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# СОДЕРЖАНИЕ

Редакционная статья
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**Уважаемые читатели!**

Представляем очередной выпуск журнала, в котором нашли отражение самые разные проблемы нашей и смежных с ней специальностей.

Традиционная для нашего журнала тема эндопротезирования в этом выпуске представлена работой А.Н. Цеда с соавторами, в которой анализируются особенности выполнения этой операции у пациентов с первичной идиопатической тромбоцитопенией, заключающиеся в более длительной предоперационной подготовке, увеличении интраоперационной кровопотери и объема переливания гемокомпонентов.

Свой метод устранения посттравматической контрактуры коленного сустава с использованием ортопедического гексапода представили С.А. Рохоев с соавторами.

Детская травматология и ортопедия представлена в этом выпуске работами наших коллег из Центра им. Г.И. Турнера. П.И. Бортулев с соавторами представили результаты сравнительного исследования эффективности двух видов остеотомии при дисплазии тазобедренного сустава — по Salter и по Pemberton. С.Ю. Семенов с соавторами выявили изменения рентгенометрических параметров при нестабильности дистального лучелоктевого сустава у детей, а также их влияние на планирование хирургического вмешательства и прогнозирование восстановления анатомии и функции предплечья.

В разделе «Дискуссии» представлены различные взгляды и подходы к выполнению экстренных и плановых операций остеосинтеза пациентам с переломами длинных костей в крупных городах Российской Федерации. Приглашаем наших коллег присоединиться к обсуждению этой актуальной проблемы.

Наше издание является научно-практическим, и мы стараемся уделять достаточно внимания экспериментальным и теоретическим работам, которые являются базой будущих клинических исследований. В этом выпуске экспериментальные исследования представлены двумя статьями. А.В. Петряйкин с соавторами представили результаты сравнения четырех денситометров разной геометрии и фирм-производителей при моделировании различного водно-жирового окружения. М.В. Стогов с соавторами провели исследование на животных, показавшее, что применение нагрузок в зоне имплантации чрескожных имплантатов положительно сказывается на их приживаемости и снижает обсемененность этой области.

Как всегда, мы отобрали наиболее интересные и редкие клинические наблюдения, а также представляем вашему вниманию интересный обзор литературы по проблеме лечения пациентов с контрактурой Дюпюитрена.

Уважаемые коллеги, несмотря на то, что Министерство образования и науки России в сложившихся условиях приостановило до декабря 2022 года учет индексации публикаций отечественных ученых в международных базах дан-

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ных, в том числе и в Web of Science, куда входит наш журнал, мы приняли решение сохранить принятые в журнале международные критерии оценки качества поступающих статей. Сейчас в Российской Федерации создается новая система оценки результативности научных исследований и разработок, в которой будут учитываться публикации в высокорейтинговых отечественных изданиях, входящих в ядро РИНЦ и Russian Science Citation Index. Наш журнал входит в обе эти базы, и задача редакции и редколлегии — сохранить высокий рейтинг журнала. А сделать это можно, только публикуя высококачественные востребованные читателями статьи.

Будем рады увидеть ваши работы на страницах нашего журнала.

*С уважением,*
*главный редактор журнала*
*«Травматология и ортопедия России»*
*член-корреспондент РАН профессор Р.М. Тихилов*

Original Article
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# Treatment of Extension Knee Contractures with Ilizarov Apparatus Versus Orthopedic Hexapod Ortho-SUV Frame

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***Background.*** In case if it is impossible to eliminate the knee contracture by soft tissue release, external fixation is additionally used. Most often, the Ilizarov apparatus with a uniaxial hinge is used for this purpose. Orthopedic hexapods, unlike the Ilizarov frame, are able to reproduce the kinematics of movements in the knee joint.

***Aim of the study*** — to evaluate the effectiveness of orthopedic hexapod for the treatment of patients with knee extension contractures in comparison with the Ilizarov apparatus.

***Methods.*** We analyzed 64 cases of combined treatment of extension knee contractures, which were divided into two groups. In the 1st group (31 patients) in addition to the soft tissue release, the orthopedic hexapod Ortho-SUV Frame (OSF) was used. In the 2nd group (33 patients) the Ilizarov apparatus with an uniaxial hinge was used. In a comparative analysis between groups, the number of flexion-extension cycles, the time required to complete them, and the time needed for complete knee range of motion (ROM) restoration were evaluated. Functional results were assessed using specialized scales-questionnaires KSS, Lysholm, LEFS in 2 days, 6 and 12 mon. after frame dismantling.

***Results.*** Comparing the total external fixation period, as well as the time needed for ROM restoration, no significant difference between groups was found ($p>0.05$). When using the orthopedic hexapod, in comparison with the Ilizarov apparatus, fewer flexion-extension cycles were required. When assessing the amplitude of movements in 12 mon. in the first group, excellent results were found in 27 patients and good results in 4. In the second group, in all 33 patients good ROM was evaluated. On average, the ROM in the 1st group was 20° more than in the 2nd group. The knee function in 12 mon. was 16 points higher on the KSS in the 1st group, 5 points higher on the Lysholm scale, and 15 points higher on the LEFS scale than in the 2nd group. When analyzing the frequency of complications, no significant differences were found ($p>0.05$).

***Conclusions.*** The results obtained indicate the effectiveness of the orthopedic hexapod in the treatment of patients with knee extension contractures.

**Keywords:** knee joint stiffness, knee joint contracture, quadricepsplasty, external fixation, Ilizarov apparatus, orthopedic hexapod.

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# Сравнительная оценка результатов использования аппарата Илизарова и ортопедического гексапода Орто-СУВ при лечении разгибательных контрактур коленного сустава

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***Актуальность.*** При невозможности одномоментно устранить контрактуру коленного сустава путем мягкотканного релиза дополнительно используются аппараты внешней фиксации (АВФ), наиболее часто — аппарат Илизарова с одноосевым шарниром. Также могут применяться ортопедические гексаподы, которые, в отличие от аппарата Илизарова, способны воспроизвести кинематику движений в коленном суставе.

***Цель исследования*** — оценить эффективность применения ортопедического гексапода для лечения пациентов с разгибательными контрактурами коленного сустава в сравнении с использованием аппарата Илизарова.

