турникета более 90 мин. при вмешательствах на верхней конечности, а также если операция мо-

жет существенно затруднить двигательную активность пациента или при наличии эпизодов ВТЭО в анамнезе рекомендуется рассмотреть возможность периоперационной профилактики ВТЭО [44] УУР В (УДД — 2)

### *2.4.7. Плановые операции на позвоночнике*

• Рекомендовано рассмотреть возможность назначения фармакологической профилактики ВТЭО НМГ при плановых операциях на позвоночнике в случаях, когда риск ВТЭО превышает риск кровотечения, с учетом индивидуальных особенностей пациента (см. табл. 2.1, 2.2) и хирургических факторов (большая длительная операция, операция с комбинированным передне-задним доступом), а также в соответствии с клинической оценкой, проводимой лечащим врачом [23, 45, 46, 47]. УУР В (УДД — 1)

• Пациентам с высоким риском кровотечения рекомендуется до операции применять механическую тромбопрофилактику, а первое введение НМГ отложить до достижения гемостаза (12–24 ч. после операции) [23, 45, 46, 47]. УУР В (УДД — 2)

• В случае поступления пациента с ограничением двигательной активности, в том числе по поводу геми- и тетрапареза/-паралича рекомендовано начать фармакологическую профилактику ВТЭО в дооперационном периоде [18, 287]. УУР А (УДД — 1)

### *2.4.8. Тяжелые травмы (множественные и сочетанные, включая черепно-мозговую, спинного мозга, позвоночника, таза/нижних конечностей)*

• Все пациенты с тяжелыми травмами относятся к группе высокого риска развития ВТЭО.

• При поступлении пациента с тяжелой травмой рекомендуется рассмотреть возможность назначения механической профилактики ВТЭО [23, 48]. УУР В (УДД — 2)

• У пациентов с тяжелой травмой рекомендуется переоценка и документирование риска развития ВТЭО и кровотечения ежедневно или чаще при изменении их клинического состояния. УУР В (УДД — 1)

• Пациентам с тяжелой травмой рекомендуется назначение фармакологической профилактики ВТЭО как можно скорее, как только риск ВТЭО превысит риск кровотечения [21, 23]. УУР В (УДД — 1)

• При наличии у пациента с тяжелой травмой неполного повреждения спинного мозга, спинальной гематомы или внутричерепного кровоизлияния рекомендуется отложить фармакологическую профилактику до достижения удовлетворительного гемостаза (обычно на 1–3-и сут.) [21, 23]. УУР В (УДД — 1)

• Пациентам с тяжелой травмой рекомендуется продолжать фармакологическую тромбопрофилактику до восстановления ожидаемой двигательной активности [23]. УУР В (УДД — 2)

• Пациентам с острой травмой спинного мозга или с черепно-мозговой травмой рекомендовано продолжать фармакологическую профилактику ВТЭО в течение 3 мес. после травмы и/или операции или до окончания периода реабилитации в условиях стационара [18, 23, 49, 50]. УУР С (УДД — 2)

### *2.4.9. Онкоортопедия*

• Рекомендовано дополнительно оценивать и документировать риск развития ВТЭО у пациентов с учетом основного заболевания и предполагаемого хирургического вмешательства (табл. 2.7) [51, 52].УУР В (УДД — 1)

• Всем больным со злокачественными новообразованиями при проведении хирургического лечения рекомендуется проводить профилактику ВТЭО, объем которой определяется степенью риска ВТЭО и включает медикаментозные и механические способы ТП, при этом ранняя активизация больных необходима во всех случаях [51, 52]. УУР А (УДД — 2)

• Онкологическим больным, которым планируется хирургическое лечение, рекомендуется выполнить доплерографию вен нижних конечностей с максимальным приближением исследования к дате операции [28, 53]. УУР С (УДД– 3)

***Комментарии.*** *Планируя меры профилактики ВТЭО, следует учитывать возможность бессимптомного ТГВ у существенной части онкохирургических больных [28, 52, 53].*

• При невозможности выполнения пациенту операции по поводу патологического перелома бедренной кости в первые сутки рекомендовано начать медикаментозную профилактику с применением НМГ или НФГ сразу после установки диагноза, в случае высокого риска развития или продолжающегося кровотечения проводить профилактику следует немедикаментозными средствами [28, 52]. УУР А (УДД — 2)

• Целесообразно продление профилактики ВТЭО не только до восстановления прежней или ожидаемой двигательной активности, но и далее с учетом степени риска тромбоза со стороны пациента [52, 54]. УУР В (УДД — 2)

• У онкоортопедических пациентов рекомендовано рассмотреть возможность сокращения длительности использования или отказа от манипуляций, повышающих риск образования тромбов (применение турникета или жгута, проведение общей анестезии, длительная иммобилизация и пр.) [56, 56, 57]. УУР В (УДД — 2)

• Онкологическим пациентам с доброкачественным новообразованием кости и низкой сте-

пенью риска развития ВТЭО возможно проведение тромбопрофилактики только механическими способами (эластическая компрессия нижних конечностей, перемежающаяся пневмокомпрессия, миостимуляция мышц голени и т.д.), если иного не требует характер оперативного вмешательства [52]. УУР В (УДД — 2)

*Таблица 2.7*

**Степени риска ВТЭО при операциях по поводу опухолей и опухолеподобных поражений костей в зависимости от характера оперативного вмешательства**

| Степень риска | Оперативное вмешательство |
|---|---|
| Высокая | • Онкологическое эндопротезирование костей таза, тазобедренного или коленного сустава<br>• Онкологическое эндопротезирование бедренной кости<br>• Расширенная резекция костей таза<br>• Резекция бедренной кости с замещением дефекта имплантатом или костной пластикой<br>• Спондило- и дискэктомия с замещением имплантатом или передним спондилодезом<br>• Межподвздошнобрюшное вычленение<br>• Межлопаточногрудное вычленение |
| Средняя | • Внутриочаговая или сегментарная резекция длинных костей, за исключением бедренной<br>• Плоскостная резекция подвздошной кости<br>• Плоскостная резекция дужек, остистых и поперечных отростков позвонков<br>• Онкологическое эндопротезирование плечевого сустава<br>• Ампутация и экзартикуляция сегментов, за исключением ампутации бедра |
| Низкая | • Плоскостная или краевая резекция длинных костей<br>• Внутриочаговая или сегментарная резекция коротких костей с костной пластикой дефекта<br>• Плоскостная, краевая резекция коротких костей<br>• Онкологическое эндопротезрование голеностопного, лучезапястного локтевого, межфаланговых суставов |

### *2.4.10. Пациенты, длительно получающие антитромботические препараты*

• Пациенты с заболеваниями и повреждениями ОДА, длительно получающие антикоагулянты и антиагреганты по терапевтическим показаниям, имеют высокий риск развития ВТЭО и при этом на момент госпитализации высокий риск развития геморрагических осложнений.

• Пациентам, получающим постоянно антитромботические препараты, в случаях когда риск ВТЭО планируемого вмешательства на ОДА превышает риск кровотечения, рекомендуется проведение фармакологической профилактики (НМГ, прямые пероральные антикоагулянты и пр.) [58]. УУР С (УДД — 2)

• Пациентам, получающим постоянно ацетилсалициловую кислоту (АСК) и поступающим для плановой операции на ОДА с низким (малые ортопедические вмешательства, когда трансфузий обычно не требуется) и умеренным (большие ортопедические вмешательства, в том числе эндопротезирование суставов, с возможными трансфузиями) риском кровотечения, прием антиагреганта не прерывается [26, 58, 59]. УУР В (УДД — 2)

• Пациентам, получающим постоянно АСК и поступающим для плановой операции на ОДА, с высоким риском кровотечения (нейрохирургические вмешательства) рекомендуется отменить препарат за 3 дня до операции [26, 58]. УУР С (УДД — 2)

• Пациентам, поступающим для плановой операции на ОДА и получающим клопидогрель, тикагрелор или прасугрель, рекомендуется отменить антиагрегант соответственно за 5, 5 и 7 дней до операции [26, 58, 59]. УУР С (УДД — 2)

• После операции прием АСК возможно возобновить сразу по достижении гемостаза; прием клопидогреля, тикагрелора или прасугреля — через 24–48 ч. [58]. УУР С (УДД — 2)

• Пациентам, постоянно получающим клопидогрель, тикагрелор или прасугрель, при необходимости неотложного хирургического вмешательства на ОДА для экстренного прерывания эффектов антиагрегантов рекомендуется проведение трансфузии тромбоконцентрата — 2 дозы на 7 кг массы тела больного (может быть неэффективен в течение 12 ч. после введения тикагрелора) [26]. УУР С (УДД — 2)

• Пациентам, поступившим для планового хирургического вмешательства и получающим АВК (варфарин), рекомендуется определить МНО [28]:

– при уровне МНО<1,5 возможно безотлагательное выполнение оперативного вмешательства с началом фармакологической тромбопрофилактики (НМГ, НФГ) в послеоперационном периоде;

– при уровне МНО>2, необходимо отменить АВК минимум за 5 сут. до операции и ежедневно мониторировать МНО, когда значение МНО станет <2

рекомендовано вводить НМГ (при отстуствии НФГ в виде в/в инфузии в лечебных дозах), введение НМГ прервать за 24 ч. до операции, НФГ — за 4–6 ч. УУР В (УДД — 2)

• Пациентам, постоянно получающим ПОАК, рекомендуется отсрочить плановое оперативное вмешательство с умеренным и высоким риском кровотечения на срок, зависящий от принимаемого препарата и функции почек (табл. 2.8). В большинстве случаев прием ПОАК возобновляют после операции по достижении стойкого гемостаза, но у отдельных категорий пациентов, у которых риски ВТЭО существенно превышают риск развития кровотечения, может быть рассмотрена «терапия моста» с периоперационным применением парентеральных антикоагулянтов [27, 60, 61]. УУР В (УДД — 3)

***Комментарий.*** *Процедуры с незначительным риском можно выполнить при остаточной концентрации ПОАК (не ранее чем через 12 ч. после приема последней дозы) с возобновлением терапии в тот же день или (самое позднее) на следующий день.*

• Пациентам, постоянно получающим ПОАК, при необходимости неотложного хирургического вмешательства на ОДА в порядке неотложной помощи рекомендуется выполнение алгоритма, представленного в таблице 2.9 [27, 60, 63]. УУР В (УДД — 3)

*Таблица 2.8*

**Сроки после приема последней дозы, рекомендуемые для выполнения оперативных вмешательств с умеренным и высоким риском кровотечений [62]**

| Клиренс креатинина*, мл/мин | Дабигатрана этексилат | | Апиксабан, ривароксабан | |
|---|---|---|---|---|
| | Низкий риск кровотечения | Высокий риск кровотечения | Низкий риск кровотечения | Высокий риск кровотечения |
| ≥ 80 | ≥24 ч | ≥48 ч | ≥24 ч | ≥48 ч |
| 50–79 | ≥36 ч | ≥72 ч | | |
| 30–49 | ≥48 ч | ≥96 ч | | |
| 15–29 | Не показано | Не показано | ≥36 ч | |
| <15 | Нет зарегистрированного показания | | | |

* По формуле Кокрофта – Голта.

*Таблица 2.9*

**Тактика при экстренных и срочных хирургических вмешательствах/процедурах у пациентов, получающих ПОАК [27, 60, 63]**

**Шаг 1.** Сбор анамнеза
• Уточнение сопутствующей патологии и принимаемых препаратов, определяющих риски кровотечений
• Антикоагулянт, принимаемый пациентом, доза препарата, время приема последней дозы

**Шаг 2.** Специфика обследования пациента
• Клиренс креатитина (расчет по Кокрофту – Голту)
• Коагулограмма (в зависимости от возможностей лаборатории)[1]

**Шаг 3.** На основании информации, полученной на этапе 1 и 2, дать ответ на вопрос:
«Находится ли пациент в состоянии гипокоагуляции?»
• Если есть убедительные доказательства, что пациент не находится в состоянии гипокоагугляции — можно выполнять вмешательство.
• Если пациент находится в состоянии гипокоагуляции или отсутствуют убедительные доказательства обратного — см. шаг 4

**Шаг 4.** Ответить на вопрос: «Можно ли отложить данную процедуру/вмешательство во времени без негативного влияния на исход лечения пациента?»
• Если ответ «да» — рассмотреть возможность выполнения вмешательства после прекращения антикоагулянтного эффекта ПОАК (см. табл. 5.6)
• Если ответ «нет» — см. шаг 5

*Окончание таблицы 2.9*

**Шаг 5.** Мероприятия, направленные на профилактику/снижение риска периоперационных кровотечений

| Низкий риск кровотечения | Умеренный риск кровотечения | Высокий риск кровотечения |
|---|---|---|
| • Временная отмена антикоагулянта.<br>• Активированный уголь[2] 30–50 г<br>• Общие мероприятия, направленные на минимизацию кровопотери | • Временная отмена антикоагулянта.<br>• Активированный уголь[2] — 30–50 г<br>• Общие мероприятия, направленные на минимизацию кровопотери<br>• Меры, направленные на нейтрализацию антикоагулянтного эффекта[3] — перед выполнением процедуры/вмешательства либо только в случае развития тяжелого кровотечения (необходимость нейтрализации антикоагулянтного эффекта перед вмешательством определяется в индивидуальном порядке) | • Временная отмена антикоагулянта<br>• Активированный уголь[2] — 30–50 г<br>• Общие мероприятия, направленные на минимизацию кровопотери<br>• Меры направленные на нейтрализацию антикоагулянтного эффекта[3] — перед выполнением процедуры/вмешательства |

Дозировки препаратов, применяемых для нейтрализации антикоагулянтного эффекта:
— идаруцизумаб (2 флакона по 2,5 г/50 мл) в виде двух внутривенных последовательных болюсных введений или инфузий длительностью не более 5–10 мин. каждая;
— нКПК (неактивированный концентрат протромбинового комплекса) — начальная доза 50 МЕ/кг, возможно последующее введение дозы 25 МЕ/кг;
— аКПК (активированный концентрат протромбинового комплекса) — 50 ЕД/кг (максимальная доза — 200 ЕД/кг в сут.);
— rVIIa (рекомбинантный фактор VIIa) — 90 мкг/кг

[1] Для дабигатрана — активированное частичное тромбопластиновое время, экариновое время свертывания, тромбиновое время, тромбиновое время в разведении, для ингибиторов Ха фактора (ривароксабан, апиксабан) — протромбиновое время, протромбин по Квику (%), анти Ха активность плазмы.

[2] Если последняя доза препарата принята 2–4 ч. назад.

[3] У пациентов, получавших дабигатран, — введение идаруцизумаба или нКПК, аКПК, rVIIa (в случае недоступности идаруцизумаба), у пациентов, получавших ингибиторы Ха фактора (ривароксабан, апиксабан), — нКПК, аКПК, rVIIa (применение нКПК, аКПК, rVIIa с осторожностью, в особенности у пациентов с высоким риском тромбозов, данные по эффективности и безопасности применения у пациентов, получавших ПОАК, ограничены).

### 2.5. Лабораторный контроль на фоне фармакологической профилактики

Настоящие рекомендации не подразумевают обязательного лабораторного контроля состояния гемостаза за исключением определения МНО при приеме антагонистов витамина К. Однако для выбора дозы, определения безопасности и выявления противопоказаний к использованию НМГ, фондапаринукса и ПОАК имеет значение функция почек, которую следует оценивать у всех больных по величине клиренса креатинина или скорости клубочковой фильтрации.

В ряде случаев на фоне проведения фармакологической профилактики целесообразна лабораторная оценка гемостаза с использованием доступных для конкретного лечебного учреждения методов. Лабораторный контроль показан: при экстренных вмешательствах в течение периода эффективного действия противотромботических средств; в случаях нестандартного эффекта антитромботической терапии по данным анамнеза (повышенная или пониженная чувствительность к препарату); при тяжелых и сочетанных нарушениях гемостаза (перенесенная массивная кровопотеря, состоявшиеся тромбозы, высокий риск тромботических осложнений, тромбозы на фоне тромбоцитопении и т.д.); при наличии клинических проявлений нарушений гемостаза в виде прогрессирующего тромбоза или кровоточивости.

На фоне введения НФГ или препаратов НМГ возможно уменьшение содержания тромбоцитов в крови. Иммунная тромбоцитопения обычно возникает через 4–14 сут. после начала введения гепарина (чаще при использовании НФГ), но может развиваться и раньше у больных, недавно получавших препараты гепарина. Для своевременного выявления иммунной тромбоцитопении необходимо контролировать содержание тромбоцитов в крови:

– при ведении профилактических или лечебных доз гепарина — как минимум через день с 4-х по 14-е сут. лечения или до более ранней отмены препарата;

– если больному вводили гепарин в ближайшие 3,5 мес., первое определение числа тромбоцитов следует осуществить в ближайшие 24 ч. после начала применения гепарина, а при любом ухудшении состояния в пределах получаса после внутривенного введения НФГ — немедленно.

Если содержание тромбоцитов в крови уменьшится в 2 и более раза от исходного уровня и/или будет составлять менее $100\times10^9$/л, следует прекратить любое введение гепарина и выполнить УЗАС вен нижних конечностей с целью поиска ТГВ. В период низкого содержания тромбоцитов в крови можно использовать ингибиторы тромбина прямого действия (дабигатрана этексилат) или ингибиторы Ха фактора (фондапаринукс, ривароксабан). После восстановления содержания тромбоцитов в крови можно перейти на АВК, начиная их применение с низких доз (для варфарина не выше 5 мг/сут.).

Применение НФГ, НМГ, фондапаринукса натрия, дабигатрана этексилата, апиксабана и ривароксабана в профилактических дозах не требует рутинного контроля системы гемостаза.

## 3. ДИАГНОСТИКА ВТЭО

Клинические проявления зависят от локализации тромбоза, распространенности и характера поражения венозного русла, а также длительности заболевания. В начальный период при неокклюзивных формах клиническая симптоматика слабо выражена либо вообще отсутствует. Иногда первым признаком ТГВ могут быть симптомы ТЭЛА. Типичный спектр симптоматики включает отек всей конечности либо ее части, цианоз кожных покровов и усиление рисунка подкожных вен, распирающую боль в конечности, боль по ходу сосудисто-нервного пучка [28].

Основными целями диагностики острого венозного тромбоза при подтверждении диагноза являются определение его локализации, распространенности и эмболоопасности. К эмболоопасным ТГВ относят флотирующие тромбы, имеющие единственную точку фиксации в дистальном отделе. Тромбоз поверхностных вен представляет угрозу развития ТЭЛА при переходе на глубокую венозную систему.