***Материал и методы.*** Проанализировано 64 случая комбинированного лечения разгибательных контрактур коленного сустава, сформировавшихся вследствие внесуставных переломов бедренной кости. Пациенты были разделены на две группы. В первой группе при лечении 31 пациента в дополнение к мягкотканному релизу применяли ортопедический гексапод Орто-СУВ. Во второй группе при лечении 33 пациентов использовали аппарат Илизарова с одноосевым шарниром. При сравнительном анализе между группами оценивали количество циклов сгибания-разгибания; время, необходимое на их выполнение; общее время восстановления движений в АВФ. Функциональные результаты оценивали по амплитуде движений в коленном суставе и специализированным шкалам-опросникам KSS, Lysholm, LEFS по прошествии 2 дней, а также через 6 и 12 мес. с момента демонтажа АВФ.

***Результаты.*** При сравнении общей длительности использования АВФ, а также времени, необходимого для разработки движений, значимой разницы не выявлено ($p$>0,05). При использовании ортопедического гексапода потребовалось выполнение меньшего количества циклов сгибания-разгибания по сравнению с применением аппарата Илизарова. При оценке амплитуды движений через 12 мес. в первой группе отличные результаты получены в 27 случаях и хорошие — в 4 случаях. Во второй группе во всех 33 случаях была отмечена хорошая амплитуда движений. В среднем амплитуда движений в первой группе была на 20° выше, чем во второй группе. Оценка функции коленного сустава через 12 мес. по шкале KSS в первой группе была выше на 16 баллов, по шкале Lysholm — на 5 баллов, по шкале LEFS — на 15 баллов, чем во второй группе. При анализе частоты осложнений значимые различия не были выявлены ($p$>0,05).

***Заключение.*** Полученные результаты свидетельствуют об эффективности использования ортопедического гексапода при лечении пациентов с разгибательными контрактурами коленного сустава.

**Ключевые слова:** коленный сустав, контрактура, артролиз, тенолиз, миолиз, квадрицепспластика, аппараты внешней фиксации, аппарат Илизарова, ортопедический гексапод.

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## BACKGROUND

The formation of extensor contracture of the knee joint after a fracture of the femur has been registered in 20-38% of all relevant cases [1, 2, 3, 4]. The resulting restriction of flexion in the knee joint significantly impairs the quality-of-life of patients [5, 6, 7]. Quadricepsplasty, a soft tissue intervention aimed at eliminating scars and adhesions with the restoration of the sliding properties of the quadriceps muscle (QM) is the most commonly used surgery to eliminate extensor contractures [8, 9, 10, 11]. However, long-term contractures lead to persistent secondary changes in the soft tissues, their contraction, and partial cicatricial degeneration [12, 13]. In such cases, attempts at acute elimination of contracture to achieve the required range of motion (ROM) are deemed dangerous considering the possible damage to the QM tendon, avulsion fracture of the patella, or tibial tuberosity [14, 15, 16, 17]. To avoid these complications, the soft tissue stage of the surgery is generally supplemented with the use of an external fixation (ExFix), most often the Ilizarov apparatus [18, 19, 20, 21]. Moreover, a single-axis hinged mechanism not only enables the reproduction of the kinematics of movements in the knee joint [22, 23, 24]. However, this is possible when using an orthopedic hexapods [25, 26, 27, 28].

Based on these results, the present study aimed to evaluate the efficiency of an orthopedic hexapod for the treatment of patients with extensor contractures of the knee joint in comparison with the Ilizarov apparatus.

## METHODS

### Study design

A retro- and prospective cohort non-randomized study was performed.

### Patients

All patients included in this study were treated at the Vreden National Medical Research Center of Traumatology and Orthopedics from 2003 to 2021. A total of 64 cases of combined (soft tissue release and ExFix ) treatment of the extensor contractures of the knee joint resulting from extra-articular fractures of the femur was analyzed in this study.

Group 1 (main) consisted of 31 patients who underwent treatment with the orthopedic hexapod Ortho-SUV for contracture, after the soft tissue stage of the surgery [29]. A total of 19 patients were analyzed retrospectively and 12 prospectively. Group 2 (comparison group) included 33 patients in whom the Ilizarov apparatus with a single-axis hinged system was employed after the soft tissue release. Both the groups were compared in terms of gender, age, fracture location, treatment method, duration of the contracture, and the preoperative range of motion ($p > 0.05$) (Table 1).

*Table 1*

**Characteristics of patients in the study groups (Me [Q25; Q75])**

| Indicator | | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) |
|---|---|---|---|
| Number of patients. n | | 31 | 33 |
| Age. years | | 33 [18; 55] | 35 [19; 57] |
| Gender, m/f | | 21 (67.8%) / 10 (32.2%) | 20 (60.6%) /13 (39.9%) |
| Classification of fractures according AO/OTA: | | | |
| 32- | | 10 (32.3%) | 14 (42.4%) |
| 33-A2 and A3 | | 21 (67.7%) | 19 (57.6%) |
| Fracture treatment method | Conservative treatment | 12 (38.7%) | 14 (42.4%) |
| | MOS plate | 9 (29.0%) | 7 (21.2%) |
| | ExFix | 4 (12.9%) | 6 (18.1%) |
| | BIOS | 2 (6.5%) | 4 (12.1%) |
| | SO | 4 (12.9%) | 2 (6.1%) |
| Duration of the contracture | | | |
| 2 years | | 12 (38.7%) | 15 (45.4%) |
| 3 years | | 15 (48.3%) | 15 (45.4%) |
| 4 years | | 4 (12.9%) | 3 (9.1%) |
| Range of movement before surgery. deg. | | 20 [15; 35] | 30 [20; 35] |

MOS — metal osteosynthesis; BIOS — blockable intramedullary osteosynthesis; SO — sequential osteosynthesis.