Целесообразно провести все диагностические исследования при подозрении на венозное тромбоэмболическое осложнение (ВТЭО) в течение 24 ч., чтобы обеспечить быстрое лечение, если диагноз подтвержден, и избежать ненужных повторных доз антикоагулянтов, если диагноз исключен.

### 3.1. Жалобы и анамнез

При обследовании пациентов с подозрением на острый венозный тромбоз и/или ТЭЛА у всех больных рекомендуется активное уточнение жалоб, которые могут свидетельствовать о наличии тромботического поражения вен и легочной тромбоэмболии, и тщательный сбор анамнеза для выявления, в том числе малосимптомных форм венозного тромбоза и тромбоэмболии дистальных ветвей легочных артерий [64, 65, 66]. УУР А (УДД — 1)

### 3.2. Физикальное обследование

Клинические признаки тромбоза поверхностных (подкожных) и глубоких вен конечностей существенно различаются. Тромбоз поверхностных вен в клинической практике традиционно обозначают термином «тромбофлебит» в связи с наличием легко выявляемых признаков воспаления (как правило, асептического) стенки вены и паравазальной клетчатки.

Клинические признаки тромбоза поверхностных вен:

– боль по ходу тромбированных подкожных вен;

– полоса гиперемии в проекции пораженной вены;

– при пальпации — шнуровидный, плотный, резко болезненный тяж;

– местное повышение температуры, гиперестезия кожных покровов.

Клинические проявления ТГВ менее специфичны, зависят от локализации тромбоза, распространенности и характера поражения венозного русла, длительности заболевания. На фоне посттравматического (послеоперационного) отека клиническое выявление ТГВ представляет сложную задачу. В начальный период при неокклюзивных формах тромбоза клиническая симптоматика не выражена либо вообще отсутствует. Нередко первыми признаками, свидетельствующими о ТГВ, у госпитального пациента могут быть симптомы ТЭЛА.

Типичный спектр симптоматики ТГВ включает:

– отек всей конечности либо голени;

– цианоз кожных покровов и усиление рисунка подкожных вен;

– распирающую боль в конечности;

– боль по ходу сосудисто-нервного пучка.

Всем пациентам с подозрением на ВТЭО следует выполнить физикальное обследование для исключения других причин клинической симптоматики [67, 68, 69, 70] УУР А (УДД — 1)

Для клинической оценки вероятности ТГВ при обследовании пациента рекомендуется использование индекса Wells (табл. 3.1). По сумме набранных баллов больных разделяют на группы с низкой, средней и высокой вероятностью венозного тромбоза [71, 72, 73, 74, 75] УУР А (УДД — 1).

У больных с подозрением на ТЭЛА ее вероятность рекомендуется оценить с помощью модифицированного правила Geneva или правила Wells (табл. 3.2 и 3.3) [72, 74, 76, 77]. УУР А (УДД — 1)

### 3.3. Лабораторная диагностика

• Пациентам без клинических признаков, позволяющих предположить ТГВ и/или ТЭЛА, проводить определение уровня D-димера в плазме с целью скрининга не рекомендуется. [78, 79, 80, 81]. УУР В (УДД — 2)

• Больным с клинической симптоматикой и анамнезом, не оставляющими сомнений в наличии ТГВ и/или ТЭЛА, проводить определение уровня D-димера не рекомендуется [11, 82]. УУР В (УДД — 2).

*Таблица 3.1*

**Оценка вероятности ТГВ нижних конечностей по клиническим данным: индекс Wells [72]**

| Клинический признак | Количество баллов |
|---|---|
| Активное злокачественное новообразование (в настоящее время или в предшествующие 6 мес.) | 1 |
| Парез, паралич или недавняя гипсовая иммобилизации нижней(их) конечности(ей) | 1 |
| Постельный режим 3 и более сут. или большая операция в течение последних 12 нед. | 1 |
| Болезненность при пальпации по ходу глубоких вен | 1 |
| Распространенный отек нижней конечности | 1 |
| Разница периметра голени за счет отека более 3 см по сравнению со здоровой конечностью (на уровне 10 см ниже tibial tuberosity) | 1 |
| Расширенные коллатеральные поверхностные вены (не варикоз) | 1 |
| Документированный ТГВ в анамнезе | 1 |
| Альтернативный диагноз как минимум столь же вероятен, как и ТГВ | -2 |
| Вероятность наличия ТГВ нижних конечностей | Сумма баллов |
| Низкая (около 3%) | 0 |
| Средняя (около 17%) | 1–2 |
| Высокая (около 75%) | ≥3 |

*Таблица 3.2*

**Оценка вероятности ТЭЛА по клиническим данным: модифицированное правило Geneva [77]**

| Показатель | Количество баллов | |
|---|---|---|
| | полная версия | упрощенная версия |
| Ранее перенесенные ТГВ или ТЭЛА | 3 | 1 |
| ЧСС 75–94 уд. в 1 мин. | 3 | 1 |
| ЧСС ≥95 уд. в 1 мин. | 5 | 2 |
| Операция или перелом в течение последнего месяца | 2 | 1 |
| Кровохарканье | 2 | 1 |
| Активное злокачественное новообразование | 2 | 1 |
| Боль в одной нижней конечности | 3 | 1 |
| Боль при пальпации в проекции глубоких вен нижней конечности и односторонний отек | 4 | 1 |
| Возраст более 65 лет | 1 | 1 |
| Вероятность ТЭЛА по клиническим данным | | |
| *Трехуровневая шкала* | Сумма баллов | |
| низкая | 0–3 | 0–1 |
| средняя | 4–10 | 2–4 |
| высокая | ≥11 | ≥5 |
| *Двухуровневая шкала* | Сумма баллов | |
| ТЭЛА маловероятна | 0–5 | 0–2 |
| ТЭЛА вероятна | ≥6 | ≥3 |

*Таблица 3.3*

**Оценка вероятности ТЭЛА по клиническим данным: правило Wells [76]**

| Показатель | Количество баллов | |
|---|---|---|
| | Полная версия | Упрощенная версия |
| ТГВ или ТЭЛА в анамнезе | 1,5 | 1 |
| ЧСС > 100 уд. в 1 мин. | 1,5 | 1 |
| Операция или иммобилизация в последние 4 нед. | 1,5 | 1 |
| Кровохарканье | 1 | 1 |
| Активное злокачественное новообразование | 1 | 1 |
| Клинические признаки ТГВ | 3 | 1 |
| Альтернативный диагноз менее вероятен, чем ТЭЛА | 3 | 1 |
| Вероятность ТЭЛА по клиническим данным | | |
| *Трехуровневая шкала* | Сумма баллов | |
| низкая | 0–1 | не оценивается |
| средняя | 2–6 | не оценивается |
| высокая | ≥7 | не оценивается |
| *Двухуровневая шкала* | Сумма баллов | |
| ТЭЛА маловероятна | 0–4 | 0–1 |
| ТЭЛА вероятна | ≥5 | ≥2 |

• Больным с клиническими признаками, позволяющими заподозрить ТГВ и/или ТЭЛА, при отсутствии возможности выполнить в ближайшие часы компрессионное УЗАС рекомендуется определить уровень D-димера [83, 84]. УУР А (УДД — 2).

### 3.4. Инструментальная диагностика

• Всем пациентам с подозрением на тромбоз поверхностных, глубоких вен нижних конечностей и/или ТЭЛА рекомендуется выполнение ультразвукового компрессионного дуплексного ангиосканирования вен нижних конечностей и таза с целью уточнения диагноза и определения дальнейшей тактики лечения [79, 85, 86, 87, 88, 89, 90]. УУР А (УДД — 1)

• При распространении тромбоза на илиокавальный сегмент в случае невозможности определения его проксимальной границы и эмболоопасности по данным дуплексного УЗАС рекомендуется выполнение ретроградной илиокавографии или спиральной компьютерной томографии [91, 92, 93, 94]. УУР В (УДД — 2)

• Пациентам, которым оперативное лечение планируется в отсроченном порядке через несколько дней после травмы, рекомендуется выполнение УЗАС обеих нижних конечностей с максимальным приближением исследования к дате операции для выявления бессимптомных венозных тромбозов, особенно если адекватная медикаментозная профилактика не проводилась [89, 95, 96, 97, 98, 99]. УУР А (УДД — 2)

• Пациентам, которым профилактические мероприятия не выполнялись в полном объеме или у которых имеется особенно высокий риск развития ВТЭО, рекомендуется выполнение УЗАС перед началом активизации для выявления бессимптомных тромбозов глубоких вен [18, 96, 99, 100]. УУР А (УДД — 2)

• Пациенту, находящемуся в травматологическом или ортопедическом отделении при подозрении на легочную тромбоэмболию в экстренном порядке необходимо выполнить электрокардиографию и рентгенографию органов грудной клетки для исключения иной патологии сердечно-сосудистой и дыхательной систем [28, 101, 102, 103] УУР А (УДД — 2).

## 4. ЛЕЧЕНИЕ ВТЭО

Задачи лечения ТГВ независимо от его локализации следующие:

– остановить распространение тромботического процесса;

– предотвратить ТЭЛА;

– не допустить прогрессирование отека и возможную венозную гангрену;

– восстановить (полностью или частично) проходимость глубоких вен;

– предупредить рецидив тромбоза.