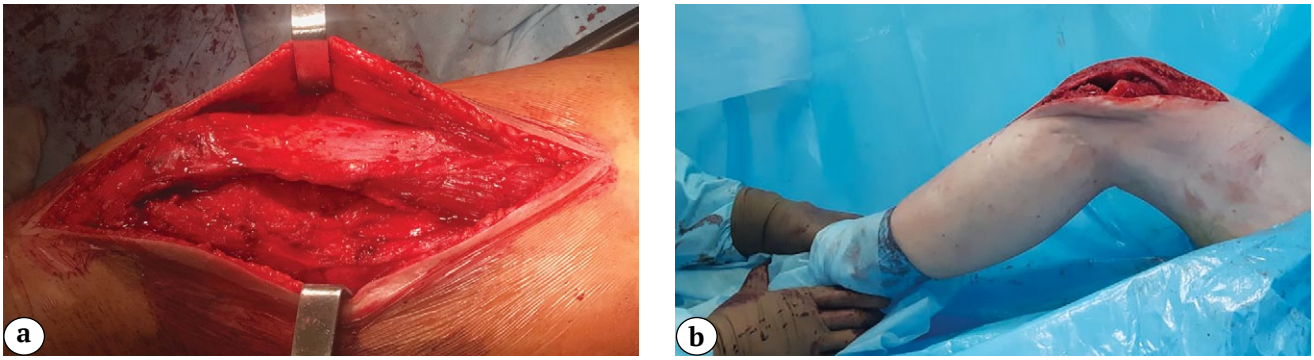


**Fig. 1.** Soft tissue procedure: a — after soft tissue release; b — maximal flexion 65°

Unfortunately, it was not possible to detail the types and the groups of diaphyseal and the subgroups of extra-articular fractures that consequently led to the contracture.

## Surgical technique

In both the groups, stage 1 was Thompson quadricepsplasty, as modified by S.B. Hanh et al. [30]. Through a linear incision along the anterolateral surface, access was made to the heads, the QM tendon, and the patella (Fig. 1 a). The joint cavity and the ligament of the patella were freed from adhesions from the fibrous Hoffa's pad, after which the rectus femoris was mobilized along the entire length up to the upper third of the thigh. The intermediate muscle, as a rule, represents a hypotrophic cicatricial-degenerate cord, which is always excised. Only if, after the soft tissue stage of the surgery, the required ROM is not achieved (Fig. 1 b), that is, the main cause of the contracture is the QM retraction, applying ExFix frame to the knee joint was used.

In both the groups, when applying ExFix, two supports on the femur (sector and ring) and one ring support on the lower leg were mounted. Bone components, wires, and threaded pins were inserted into the projections of the so-called "Recommended positions (RP)" [31].

The Ortho-SUV Frame (OSF) hexapod assembly, specially designed for the treatment of knee joint contractures, was adopted [32]. Its peculiarities involved the fact that the base ring was installed in the sagittal plane at an angle of 60° to the anatomical axis of the femur, while the mobile ring was mounted at an angle of 120° to the anatomical axis of the tibia. An additional "dummy" sector was used to fix the strut # 1 (Fig. 2 a).

On the next day of the surgery, an X-ray of the knee joint was performed in 2 projections. Using the Adobe Photoshop 2020 (Adobe Systems, Inc.), a specially designed template was superimposed on the lateral radiograph with marked instantaneous centers of rotation of the knee joint and the angles of rotation (Fig. 2 b). When calculating in the computer program SUV-Software v.7.2, a distraction of 5-7 mm was set, and the "multi total residual" software option was used to calculate the flexion up to an angle of 120° at intervals of 10° (Fig. 2 c). In addition, when calculating, the internal rotation of the tibia was added at flexion angles of 10°, 30°, 60°, 90°, and 120°. The flexion rate of 2.5° per day for 4 cycles was selected, as a result of which the program calculated the change in the strut length to provide 10° flexion in 4 days.

Distraction was started on days 3-7, followed by a period of passive-active development of movements. The passive-active development of movements included the cycles of passive flexion-extension of the lower leg using an orthopedic hexapod. Simultaneously, active exercises were started after the complete cycle 1 of passive flexion-extension with the use of an OSF orthopedic hexapod. To develop active movements, struts ## 2, 4, and 6 were temporarily detached from the mobile ring. Having fixed the struts again, the patients were recommended exercises that involved touching the tips of the toes with their fingers and lifting the weight of the lower limb, first with the help of a cable, and subsequently without it. Active exercises for the lower

leg flexors were performed daily for 30-40 min at an interval of 5-6 h. The cycles were repeated until the amplitude of active movements in the knee joint reached an angle of 90°. The initial rate of flexion, depending on the pain syndrome, could be accelerated or slowed down. As a rule, the rate of flexion-extension for each subsequent cycle was greater than that of the previous one.

To prevent the rebound effect (decrease in the range of motion due to soft tissue retraction) in the postoperative period, upon reaching an active range of motion of 70-80º, the fixation of the knee joint for the night in the position of the maximum possible flexion and extension was alternated daily. The frame was dismantled after the patient could independently flex the knee joint to a 90° flexion angle.

In group 2 (Ilizarov apparatus), the frame assembly included base ring applied in distal third of the femur, while mobile ring was mounted in the proximal third of the lower leg. In the frontal plane, the rings were oriented perpendicular to the common mechanical axis. In the sagittal plane, the base and mobile rings were oriented perpendicular to the anatomical axes of the femur and tibia. The axial hinges were placed under the C-arm control in the projection of the flexion-extension axis of the knee joint [33]. Passive movements were performed using swivel hinge (“motor”) (Fig. 3).

Postoperative management did not differ from that used for group 1. To perform active exercises, the axial hinges were disconnected.

After the frame dismantling, patients of both groups continued complex rehabilitation treatment that included exercise therapy, low-frequency magnetic therapy, massage, and mechanotherapy.