Хирургические и терапевтические методы в лечении ТГВ используют комплексно в зависимости от приоритета задач, решаемых при лечении больного. Сфера приложения хирургических вмешательств в связи с появлением новых поколений эффективных антикоагулянтов и высокоинформативных неинвазивных методов диагностики, которые возможно использовать для динамического наблюдения за эффективностью лечения, в настоящее время имеет отчетливую тенденцию к сужению. В доминирующей доле наблюдений их задача — предотвращение массивной легочной эмболии. В послеоперационном периоде обязательно (при отсутствии противопоказаний к антикоагулянтам) проведение длительной антикоагулянтной терапии.

Выявление признаков острого тромбоза поверхностных, глубоких вен и/или ТЭЛА, а также обоснованное подозрение на них является основанием для консультации сосудистого хирурга. Дальнейшее лечение больных с ВТЭО проводят совместно сосудистый хирург и травматолог-ортопед.

Операции на ОДА должны быть отложены до устранения опасности возможной легочной тромбоэмболии. При наличии гипсовой повязки следует ее рассечь и развести края. До инструментального обследования больным с ТГВ и/или ТЭЛА должен быть предписан строгий постельный режим для снижения риска развития или прогрессирования ТЭЛА. После обследования пациенты с неэмболоопасными формами венозного тромбоза могут быть активизированы.

### 4.1. Консервативное лечение

• Всем больным с ТГВ и/или ТЭЛА рекомендуется проведение антикоагулянтной терапии (при отсутствии противопоказаний) терапевтическими дозами нефракционированного гепарина (НФГ), низкомолекулярных гепаринов (НМГ), фондапаринукса натрия, прямых оральных антикоагулянтов (ПОАК) и антагонистами витамина К (табл. 4.1) [32, 104, 105, 106]. УУР А (УДД — 1).

• При обоснованном подозрении на ВТЭО рекомендуется начинать антикоагулянтную терапию до инструментальной верификации диагноза [104]. УУР С (УДД– 3).

• Пациентам с тромбозом поверхностных вен (ТПВ) рекомендуется проводить динамическую оценку течения заболевания (клиническую и на основании УЗАС) не реже 1 раза в 5–7 дней с целью исключения прогрессирования тромботического процесса [107, 108, 109]. УУР В (УДД — 2).

• Пациентам с ТПВ при низком риске перехода тромба на глубокие вены (изолированный тромбофлебит варикозных и неварикозных притоков магистральных поверхностных вен) рекомендуется назначать системные НПВС, эластичную компрессию, топические средства, локальную гипотермию [107, 108, 109]. УУР В (УДД — 2).

*Таблица 4.1*

**Режимы использования и дозировка антикоагулянтов для лечения ТГВ**

| Антикоагулянт | Способ введения | Режим дозирования | |
|---|---|---|---|
| | | 2 раза в сутки | 1 раз в сутки |
| Далтепарин натрия | п/к | 100 МЕ/кг | 200 МЕ/кг |
| Надропарин кальция | п/к | 86 МЕ/кг | 171 МЕ/кг |
| Парнапарин натрия* | п/к | 6400 МЕ | – |
| Эноксапирин натрия* | п/к | 100 МЕ (1 мг)/кг | 150 МЕ (1,5 мг)/кг |
| НФГ* | в/в затем возможно п/к | Внутривенно болюсом 5000 ЕД, далее инфузия со скоростью 1000–2000 ЕД/ч., подбор дозы по значениям АЧТВ | |
| Антагонисты витамина К (варфарин*) | per os | Подбор дозы (МНО в диапазоне 2,0–3,0) | |
| Фондапаринукс натрия | п/к | – | 5–10 мг (в зависимости от массы тела) |
| Апиксабан* | per os | 10 мг 2 раза/сут. per os (7 дней), затем 5 мг 2 раза/сут. (до 6 мес.), далее по 2,5 мг 2 раза/сут. | |
| Дабигатрана этексилат* | per os | ≥5 сут. НМГ, затем 150 мг 2 раза/сут. per os | |
| Ривароксабан* | per os | 15 мг 2 раза/сут. per os (3 нед.), затем 20 мг 1 раз/сут. | |

* Препарат включен в Перечень жизненно необходимых и важнейших лекарственных препаратов для медицинского применения на 2020 г. (Приложение № 1 к распоряжению Правительства Российской Федерации от 12 октября 2019 г. № 2406-р).

• Пациентам с ТПВ при умеренном риске (тромбофлебит ствола магистральной подкожной вены с проксимальной границей тромба дистальнее 3 см от соустья; тромбоз надфасциального сегмента перфорантной вены до уровня фасции) и высоком риске (тромбофлебит магистральной поверхностной вены любой протяженности с проксимальной границей тромба на расстоянии 3 см от соустья или ближе) перехода тромба на глубокие вены в качестве приоритетного метода лечения рекомендуется антикоагулянтная терапия в течение 45 дней [107, 108, 109]. УУР В (УДД — 2).

• У больных с неэмболоопасными формами ТГВ антикоагулянтная терапия рекомендуется в качестве основного метода лечения. В случаях выполнения по показаниям хирургического или эндоваскулярного вмешательства, системного или регионарного тромболизиса рекомендуется последующее проведение антикоагулянтной терапии [104, 105]. УУР А (УДД — 1).

• Рекомендуется использовать одинаковые подходы к применению антикоагулянтов при ТГВ (нижних и верхних конечностей) и ТЭЛА [104, 110, 111, 112]. УУР В (УДД — 2).

• Всем больным с ТГВ нижних конечностей рекомендуется (при отсутствии противопоказаний) эластическая компрессия обеих нижних конечностей с использованием компрессионного трикотажа 2–3-го класса [113, 114]. УУР С (УДД — 2).

• Лечение больных с ТГВ, которым предполагается хирургическое, эндоваскулярное вмешательство или тромболизис, а также находящимся на ИВЛ, рекомендуется начинать с парентерального введения антикоагулянтов (НФГ, НМГ, фондапаринукс) [104, 115]. УУР А (УДД — 2).

• Антикоагулянтную терапию у больных, находящихся в стабильном состоянии и которым не планируют выполнение оперативного вмешательства или тромболизиса, рекомендуется проводить с использованием ПОАК [104, 105, 156]. УУР А (УДД — 1).

• Большинству пациентов с ТГВ рекомендуется проведение антикоагулянтной терапии в течение не менее 3 мес. [104, 105]. УУР А (УДД — 1).

• Больным с проксимальной локализацией ТГВ, перенесшим ТЭЛА, при наличии тромбофилий, сопряженных с высоким риском рецидива ВТЭО (антифосфолипидный синдром, дефицит антикоагулянтных протеинов С или S, мутации фактора V Лейдена или протромбина G20210A), при низком риске кровотечения и возможности поддерживать стабильный уровень антикоагуляции рекомендуется продолжение антикоагулянтной терапии до 6 мес. и более [104, 105] УУР А (УДД — 1).

• У больных с ТГВ на фоне злокачественных новообразований с высоким риском кровотечения, а также у беременных, которым противопоказаны оральные антикоагулянты, рекомендуется продленное использование НМГ (подкожное введение лечебной дозы в первый месяц с возможностью последующего снижения до 75% от лечебной) [116, 117, 118]. УУР А (УДД — 2).

• При выявлении в стационаре неэмболоопасной формы ТГВ у больного с повреждениями или заболеваниями ОДА, не нуждающегося по этому поводу в экстренном или срочном оперативном вмешательстве, рекомендуется проведение антикоагулянтной терапии парентеральными препаратами (лечебные дозы НМГ предпочтительны) и динамический ультразвуковой контроль за состоянием тромба и венозного русла. После стабилизации тромботического процесса, подтвержденного данными УЗАС, и стихания острых клинических проявлений тромбоза (через 3–5 сут.) возможно выполнение оперативного вмешательства на ОДА [119]. УУР В (УДД — 3).

• Проведение тромболитической терапии массивной тромбоэмболии легочных артерий рекомендуется при отсутствии показаний больным с высоким риском смерти во время госпитализации в ближайшие 30 сут. Высокий риск смерти характеризует одновременное наличие следующих признаков: шок или снижение АД ≥40 мм рт. ст. более чем на 15 мин.; III–V классы по шкале PESI (Pulmonary Embolism Severity Index), признаки дисфункции правого желудочка по данным эхокардиографии или КТ, повышенный уровень сердечных биомаркеров в крови. При наличии противопоказаний к тромболитикам и во всех остальных случаях рекомендуется проведение антикоагулянтной терапии. При лечении ТЭЛА рекомендуются подходы к выбору антикоагулянтов, режиму и длительности их использования аналогичные ТГВ [115, 120]. УУР А (УДД — 2).

### 4.2. Оперативное лечение

• Больному с ТПВ рекомендуется выполнение кроссэктомии (высокой приустьевой перевязки большой подкожной вены) при наличии противопоказаний для проведения антикоагулянтной терапии и при невозможности точной оценки распространенности тромботического процесса с помощью УЗАС, если проксимальная граница клинических проявлений тромбоза в бассейне большой подкожной вены достигает средней трети бедра и/или в бассейне малой подкожной вены — верхней трети голени, что рекомендуется расценивать как ситуацию высокого риска перехода тромба в систему глубоких вен [121, 122, 123]. УУД В (УДД — 3).