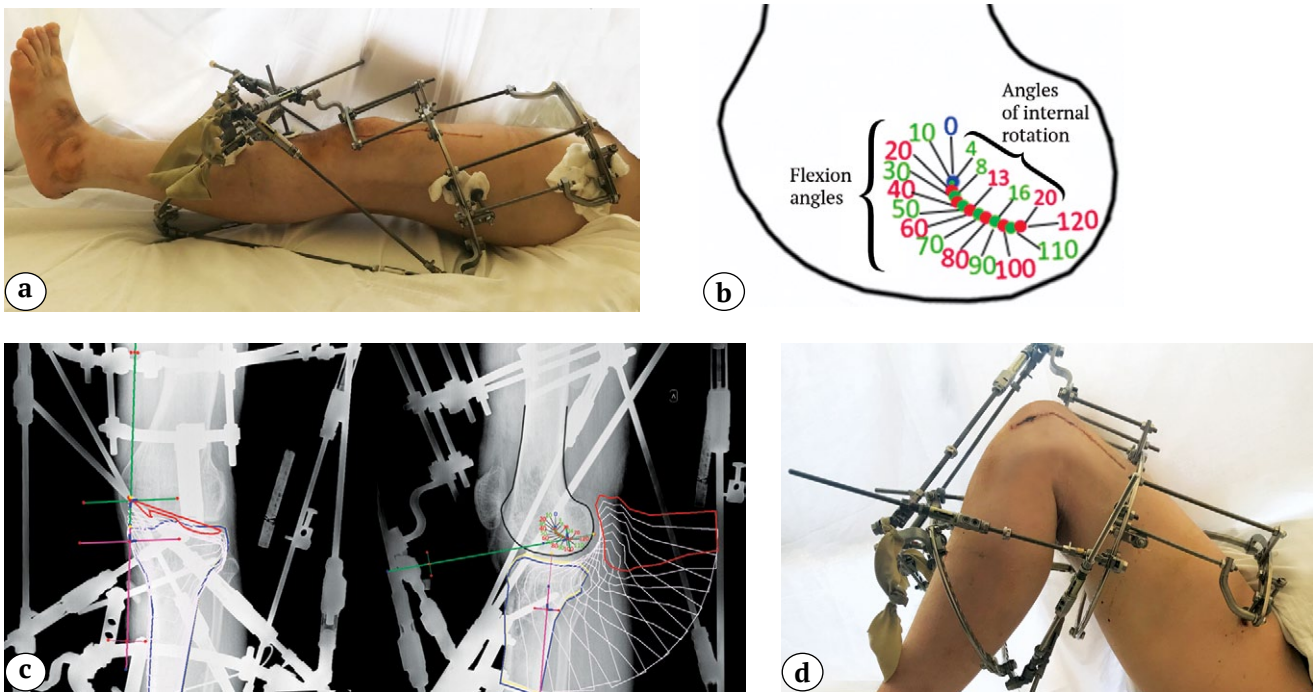


**Fig. 2.** Usage of Ortho-SUV Frame (OSF) hexapod:
a — after frame applying;
b — the template, in wich accordance the movements in the knee joint were modelled;
c — OSF software window;
d — maximal flexion achieved

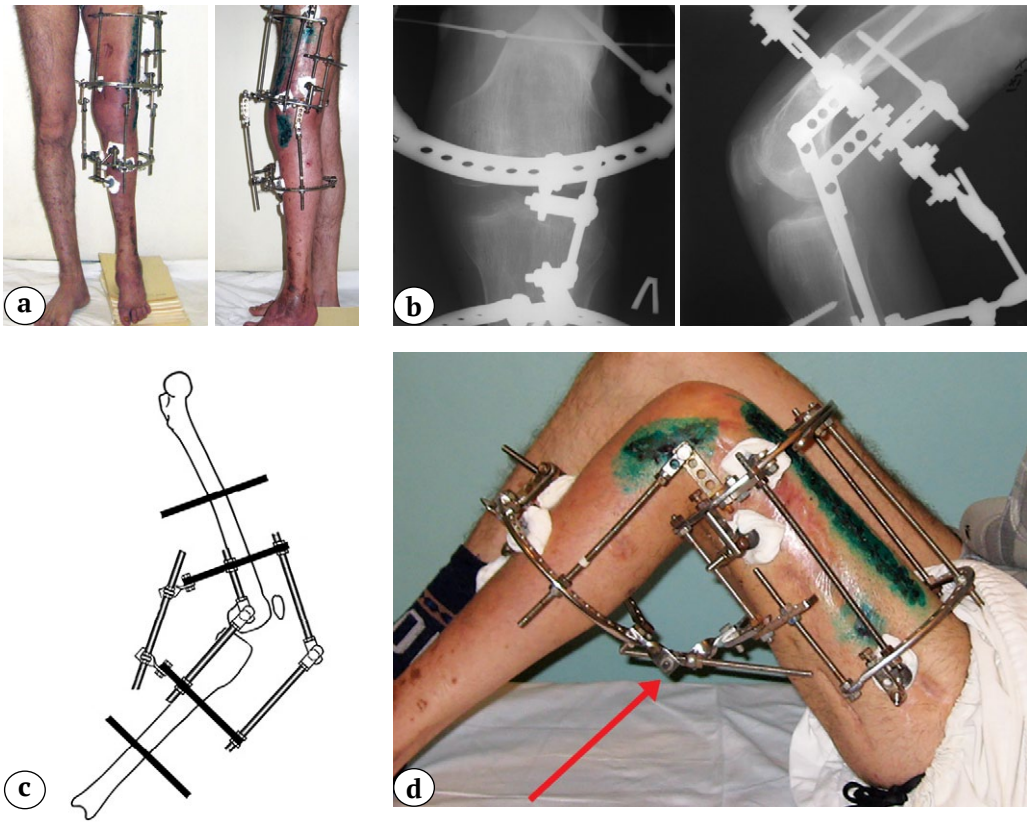


**Fig. 3.** Usage of Ilizarov apparatus:
a — after frame applying; b — X–ray during treatment;
c — axial and swivel hinges; d — ring-to-ring collision

## Comparison of results

In a comparative analysis between groups, the duration of the movement development period (MDP) using ExFix was evaluated, along with the number of flexion-extension cycles, the time spent on their implementation (cycle duration), and the range of motion in the joint. The final ROM was assessed as excellent at ≥110°, good at 90-109°, satisfactory at 60-89°, and unsatisfactory at ≤60°. The classification of Caton (1991) [34] was used to assess the relationship between complications and treatment outcomes. The KSS [35], Lysholm, and LEFS questionnaires were used to assess the function of the knee joint and the lower limb in general. The evaluation was performed at the stages before the surgery, on day 2 after the ExFix dismantling, and at 6 and 12 months after the ExFix frame dismantling. In 12 prospective patients from the main group, an additional assessment was performed at 3 and 9 months after the ExFix dismantling.

## Statistical analysis

The data obtained were recorded in Microsoft Excel spreadsheets. Statistical data analysis was performed using the Statistica v.10 software. The analysis of the normality of distribution was performed using the Shapiro-Wilk test. The distribution of most of the studied numerical variables differed from the normal one; therefore, nonparametric methods of statistical analysis were applied. To assess the quantitative parameters in 2 independent groups, the Mann-Whitney *U*-test was used. As is customary when using nonparametric methods, quantitative data were presented as a median as well as lower and upper quartiles. To calculate the relationship between quantitative parameters, the Spearman correlation coefficient was adopted. The comparison of the frequency characteristics of nominal data was performed using the $\chi^2$ test (with the Yates correction for small cohorts) and Fisher's test. The assessment of the depen-

dent samples in the same group and the study of the indicators in dynamics after surgical treatment were performed using the Wilcoxon and Friedman criteria.