• Выполнение эндоваскулярных (имплантация кава-фильтра, катетерная тромбэктомия) и открытых хирургических вмешательств (тромбэктомия, перевязка глубокой вены проксимальнее тром-

ба, пликация НПВ) в качестве метода предотвращения массивной ТЭЛА рекомендуется больным с ТГВ по следующим показаниям [40, 124]. УУД В (УДД — 2):

– невозможность проведения надлежащей антикоагулянтной терапии;

– неэффективность адекватной антикоагулянтной терапии, на фоне которой происходит нарастание тромбоза с формированием эмболоопасного тромба (флотирующего тромба значительного диаметра длиной более 5–7 см);

– наличие эмболоопасного тромба илиокавального сегмента в момент первичной диагностики тромбоза;

– рецидивирующая ТЭЛА с высокой (систолическое давление в легочном стволе >50 мм рт. ст.) легочной гипертензией;

– некорректная позиция установленной ранее постоянной модели кава-фильтра (например, миграция его в почечную вену), исключающая возможность повторной имплантации (пликацию производят после флеботомии и удаления кава-фильтра).

• При выявлении в стационаре эмболоопасного (флотирующего) тромба у больного с повреждениями или заболеваниями ОДА, не нуждающегося по этому поводу в экстренном или срочном оперативном вмешательстве, рекомендуется имплантация съемной модели кава-фильтра, после чего возможно оперативное вмешательство на ОДА в сроки, определяемые травматологом-ортопедом. Тактику антикоагулянтной терапии рекомендуется использовать аналогичную применяемой при неэмболоопасной форме ТГВ [125, 126]. УУД В (УДД — 3).

• При выявлении в стационаре тромбоза илиокавального сегмента у больного с повреждениями или заболеваниями ОДА и нуждающегося по этому поводу в экстренном или срочном оперативном вмешательстве любой формы, из-за высокой вероятности прогрессирования тромботического процесса рекомендуется имплантация съемной модели кава-фильтра с последующим выполнением предполагаемого оперативного вмешательства на ОДА [125, 126]. УУД В (УДД — 3).

• При выявлении в стационаре эмболоопасного тромба бедренно-подколенного сегмента у больного с повреждениями или заболеваниями ОДА, нуждающегося по этому поводу в экстренном или срочном оперативном вмешательстве, рекомендуется имплантация съемной модели кава-фильтра либо в качестве альтернативы перевязка (или пликация) поверхностной бедренной вены рассасывающейся лигатурой с последующим выполнением предполагаемого оперативного вмешательства на ОДА [125, 126]. УУД В (УДД — 3).

• При выявлении в стационаре изолированного тромбоза вен голени у пациента, нуждающегося в выполнении экстренного или срочного оперативного вмешательства на опорно-двигательном аппарате, рекомендуется проведение необходимого вмешательства и назначение антикоагулянтной терапии в послеоперационном периоде на фоне динамического ультразвукового контроля состояния тромба и венозного русла [125, 126]. УУД В (УДД — 3).

## Термины и определения

*Венозные тромбоэмболические осложнения (ВТЭО)* — собирательное понятие, объединяющее тромбоз подкожных, глубоких вен, а также легочную тромбоэмболию.

*Тромбоз глубоких вен (ТГВ)* — наличие тромба в глубокой вене, который может вызвать ее окклюзию.

*Тромбоз поверхностных вен (ТПВ, тромбофлебит)* — наличие тромба в поверхностной вене, которое обычно сопровождается клинически определяемым воспалением.

*Тромбоэмболия легочных артерий* (ТЭЛА, легочная тромбоэмболия, легочная эмболия, тромбоэмболия легочной артерии) — попадание в артерии малого круга кровообращения тромбов — эмболов, которые мигрировали из вен большого круга.

*Посттромботическая болезнь (ПТБ)* — хроническое заболевание, обусловленное органическим поражением глубоких вен вследствие перенесенного тромбоза. Проявляется нарушением венозного оттока из пораженной конечности.

*Профилактика ВТЭО* — система мер, направленная на предупреждение развития опасных для жизни пациента и функции конечности осложнений (ТЭЛА и ТГВ).

## Список сокращений

АВК — антагонисты витамина К (антикоагулянты непрямого действия)
АД — артериальное давление
АСК — ацетилсалициловая кислота
АЧТВ — активированное частичное тромбопластиновое время
ВТЭО — венозные тромбоэмболические осложнения
КС — коленный сустав
МНО — международное нормализованное отношение
НМГ — низкомолекулярные гепарины
НПВ — нижняя полая вена
НПВС — нестероидные противовоспалительные средства
НФГ — нефракционированный гепарин
ОДА — опорно-двигательный аппарат
ПОАК — прямые оральные антикоагулянты

ППМК — последовательная перемежающаяся пневматическая компрессия
РКИ — рандомизированные клинические исследования
ТБС — тазобедренный сустав
ТВ — тромбиновое время
ТГВ — тромбоз глубоких вен
ТПВ — тромбоз поверхностных вен
ТП — тромбопрофилактика
ТЭЛА — тромбоэмболия легочных артерий
УДД — уровень достоверности доказательств
УЗАС — ультразвуковое ангиосканирование
УУР — уровень убедительности рекомендации
ЭП — эндопротезирование

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## ПРИЛОЖЕНИЕ

### Методология разработки клинических рекомендаций

Методы, используемые для сбора/выбора доказательств: поиск в электронных базах данных

Описание методов, используемых для сбора доказательств: доказательной базой для написания настоящих методических рекомендаций являются материалы, вошедшие в MedLine, PubMed, базу Cochrane, материалы издательства Elsevier и статьи в авторитетных отечественных журналах по травматологии и ортопедии. Глубина поиска составляет 20 лет. Полученные сведения ранжированы по уровню достоверности (доказательности) в зависимости от количества и качества исследований по данной проблеме. Авторы использовали методику оценки уровня убедительности рекомендаций и степени достоверности доказательств согласно Приложению 2 к Требованиям к структуре клинических рекомендаций, составу и научной обоснованности включаемой в клинические рекомендации информации, утвержденным приказом Минздрава России от 28.02.2019 г. № 1034.

*Таблица П1*

**Шкала оценки уровней достоверности доказательств (УДД) для методов диагностики (диагностических вмешательств)**

| Уровень достоверности | Тип данных |
|---|---|
| 1 | Систематические обзоры исследований с контролем референсным методом или систематический обзор рандомизированных клинических исследований с применением метаанализа |
| 2 | Отдельные исследования с контролем референсным методом или рандомизированные клинические исследования и систематические обзоры исследований любого дизайна, за исключением рандомизированных клинических исследований с применением метаанализа |
| 3 | Исследования без последовательного контроля референсным методом или исследования с референсным методом, не являющимся независимым от исследуемого метода, или нерандомизированные сравнительные исследования, в том числе когортные исследования любого дизайна |
| 4 | Несравнительные исследования, описание клинического случая |
| 5 | Имеется лишь обоснование механизма действия или мнение экспертов |

*Таблица П3*

**Шкала определения уровней убедительности рекомендаций**

| Категория | Описание |
|---|---|
| A | Однозначная (сильная) рекомендация (все исследования имеют высокое или удовлетворительное методологическое качество, их выводы по интересующим исходам являются согласованными) |
| B | Неоднозначная (условная) рекомендация (не все исследования имеют высокое или удовлетворительное методологическое качество, их выводы по интересующим исходам не являются согласованными) |
| C | Низкая (слабая) рекомендация — отсутствие доказательств надлежащего качества (все исследования имеют низкое методологическое качество, их выводы по интересующим исходам не являются согласованными) |

*Таблица П2*

**Шкала оценки уровней достоверности доказательств (УДД) для методов профилактики, лечения и реабилитации (профилактических, лечебных, реабилитационных вмешательств)**

| Уровень достоверности | Тип данных |
|---|---|
| 1 | Систематический обзор рандомизированных клинических исследований с применением метаанализа |
| 2 | Отдельные рандомизированные клинические исследования и систематические обзоры исследований любого дизайна, за исключением рандомизированных клинических исследований с применением метаанализа |
| 3 | Нерандомизированные сравнительные исследования, в том числе когортные исследования любого дизайна |
| 4 | Несравнительные, описание клинического случая или серии случаев, исследование «случай-контроль» |
| 5 | Имеется лишь обоснование механизма действия вмешательства (доклинические исследования) или мнение экспертов |

## ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

***Заявленный вклад авторов***

Все авторы сделали эквивалентный вклад в подготовку публикации.

Все авторы прочли и одобрили финальную версию рукописи статьи. Все авторы согласны нести ответственность за все аспекты работы, чтобы обеспечить надлежащее рассмотрение и решение всех возможных вопросов, связанных с корректностью и надежностью любой части работы.

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## DISCLAIMERS

***Author contribution***

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Сведения об авторах***

✉ *Касимова Алина Рашидовна* — канд. мед. наук
Адрес: Россия, 195427, г. Санкт-Петербург,
ул. Академика Байкова, д. 8
https://orcid.org/0000-0001-6284-7133
e-mail: kasi-alina@yandex.ru

*Божкова Светлана Анатольевна* — д-р мед. наук
https://orcid.org/0000-0002-2083-2424
e-mail: clinpharm-rniito@yandex.ru

*Тихилов Рашид Муртузалиевич* — чл.-корр. РАН,
д-р мед. наук, профессор
https://orcid.org/0000-0003-0733-2414
e-mail: rtikhilov@gmail.com

*Андрияшкин Вячеслав Валентинович* – д-р мед. наук
https://orcid.org/0000-0002-6997-4415
e-mail: andriyashkin@gmail.com

*Ахтямов Ильдар Фуатович* – д-р мед. наук, профессор
https://orcid.org/0000-0002-4910-8835
e-mail: yalta60@mail.ru

*Белов Михаил Викторович* — канд. мед. наук
https://orcid.org/0000-0001-7955-3625
e-mail: Micbelov@yandex.ru

*Дианов Сергей Вячеславович* — д-р мед. наук, профессор
https://orcid.org/0000-0002-1412-9580
e-mail: sdianov@mail.ru

*Каплунов Олег Анатольевич* — д-р мед. наук
https://orcid.org/0000-0001-6634-4162
e-mail: volortho@mail.ru

*Копенкин Сергей Семенович* — канд. мед. наук
https://orcid.org/0000-0001-7572-4976
e-mail: serko2001@mail.ru

*Маланин Дмитрий Александрович* — д-р мед. наук,
профессор
https://orcid.org/0000-0001-7507-0570
e-mail: malanin67@mail.ru

*Муштин Никита Евгеньевич* — канд. мед. наук
https://orcid.org/0000-0002-7264-7861
e-mail: mushtin.nikita@yandex.ru

*Цед Александр Николаевич* — д-р мед. наук
https://orcid.org/0000-0001-8392-5380
e-mail: travma1@mail.ru

***Authors' information***

✉ *Alina R. Kasimova* — Cand. Sci. (Med.)
Address: 8, Akademika Baykova str., St. Petersburg,
195427, Russia
https://orcid.org/0000-0001-6284-7133
e-mail: kasi-alina@yandex.ru

*Svetlana A. Bozhkova* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-2083-2424
e-mail: clinpharm-rniito@yandex.ru

*Rashid M. Tikhilov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0003-0733-2414
e-mail: rtikhilov@gmail.com

*Vyacheslav V. Andriyashkin* — Dr. Sci. (Med.)
https://orcid.org/0000-0002-6997-4415
e-mail: andriyashkin@gmail.com

*Il'dar F. Akhtyamov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0002-4910-8835
e-mail: yalta60@mail.ru

*Mikhail V. Belov* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-7955-3625
e-mail: Micbelov@yandex.ru

*Sergei V. Dianov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0002-1412-9580
e-mail: sdianov@mail.ru

*Oleg A. Kaplunov* — Dr. Sci. (Med.)
https://orcid.org/0000-0001-6634-4162
e-mail: volortho@mail.ru

*Sergei S. Kopenkin* — Cand. Sci. (Med.)
https://orcid.org/0000-0001-7572-4976
e-mail: serko2001@mail.ru

*Dmitrii A. Malanin* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0001-7507-0570
e-mail: malanin67@mail.ru

*Nikita E. Mushtin* — Cand. Sci. (Med.)
https://orcid.org/0000-0002-7264-7861
e-mail: mushtin.nikita@yandex.ru

*Alexander N. Tsed* — Dr. Sci. (Med.)
https://orcid.org/0000-0001-8392-5380
e-mail: travma1@mail.ru

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# Rozov and Kessler Tendon Sutures: Common Properties and Differences

Pavel A. Berezin [1], Aleksandr S. Zolotov [2], Rodion D. Volykhin [3], Elena N. Evdokimova [4], Lev I. Morozov [5], Ilya A. Lazarev [5]

[1] *Yaroslavl State Medical University, Yaroslavl, Russia*

[2] *Far Eastern Federal University, Vladivostok, Russia*

[3] *Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russia*

[4] *Arkhangelsk Regional Clinical Hospital, Arkhangelsk, Russia*

[5] *Northern State Medical University, Arkhangelsk, Russia*

***Background.*** The Kessler suture is one of the most common tendon repair techniques and can be found schematically in most manuals of hand surgery, along with Bunnel and Tsuge sutures. In our country, the seam proposed by V.I. Rozov, while a number of authors believe that Rozov and Kessler sutures are very similar. Both techniques, both the Rozov's suture and the Kessler suture, have a large number of modifications that differ significantly from the originals, but retain the author's names, which confuses and hinders the analysis of the use of various methods for restoring the integrity of the tendons.
***The aim*** — to find the correct author's description of Rozov's suture and Kessler's suture, test original techniques on a tendon model, compare techniques, analyze common properties and differences.
***Methods.*** Information was searched in domestic and foreign literature, manuals on traumatology and orthopedics, monographs, methodical letters, materials of congresses, Internet resources. Approbation of the methods was carried out on a tendon model, which was a silicone rod with a diameter of 1 cm.
***Results.*** The first image of the Rozov's suture discovered by us, dates back to 1958, the original "grasping" technique of flexor tendon repair was proposed by I. Kessler in 1969. These techniques have a number of significant differences in the location of nodes, methods of fixation and planes of threads in the thickness of the tendon.
***Conclusion.*** The data of this study give reason to believe that V.I. Rozov and I. Kessler proposed two different ways of applying a tendon suture.

**Keywords**: tendon repair, Rozov suture, Kessler suture, history of medicine.

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✉ *Pavel A. Berezin*; e-mail: medicinehead@mail.ru

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# Сухожильные швы Розова и Kessler: общие свойства и различия

П.А. Березин [1], А.С. Золотов [2], Р.Д. Волыхин [3], Е.Н. Евдокимова [4], Л.И. Морозов [5], И.А. Лазарев [5]

[1] *ФГБОУ ВО «Ярославский государственный медицинский университет» Минздрава России, г. Ярославль, Россия*

[2] *ФГАОУ ВО «Дальневосточный федеральный университет», г. Владивосток, Россия*

[3] *ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия*

[4] *ГБУЗ АО «Архангельская областная клиническая больница», г. Архангельск, Россия*

[5] *ФГБОУ ВО «Северный государственный медицинский университет» Минздрава России, г. Архангельск, Россия*

***Актуальность.*** Шов Kessler является одной из наиболее распространенных методик восстановления сухожилий, а его схематическое изображение можно найти в большинстве руководств по хирургии кисти, наряду со швами Bunnel и Tsuge. В нашей стране такой же популярностью пользуется шов, предложенный В.И. Розовым, при этом ряд авторов считает, что швы Розова и Kessler очень похожи. Как шов Розова, так и шов Kessler имеют большое количество модификаций, существенно отличающихся от оригиналов, но сохраняющих при этом авторские названия, что вносит путаницу и мешает анализу использования различных способов восстановления целостности сухожилий.

***Цель исследования*** — найти корректные авторские описания шва Розова и шва Kessler, апробировать оригинальные техники на модели сухожилия, сравнить методики, проанализировать общие свойства и различия.

***Материал и методы.*** Проведен поиск информации в отечественных и зарубежных публикациях, руководствах по травматологии и ортопедии, монографиях, методических письмах, материалах съездов и конгрессов, интернет-ресурсах. Апробация методик проводилась на модели сухожилия, в качестве которой использовался силиконовый стержень диаметром 1 см.

***Результаты.*** Первое изображение шва В.И. Розова, обнаруженное нами, датируется 1958 г., оригинальная «охватывающая» техника восстановлений сухожилий сгибателей была предложена I. Kessler в 1969 г. Данные методики имеют ряд существенных различий в расположении узлов, способах фиксации и плоскостях проведения нитей в толще сухожилия.

***Заключение.*** Данные выполненного исследования дают основания полагать, что В.И. Розов и I. Kessler предложили два разных способа наложения сухожильного шва.

**Ключевые слова:** шов сухожилия, шов Розова, шов Kessler, история медицины.

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*Березин Павел Андреевич*; e-mail: medicinehead@mail.ru

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## BACKGROUND

Once every three years, hand surgeons from all countries and continents traditionally gather for an international professional congress. At each congress, a group of the most outstanding specialists is awarded the honorary title of "pioneer of hand surgery". In 2001, at the VIII Congress in Istanbul, Israeli surgeon Isidor Kessler was recognized as one of the "pioneers". The "grasping" technique of tendon repair, proposed by this scientist in 1969, is still one of the most common ways of flexor tendons suturing. Thus, according to a survey of hand surgeons conducted in the UK in 2014, 36% of them used the Kessler technique to repair flexor tendons, which was the most popular result [1]. In our country, the suture proposed by V.I. Rozov has gained similar popularity. And number of authors believe that the Kessler suture is very similar to the Rozov suture [2, 3, 4].

Both methods, both the Rozov suture and the Kessler suture, have a large number of modifications that differ significantly from the originals, but at the same time retain the author's names, which confuses and interferes with the analysis of the use of various methods for restoring the integrity of tendons.

*The aim* of the study was to find correct author's descriptions of the Rozov suture and the Kessler suture, to test original techniques on a tendon model, to compare techniques, to analyze common properties and differences.

## METHODS

Information was searched in domestic and world databases (eLibrary, PubMed, Google Scholar), manuals on traumatology and orthopedics, monographs, methodical letters, materials of congresses, Internet resources.

The approbation of the techniques was carried out on a tendon model, which used a silicone rod of circular cross-section with a diameter of 1 cm. The seams were applied with a polypropylene thread with a thickness of 0 USP (3.5 metric) on a piercing needle.

## RESULTS AND DISCUSSION

The first image of V.I. Rozov's technique was discovered by us on the pages of the collection of abstracts "New methods of diagnosis and treatment, instruments, apparatuses and devices in traumatology and orthopedics" in 1958 [5]. At the same time, in the sources previously referred to by other authors (V.I. Rozov's dissertation for the degree of Doctor of Medical Sciences (1950), his monograph "Injuries of the tendons of the hand and fingers and their treatment" (1952) and the article "Topical issues of the primary suture of the fingers flexor tendons" (1958), any mention the author's method of suturing was not revealed [2, 3]. Proceeding from this, we dare to assume that for the first time the original technique of suturing Rozov was presented in the section "Variant of the tendon suture" of this collection (Fig. 1).