## RESULTS

When comparing the period of development of movements and the period of use of ExFix in both the groups, no statistically significant difference was noted ($p>0.05$) (Table 2).

In group 1, where the Ortho-SUV orthopedic hexapod was used, an active flexion angle of 90° was achieved in 5 (16.2%) cases in 4 cycles, 24 (77.4%) cases in 5 cycles, and 2 (6.4%) cases in 6 cycles. In group 2, in 12 (36.4%) cases, to achieve an active flexion angle of 90°, 6 cycles were required, and in 21 (63.6%) cases, 7 flexion-extension cycles were necessary (Table 3). When comparing the duration of cycles, a statistically significant difference was recorded in cycles 1, 2, and 3 ($p\leq0.05$). According to Table 3, less time was spent on the first 3 cycles of group 2 than that of group 1. At the end of cycle 4, the average duration in both the groups became equal ($p > 0.05$), while the average active range of motion in group 1 remained statistically significantly greater ($p<0.05$) than that in group 2. At the end of cycle 5, the average time in group 1 was less ($p<0.05$), and the average active range of motion was also statistically significantly greater than that in group 2 ($p < 0.05$).

The maximum value of the achieved flexion angle when using the orthopedic hexapod on each cycle averaged 115° (110;115), which is 25° more than that in the comparison group, where the maximum flexion angle averaged 90° (90;90) ($p<0.05$). The amplitudes of movements on day 2 and at 12 months after ExFix dismantling were statistically significantly less in the Ilizarov apparatus group ($p<0.05$). At 12 months after ExFix dismantling, an excellent range of motion was recorded in group 1 in 27 (87.1%) patients and a good one in 4 (12.9%) cases. In group 2, in all 33 (100%) cases, the range of motion was assessed to be good (Table 4).

In group 1, the correlation analysis revealed a direct strong relationship between the maximum achieved frame-based flexion and the range of motion achieved after 12 months ($p < 0.05$; $r = 0.877$). In group 2, a direct moderate relationship was noted ($p < 0.05$; $r = 0.715$).

The mean scores on the KSS and Lysholm scales on day 2 after the frame dismantling were statistically significantly lower in group 2 ($p<0.05$), while no significant difference was noted on the LEFS scale ($p>0.05$). At 6 and 12 months after the frame dismantling, the mean scores on the KSS, Lysholm, and LEFS scales were statistically significantly lower in group 2 ($p<0.05$) (Table 5).

After 12 months in group 1 on the KSS scale, excellent results were recorded for all patients. In group 2, excellent results were registered in 10 (30.3%) patients and good results in 23 (69.7%) patients. According to the Lysholm scale, in group 1, an excellent function was noted in 29 (93.5%) cases and good function in 2 (6.4%) cases, while, in the group 2, excellent results were recorded in 9 (27.2%) patients and good results in 24 (72.8%) cases. According to the LEFS scale, in group 1, a slight limitation of the lower limb function was noted in all cases, and, in group 2, a similar result was noted in 15 (45.4%) patients, while a moderate limitation of function was noted in 18 (54.6%) cases.

Indicators of the dynamics of the average range of motion and the average score in prospective patients of group 1 are presented in Table 6. When assessing the dynamics of the average ROM in group 1, since the surgery, its increase and the achievement of excellent results were noted 9 months after the frame dismantling.

*Table 2*

**Time characteristics of both the study groups, days (Me [Q25; Q75])**

| Period | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) |
|---|---|---|
| Latent | 3 [2; 4] | 3 [2; 3] |
| Distraction | 4 [3; 4] | 5 [4; 5] |
| Movement development | 99 [91; 107] | 110 [88; 119] |
| ExFix use period | 108 [99; 120] | 109 [98; 114] |

*Table 3*

**Quantitative data of flexion-extension cycles in the study groups (Me [Q25; Q75])**

| Cycle number | Group 1 (Ortho-SUV) | | | Group 2 (Ilizarov apparatus) | | | *p* | |
|---|---|---|---|---|---|---|---|---|
| | n, % | CD, days | MAJ, deg. | n, % | CD, days | MAJ, deg. | CD, days | MAJ, deg. |
| 1 | 31/100 | 39 [37; 41] | 40 [25; 50] | 33/100 | 32 [30; 34] | 30 [20; 35] | <0.05 | <0.05 |
| 2 | 31/100 | 28 [26; 30] | 55 [45; 60] | 33/100 | 25 [22; 26] | 45 [40; 45] | <0.05 | <0.05 |
| 3 | 31/100 | 19 [16; 23] | 65 [55; 70] | 33/100 | 17 [16; 18] | 55 [50; 60] | <0.05 | <0.05 |
| 4 | 31/100 | 11 [9; 13] | 80 [70; 85] | 33/100 | 11 [10; 13] | 65 [60; 70] | >0.05 | <0.05 |
| 5 | 24/77.4 | 4 [4; 5] | 92 [90; 95] | 33/100 | 7 [6; 8] | 75 [75; 85] | <0.05 | <0.05 |
| 6 | 2/6.4 | 2.5 [2; 3] | 92 [90; 95] | 33/100 | 5 [3; 7] | 85 [85; 90] | – | – |
| 7 | – | – | – | 21/63.6 | 3 [3; 4] | 90 [90; 90] | – | – |

n — number of patients; CD — cycle duration, days; MAJ — movement amplitude in the joint.