In his abstract, Rozov notes that the variant of the suture he proposed is essentially a simplification of the technique proposed by Bloch and Bonnet (Fig. 2) [5].

An interesting fact is that in the illustration, the transverse component of the suture is depicted as a solid line, which gives the impression that the thread in this area is located outside the tendon. The author of the suture himself does not give a detailed method of its application in the text, limiting himself only to the presented drawing. In the later works of the Leningrad Research Institute of Traumatology and Orthopedics, when depicting this suture, the thread is already displayed throughout with a dotted line, which suggests that it was carried out inside the core (Fig. 3) [6].

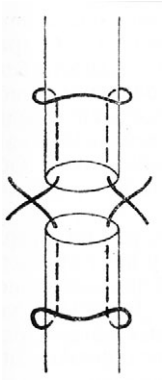

**Fig. 1.** Scheme of Rozov suture (1958) [5]

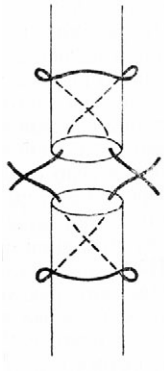

**Fig. 2.** Scheme of Bloch-Bonnet suture 1958 [5]

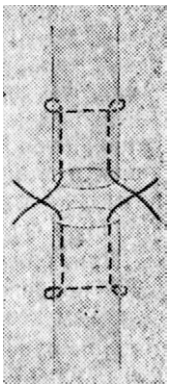

**Fig. 3.** Scheme of Rozov suture (1960) [6]

When applying the Rozov suture, each end of the injuried tendon is sutured with a separate thread, while only two small fragments of suture material remain on its sliding surface along the "side" surfaces, and the free ends of the threads are brought into the plane of rupture (Fig. 4).

The disadvantage of the Rozov suture is the fact that its intra-tendon component is located only in one plane — the frontal one, on the basis of which the probability increases that with increasing load the thread will cut through the tendon. In addition, when using this technique, the nodes are located between the ends of the restored tendon, which, according to recent data, is associated with a high risk of suture failure [7, 8, 9, 10].

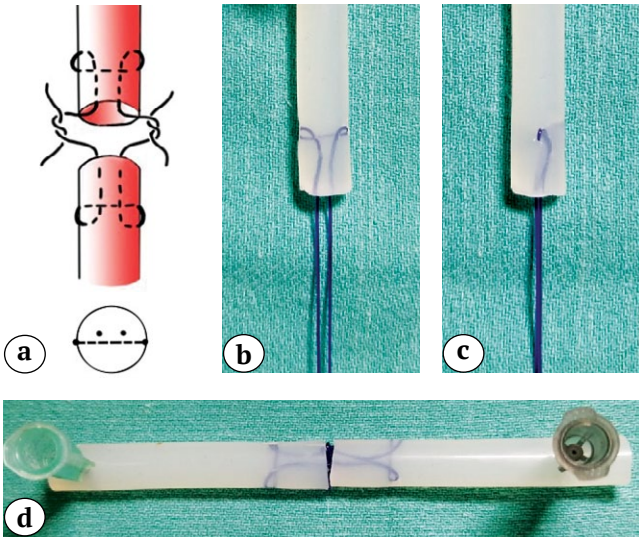


**Fig. 4.** Rozov suture: scheme of suture (a); the end of the silicone model stitched according to Rozov in frontal (b) and sagittal (c) planes; appearance of Rozov suture on a silicone model (d)

The "grasping technique" of flexor tendon repair was first proposed by Isidor Kessler in collaboration with Fuad Nissim on the pages of the journal Acta Orthopaedica Scandinavica in 1969 in an article entitled "Primary restoration of flexor tendons in the tendon canal without immobilization: an experimental and clinical study" [11].

The original Kessler suture technique involves fixing the thread to each end of the restored tendon using two locking loops located on its sliding surface (Fig. 5). This technique prevents the threads from shifting inside the tendon, reducing the likelihood of its ends diverging. Thus, Kessler's "covering" technique is a suture with interlockable loops.

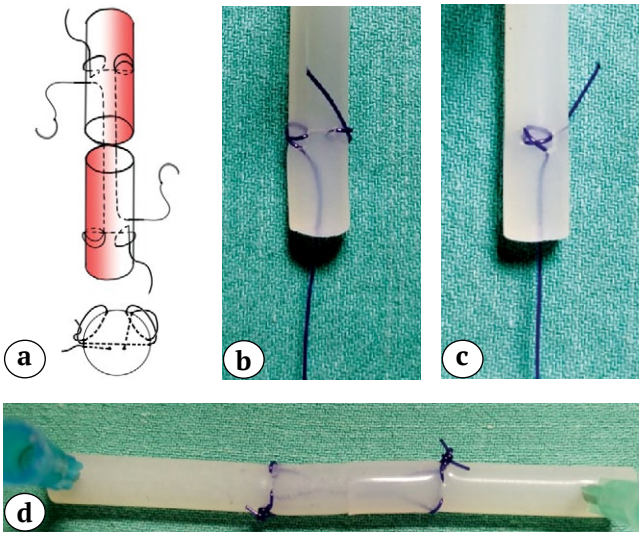


**Fig. 5.** Kessler suture (1969): scheme of suture (a); the end of the silicone model stitched according to Kessler in frontal (b) and sagittal (c) planes; Appearance of Kessler suture on a silicone model (d)

The video of the Kessler suture stages can be viewed using the QR code (Fig. 6) or by following the link https://youtu.be/m9V5hp0u4E0 .

**Fig. 6.** QR code with a link to the video of the Kessler grasping suture

In his article I. Kessler notes that the "grasping" technique is based on the technique proposed by Mason and Allen, which is probably the first blocking technique of suturing tendons [11, 12] (Fig. 7). The disadvantage of the Kessler suture is the location of the nodes fixing the threads on the surface of the tendon, which reduces it sliding properties. In order to neutralize this adverse phenomenon, the authors proposed to partially dissect the tendon channel [11].

The article, which described the Kessler technique for the first time, included preliminary data on testing the new technique on 40 chicken tendons and a description of 7 clinical cases. In 21 out of 40 experiments on a biological model, a suture failure occurred under load, but in all cases the reason for the failure was a thread break, not a tendon eruption. The authors suggested that the high frequency of breaks was due to the weakness of the 0.008 inch (approximately 0.2 mm) thick twisted wire used as a suture material, and expressed hope for the prospects of successful use of the proposed technique in the future [11].

The Kessler suture became widely known in 1973, when Doctors Urbaniak, Mortenson and Cahill presented this technique at the annual meeting of the American Society of Hand Surgeons in Las Vegas. J.R. Urbaniak and his colleagues demonstrated the results of their analysis of the tensile strength of five different methods of tendon repair. The methods studied included nodal sutures applied around the circumference and techniques proposed by Nicoladoni, Mason and Allen, Bunnell and Kessler (Fig. 7).

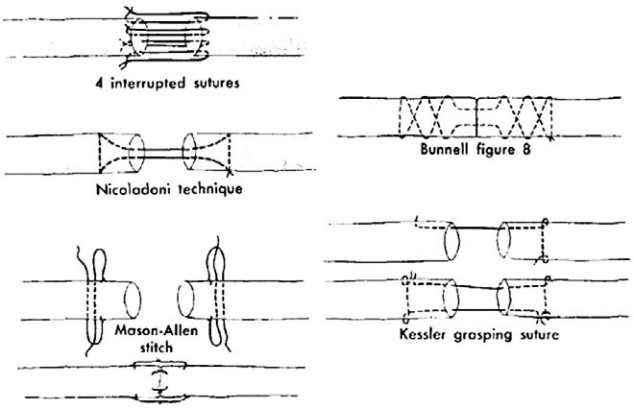


**Fig. 7.** Tendon repair techniques studied by J.R. Urbaniac et al. [Cited in 12]

In total, each of the five techniques was tested 20 times on the tendons of dogs using 4/0 stainless steel threads. The Mason and Allen technique was recognized as the most reliable, its tensile strength was 4030 g. The Kessler technique was the second with a result of 3970 g. When using both methods, the reason for the failure was the rupture of the threads in 16 cases and the suture cutting in 4 cases. In addition, the strength of the Bunnell technique and the Kessler technique in the postoperative period was compared. On the 5th day after the surgery, the Kessler suture was 3 times stronger than the Bunnell suture [12].

It should be noted that the suture technique used by J.R. Urbaniac et al. in their study differed from the original Kessler technique in that a sliding thread was used instead of a blocked loop at each corner of the restored tendon, therefore, the thread was not fixed in the tendon and could move freely in the tendon tissue (Fig. 8). This technique rather resembled the technique proposed by Kirchmayr in 1917 (fig. 9), than the original Kessler seam [12].