*Table 4*

**Range of knee motion at various times, deg. (Me[Q25; Q75])**

| Follow-up period | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) | *p* |
|---|---|---|---|
| Before surgery | 20 [15; 35] | 30 [20; 35] | >0.05 |
| After release | 55 [50; 70] | 60 [55; 70] | >0.05 |
| Before dismantling the ExFix | 115 [110; 115] | 90 [90; 90] | <0.05 |
| On the day 2 after dismantling | 90 [90; 95] | 90 [90; 90] | <0.05 |
| After 6 months | 105 [100; 110] | 95 [90; 95] | <0.05 |
| After 12 months | 115 [110; 120] | 95 [90; 95] | <0.05 |

*Table 5*

**Results of assessment the knee function on scales, score (Me [Q25; Q75])**

| Follow-up period | KSS | | Lysholm | | LEFS | |
|---|---|---|---|---|---|---|
| | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) | Group 1 (Ortho-SUV) | Group 2 (Ilizarov apparatus) |
| Before surgery | 58 [48; 62] | 60 [54; 63] | 47 [44; 53] | 50 [42; 55] | 28 [24; 30] | 27 [24; 31] |
| | *p*>0.05 | | *p*>0.05 | | *p*>0.05 | |
| On the day 2 after dismantling | 74 [71; 76] | 68 [67; 70] | 81 [76; 81] | 77 [75; 81] | 50 [48; 54] | 51 [47; 53] |
| | *p*<0.05 | | *p*<0.05 | | *p*>0.05 | |
| After 6 months | 85 [82; 86] | 78 [76; 81] | 88 [88; 91] | 86 [79; 86] | 66 [64; 70] | 58 [57; 61] |
| | *p*<0.05 | | *p*<0.05 | | *p*<0.05 | |
| After 12 months | 95 [94; 97] | 79 [77; 83] | 95 [92; 99] | 90 [86; 91] | 74 [72; 75] | 59 [58; 64] |
| | *p*<0.05 | | *p*<0.05 | | *p*<0.05 | |

When evaluating the dynamics of changes in the average scores on the KSS scale 6 months after the ExFix dismantling, excellent functions of the knee joint were noted. According to the Lysholm score, excellent functions of the knee joint were achieved 9 months after the frame removal. According to the LEFS scale, the limitation of the lower limb function was noted to be insignificant 6 months after the external device dismantling.

In group 1, complications developed in 14 (45.1%) patients, 12 (38.7%) of whom showed superficial pin-site infection (category 1). In 1 (3.2%) female patient, limited skin necrosis occurred in the postoperative period (category 2); therefore, the development of movements was temporarily suspended for the debridement. After the secondary healing of the wound, the development was continued. In another (3.2%) patient, the development was suspended due to infection in the surgical area (category 2), which necessitated revision, sanitation, and drainage of the infectious focus. As a result, the purulent-inflammatory process was discontinued, while the development was continued.

In group 2, the complications were detected in 17 (51.4%) patients; 16 (48.4%) of whom experienced superficial pin-site infection (category 1), which was stopped through conservative treatment. In 1 (3%) case, a threaded pin breaching occurred due to a fall of the patient. This case required repeated bone component insertion (category 2), after which the development of movements was continued. A comparative analysis of complications in both the groups showed no statistically significant difference ($p$>0.05).

## DISCUSSION

Fractures of the femur were accompanied by varying degrees of damage to the intermediate head of the QM [11, 13]. The scar tissue formed as a result of damage, tightly soldered to the periosteal regenerate, prevented the QM sliding, and was one of the most significant causes of contracture [10]. It can be assumed that the more severe the type and group of a fracture, the more the QM is damaged. We deliberately excluded patients with intra-articular fractures (types 33-B and 33-C) from the study in order to exclude the influence of the "articular" component of contractures. Unfortunately, it was not possible to detail the types of fractures 32- and the subgroups of fractures 33-A2 and 33-A3, because, at the time of hospitalization, there were signs of complete consolidation of the fragments with bone tissue remodeling. Available extracts from case histories did not provide sufficient information. Therefore, based on the available data, we can only state that in both the groups, mostly, contracture occurred after extra-articular fractures in the supracondylar region (33-A2 and 33-A3 according to the AO/OTA classification) (see Table 1). The formation of knee joint stiffness in patients of both groups occurred more often after conservative treatment and plate osteosynthesis. This finding is consistent with the literature data. In the study by Mousavi et al., in 11 out of 27 treated patients (40.7%), extensor stiffness was preceded by a fracture in the diaphyseal portion, at the interface of the diaphysis and the supracondylar region in 6 (22.3%) cases and in the supracondylar region of the femur in 10 (37%) cases. In 13 (48%) cases, a simple type of fracture was noted, and, in 14 (51.9%) cases, a fragmentary type was registered. When mentioning past surgical interventions, the authors noted that the formation of contracture was preceded by plate osteosynthesis in 19 (70.3%), intramedullary osteosynthesis in 5 (18.5%), and external fixation in 2 (7.4%) patients [36].

In group 1 (orthopedic hexapod), the maximum passive flexion achieved with ExFix was, on an average, 25° greater than that in group 2 (Ilizarov apparatus) (see Table 4). Although the frame was dismantled after reaching 90° of active flexion, continued rehabilitation enabled the achievement of the same amplitude that was achieved in the ExFix device by month 9 after its dismantling (Table 6).

A comparison of the groups revealed that the maximum flexion in the frame did not exceed 90-95°, as, at these angles, the length of the threaded rod on the swivel hinge end. In the comparison group, the frame was also dismantled after reaching 90° of active flexion. However, despite the continuation of rehabilitation treatment, the ROM remained the same or exceeded it by ≤5°. After 12 months, the ROM in group 1 was, on an average 20°, greater than that in group 2. Thus, it can be assumed that the higher range of motion in group 1 was directly related to the higher maximum flexion value achieved in the frame.

When analyzing the literature, we did not find any studies on the use of an orthopedic hexapod for the treatment of the knee joint extensor con-

tractures. For comparison, we could find only two papers that reported the treatment of extensor contracture using soft tissue release in addition to the use of the Ilizarov apparatus [21, 22].

Thus, Lee et al. reported the treatment of 10 patients with extensor contractures of the knee joint and found the preoperative range of motion in them averaged 25° (5-35°) [20]. As a result of the treatment, the average range of motion recorded by the authors in the last cases (without specifying the exact period of follow-up) was 93° (85-105°) [21]. The authors noted that the range of motion was the same as that at the time of dismantling the apparatus or higher in all patients, except one. The average values of the amplitude of movements obtained by the authors were similar to the present results in group 2 for 12 months after the frame dismantling.

Liu et al. reported a combination of soft tissue release with the use of the Ilizarov apparatus for the treatment of 36 patients with extension knee joints stiffness. The mean ROM before surgery was 13.8° (8-19°), after treatment, it was 102.9° (78-115°). On the other hand, the period for evaluating the result was not specified [21]. When compared with group 1 of our study, the indicator of the average range of motion was higher than that recorded by Liu et al., but, in group 2, the same indicator was lower. The higher performance noted by Liu et al. was probably associated with the use of special spring pusher hinges attached to the supports along the front side, which enabled the achievement of a larger flexion angle in the frame.