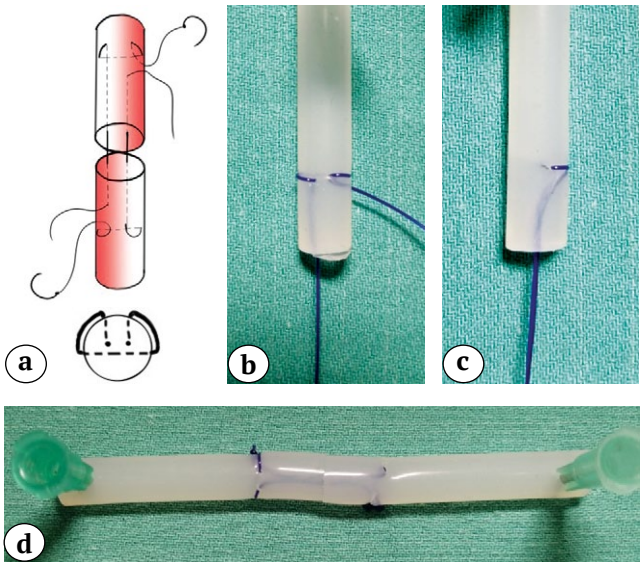


**Fig. 8.** Kessler suture in Urbaniac modification (1973): scheme of Kessler suture in the Urbaniac modification (a); the end of the silicone model stitched according to Kessler in the Urbaniac modification in frontal (b) and sagittal (c) planes; the appearance of the Kessler suture in the modification of Urbaniac on a silicone model (d)

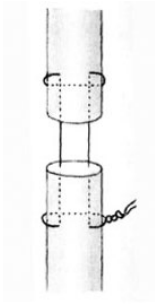

**Fig. 9.** Scheme of Kirchmayr suture (1917) [12]

It is also interesting that the Bunnel suture presented in the study differs from the original technique proposed by the author in 1918 (Fig. 10) [13]. Thus, the J.R. Urbaniac study compared the modified Kessler suture with the modification of the Bunnel suture.

It is interesting to note that Kessler knew that the suture technique proposed by Urbaniac et al. differs from the original one, and in the same 1973 he published another article in which he gave a detailed description of his "grasping" technique (Fig. 11) [14].

However, two years later, in 1975, an article by J.R. Urbaniac et al. was published, which summarized the theses of the congress of the American Society of Hand Surgeons in 1973, and their interpretation of the Kessler suture became popular and widely known as the true Kessler suture [12].

Another common technique, sometimes mistakenly interpreted as the original Kessler suture, is a variant with symmetrical suturing of the tendon ends and tying knots between them.

According to A.A. Gritsyuk and A.P. Sereda, the authorship of this technique belongs to another "pioneer" of hand surgery — a doctor from Japan Tatsuya Tajima, who used it in his practice even before 1963 [3]. T. Tajima himself, in his article "History, current status and aspects of hand surgery in Japan" (1984), notes that this technique was first described in 1975 (Fig. 12) [15]. Some authors even use a double eponym: the Kessler – Tajima suture [16].

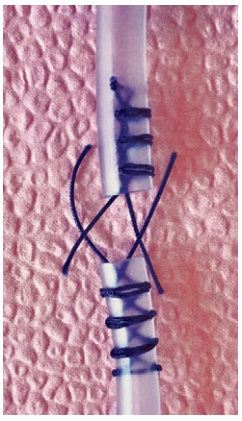

**Fig. 10.** The original suture proposed by S. Bunnel (Published with the permission of the authors) [13]

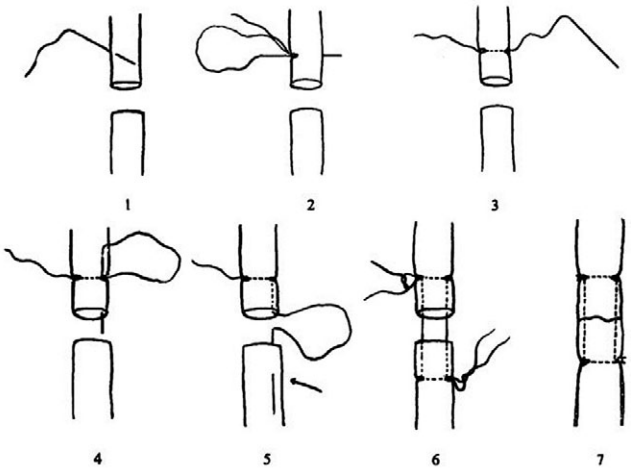


**Fig. 11.** Stepwise tendon repair technique using Kessler's grasping technique [14]

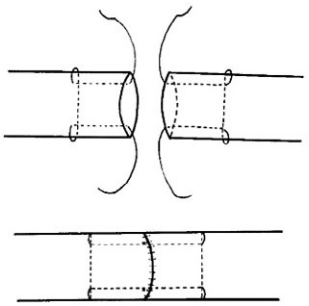

**Fig. 12.** Scheme of Tajima suture [14]

The Tajima suture is very similar to the Rozov suture, but unlike it, the threads are located internally in two planes: frontal and sagittal and thus cover most of the tendon bundles (Fig. 13).

A detailed comparison of the original tendon sutures of Rozov and Kessler reveals significant differences in the location of nodes, methods of fixation and planes of the location of the threads in the thickness of the tendon (fig. 14).

The main differences are presented in Table 1.

Common in the discussed methods of tendon suture can be considered the parallel arrangement of the main threads in the tendon tissue, the presence of two strands crossing the rupture area, and the fact that the thread is fixed by two nodes. However, these are common properties characteristic of a large number of other tendon sutures.

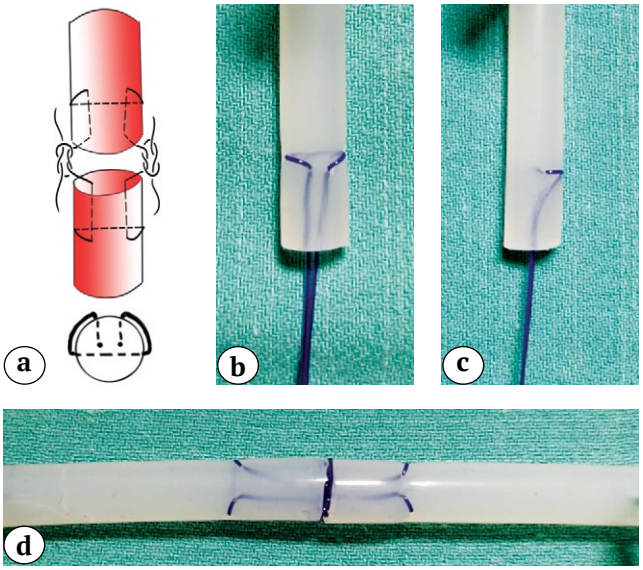


**Fig. 13.** Tajima suture (1975): scheme of Tajima suture (a); the end of the silicone model stitched according to Tajima in frontal (b) and sagittal (c) planes; the appearance of the Takima suture on a silicone model (d)

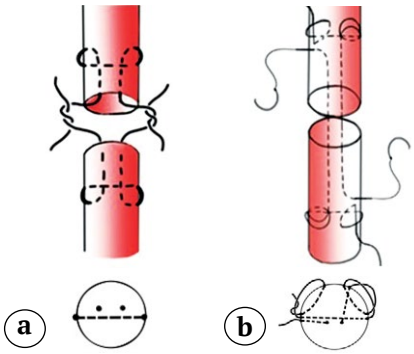


**Fig. 14.** Schemes of (a) original Rozov suture and original Kessler suture (b)

*Table 1*

**Comparative characteristics of the examined sutures**

| Suture features | Rozov suture 1958–1960 | Kessler suture 1969 |
|---|---|---|
| Knots location | Between the ends of the injuried tendon | On the surface of the tendon |
| Thread fixation | Blocking loops | Non-blocking loops |
| Core threads location | In one plane (frontal) | In two planes (frontal and sagittal) |
| Number of thread inlets and outlets at the one end of the tendon | 6 | 9 |

In this article, we did not set ourselves the task of analyzing in order to find out which method is the best. We can only assume that Kessler's "grasping" technique is more reliable due to blocking loops, however, this statement requires confirmation by conducting additional research.

## CONCLUSION

The original techniques of Rozov and Kessler are different ways of connecting the ends of injuried tendons. The suture technique used by modern surgeons in their practice and described as the Rozov suture or the Kessler suture may differ significantly from the classical version proposed by these authors.

## DISCLAIMERS

### *Author contribution*

*Berezin P.A.* — research concept and design, the collection and processing of material, writing the draft, editing.

*Zolotov A.S.* — analysis and statistical processing of data, editing.

*Volykhin R.D.* — the collection and processing of material.

*Evdokimova E.N.* — the collection and processing of material.

*Morozov L.I.* — the collection and processing of material.

*Lazarev I.A.* — the collection and processing of material.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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***Competing interests.*** The authors declare that they have no competing interests.

***Ethics approval.*** Not applicable.

Consent for publication. Not required.

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## Authors' information

✉ *Pavel A. Berezin*
Address: 6, Chkalova str., Yaroslavl, 150054, Russia
https://orcid.org/0000-0001-8777-2596
e-mail: medicinehead@mail.ru

*Aleksandr S. Zolotov* — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0002-0045-9319
e-mail: dalexpk@gmail.com

*Rodion D. Volykhin*
e-mail: 9gun@bk.ru
https://orcid.org/0000-0001-5407-7044

*Elena N. Evdokimova*
https://orcid.org/0000-0002-5614-7728
e-mail: lenalena811@yandex.ru

*Lev I. Morozov*
https://orcid.org/0000-0002-0010-1763
e-mail: morozoff41@yahoo.com

*Ilya A. Lazarev*
https://orcid.org/0000-0002-3506-8334
e-mail: il.lazarevv@yandex.ru