The analysis of the flexion-extension cycles showed that, in group 1, after each cycle, the amplitude of active movements was greater than that in group 2. At the same time, in group 2, less time was spent completing the first 3 cycles than that in group 2. To achieve an active ROM of 90° in group 1, fewer cycles were required than that in the comparison group. This is probably the reason why the mean values of the MDP and the ExFix period did not differ significantly.

The number of days of the flexion-extension cycles 1, 2, and 3 was significantly greater in group 1, as a greater flexion angle was achieved in the ExFix device, which needed more time. However, by cycle 4, this indicator equalized. It took less time to complete cycle 5 in group 1 than that in group 2. At the same time, 5 patients from group 1 after cycle 4 had already achieved the active flexion of 90°. The cycles 6 could not be compared due to the large difference in the number of patients (2 in group 1 and 33 in group 2). Six cycles were required for 2 patients from group 1 due to a temporary suspension of the development of movements from complications. In group 2, in 12 patients, the required amplitude was achieved after cycle 6. The remaining patients achieved an active flexion angle of 90° after cycle 7. When a larger flexion angle was reached in the frame, a greater stretching of the QM and hence a better function was achieved. This was probably the reason why it took fewer cycles in the main group to achieve active amplitude of 90°.

When compared with the data of both the groups of our study, Lee et al. employed ExFix for

*Table 6*

**Dynamics of changes in the average ROM amplitude and scores (Me [Q25; Q75])**

| Follow-up period | Amplitude of movements, deg. | KSS, score | Lysholm, score | LEFS, score |
|---|---|---|---|---|
| Before surgery | 27.5 [17.5; 40.0] | 58.0 [56.0; 62.0] | 50.0 [45.5; 63.0] | 28.0 [24.0; 29.5] |
| After release | 55.0 [47.5; 67.5] | – | – | – |
| After dismantling the ExFix | 95.0 [95.0; 95.0] | 74.0 [72.0; 76.5] | 79.0 [76.0; 81.0] | 51.5 [47.5; 55.5] |
| After 3 months | 100.0 [97.5; 102.5] | 80.0 [79.5; 81.5] | 84.5 [83.0; 86.0] | 55.0 [58.0; 59.5] |
| After 6 months | 110.0 [105.0; 112.0] | 84.0 [82.5; 86.0] | 91.0 [88.0; 91.0] | 67.5 [62.5; 71.0] |
| After 9 months | 115.0 [115.0; 120.0] | 93.0 [92.0; 95.0] | 97.0 [95.0; 99.0] | 71.5 [70.5; 72.5] |
| After 12 months | 115.0 [115.0; 125.0] | 95.0 [95.0; 96.5] | 99.0 [97.0; 99.0] | 73.5 [72.5; 75.0] |

longer (average 125 days). At the same time, the authors did not provide any description of the flexion-extension cycles and the assessment on functional scales [20].

Liu et al. did not describe the aspects of the flexion-extension cycles, except for the mention that the amplitude of active movements of 60° was achieved on an average of 28.5 ± 4.3 days. These data indicated higher temporal and functional characteristics than the characteristics of cycle 1 of both the groups of our study. Meanwhile, it should be noted that the values of the amplitude achieved after the soft tissue stage of surgery by Liu et al. were higher than that in both the present study groups. Data on the period of use of the Ilizarov apparatus were not provided by the authors [21].

After the frame dismantling in both the groups, an increase in the mean scores on the KSS and Lysholm functional scales was noted, however, in group 2, the corresponding mean scores were significantly lower. Based on the results of filling in the KSS questionnaire by the patients themselves and the attending physician, the causes of the lower average score in group 2 were determined. The difference was mainly attributable to a smaller range of motion and the signs of overstretching of the capsular-ligamentous structures of the knee joint. The lower limb function according to the LEFS scale at the time of the ExFix device dismantling in both groups did not differ. However, after 6 and 12 months, the difference was significantly lower in group 2, probably owing to the causes mentioned earlier.

We obtained a higher complication rate in both the groups when compared to those reported by Lee et al., who recorded inflammation of the soft tissues around the wires and pins (complication category 1) in 2 (20%) of 10 patients. This difference can be attributed to insignificant statistics owing to the small number of cases.

## CONCLUSIONS

The improvement of the knee joint ROM using an orthopedic hexapod enables the achievement of a greater angle of flexion and requires fewer flexion-extension cycles. However, a comparative analysis of the periods of movement development and the total ExFix time in both groups indicated that the hexapod had no significant advantages over the Ilizarov apparatus. The values of the parameters of the knee joint function when using the orthopedic hexapod were greater than those when using the Ilizarov apparatus, possibly due to the ability of the hexapod to provide a greater range of motion in accordance with its natural kinematics. The present results suggest that the use of an orthopedic hexapod to improve the knee joint ROM is an effective approach for the treatment of its extension stiffness, in terms of wide application of this technique in clinical practice.

## DISCLAIMERS

### *Author contribution*

*Saigidula A. Rokhoev* — the collection and processing of material, analysis and statistical processing of data, data statistical processing, manuscript writing.

*Dmitrii V. Chugaev* — the collection and processing of material, analysis and statistical processing of data.

*Leonid N. Solomin* — study coordination, research conception and design, 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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# Total Hip Arthroplasty in Patients with Idiopathic Thrombocytopenic Purpura

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***Background.*** There are no national clinical guidelines for the perioperative management of patients with idiopathic thrombocytopenia in hip arthroplasty. Most of the publications are presented in the context of general surgery, the distinguishing feature of which is the good achievement of hemostasis. However, it is impossible to achieve such a level of hemostasis with hip arthroplasty.
***The aim of the study*** was to evaluate the mid-term results of total hip arthroplasty in patients with primary idiopathic thrombocytopenia.
***Methods.*** Randomized monocenter clinical trial of 38 patients with idiopathic thrombocytopenia hip arthroplasty was performed. These patients was include in group I. As a control group, the outcomes of surgical treatment of 40 patients without thrombocytopenia over the same observation period were analyzed (group II). The mean follow-up period was 4.3 years. Exclusion criteria for the study were heparin-induced thrombocytopenia, a severe form of idiopathic thrombocytopenia in the acute stage with platelet counts less than $25\times10^9$/L.
***Results.*** The average length of hospitalization was longer in patients with idiopathic thrombocytopenia (11.1 days). The results indicate a longer preoperative preparation, including the transfusion of hemocomponents with repeated monitoring of the parameters of the clinical blood test and coagulogram. There was no significant difference in the duration of the surgical intervention, but there were differences in the amount of intraoperative blood loss and the volume of blood transfusion. Among the patients of the group II, only 3 patients required intraoperative transfusion of one dose of erythrocyte suspension, patients of the group I more often underwent blood transfusion. In the group I, complications were noted in 5 patients, in the group II — in one patient ($p = 0.067$), but the relative risk of complications was 5.2. Functional results 12 months after surgery didn't differ.
***Conclusions.*** The mid-term results of hip arthroplasty in patients with idiopathic thrombocytopenia are comparable to the results in patients of the general population. A distinctive feature of surgical intervention is an increase in the average volume of intraoperative blood loss and the need for a significantly larger transfusion of hemocomponents not only during the operation, but also in the preoperative period, which increases the duration of hospitalization.

**Keywords:** total hip arthroplasty, idiopathic thrombocytopenia, blood transfusion.

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# Эндопротезирование тазобедренного сустава у пациентов с первичной идиопатической тромбоцитопенией

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***Актуальность.*** В настоящее время отсутствуют национальные клинические рекомендации о периоперационном ведении пациентов с идиопатической тромбоцитопенией (ИПТ) при эндопротезировании тазобедренного сустава. Большинство публикаций, посвященных выполнению артропластики у данной категории пациентов представлено в контексте общей хирургии, отличительной особенностью которых является хорошее достижение гемостаза. Однако при эндопротезировании тазобедренного сустава достичь такого уровня гемостаза невозможно.

***Цель исследования*** — оценить среднесрочные результаты тотального эндопротезирования тазобедренного сустава у пациентов с первичной идиопатической тромбоцитопенией.

***Материал и методы.*** Выполнено рандомизированное моноцентровое клиническое исследование 38 пациентов с ИПТ, которым в период с 2015 по 2021 г. была выполнена артропластика тазобедренного сустава. Эти пациенты составили группу I исследования. В качестве контрольной группы были проанализированы исходы эндопротезирования тазобедренного сустава 40 пациентов без тромбоцитопении за аналогичный период наблюдения (группа II). Средний период наблюдения составил 4,3 года. Критериями невключения в исследование были гепарин-индуцированная тромбоцитопения, тяжелая форма идиопатической тромбоцитопении в стадии обострения с количеством тромбоцитов менее $25\times10^9$/л.

***Результаты.*** Средние сроки госпитализации были больше в группе I — 11,1 койко-дней по сравнению с 7,7 в группе II. Результаты свидетельствуют о более длительной предоперационной подготовке, включающей трансфузию гемокомпонентов с повторным выполнением клинического анализа крови и коагулограммы. Не получено статистически значимой разницы в продолжительности хирургического вмешательства, однако между группами имелись отличия в величине интраоперационной кровопотери и объеме гемотрансфузии. В группе II только 3 пациентам потребовалось интраоперационное переливание одной дозы эритроцитарной взвеси, пациентам группы I чаще производилась гемотрансфузия. Осложнения в группе I отмечены у 5 пациентов, во группе II — у одного пациента, что не является статически значимым отличием ($p$ = 0,067), однако относительный риск развития осложнений составил 5,2. Функциональные результаты через 12 мес. после операции между группами не отличались.

***Заключение.*** Среднесрочные результаты эндопротезирования тазобедренного сустава у пациентов с ИПТ сопоставимы с результатами эндопротезирования пациентов общей популяции. Отличительной особенностью хирургического вмешательства является увеличение объема интраоперационной кровопотери и необходимость значимо бóльшего переливания гемокопонентов не только во время операции, но и в предоперационном периоде, что увеличивает продолжительность госпитализации.

**Ключевые слова:** эндопротезирование тазобедренного сустава, идиопатическая тромбоцитопения, гемотрансфузия.

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## BACKGROUND

Idiopathic thrombocytopenia (IT) is an immune disease characterized by a transient or constant decrease in platelet count, accompanied by an increased risk of hemorrhage. According to the criteria of the International Working Group of Experts, IT is defined as an autoimmune disease characterized by isolated thrombocytopenia (platelet count less than $100\times10^9$/L) in the absence of other causes or diseases that may be accompanied by thrombocytopenia [1]. Glucocorticosteroids are widely used as first-line therapy for IT [2]. Moreover, the number of steroid-induced avascular necrosis of bones ranges 9-40% with a predominant lesion of the femoral head [3]. Patients with IT requiring surgical interventions need blood transfusion of a larger amount of blood components, especially if the surgery is performed for emergency indications.

Given the increased blood loss, more complications should be expected during total hip arthroplasty (THA) in patients with IT, such as periprosthetic infection, acute renal failure, septicemia, or pneumonia [4].

In this regard, special perioperative management of patients is necessary to prevent complications when planning hip THA; however, the available literature presents only a few reports on its results. Nezu et al. described a case of arthroplasty in a patient with refractory IT under the colchicine cover [5]. Kim et al. presented a case series of patients with IT who had undergone THA arthroplasty. In the study, the authors indicated a higher need for hemotransfusion of erythrocyte mass and platelet suspension. Moreover, the time of surgery, length of hospital stay, and levels of complications were not different from those in patients without IT [6]. Singhal et al. reported on the treatment of a 61-year-old patient with IT who underwent replacement of the knee joint. The authors noted a significant increase in the preoperative period, during which immunoglobulin transfusion was performed until the platelet level reached $280\times10^9$/L. In the course of treatment, anticoagulants and antiplatelet agents were not administered because of bleeding risk, and nonsteroidal anti-inflammatory analgesics were not used, as they reduce platelet function. The patient was discharged on day 8 after the surgery; however, he was under the supervision of hematologists for another 3 days. When the platelet count is greater than $80\times10^9$/L, the risk of bleeding is low. At a platelet count lower than $50\times10^9$/L, bleeding should be expected during or after surgery, and at a level lower than $25\times10^9$/L, bleeding can occur spontaneously; therefore, the surgery cannot be performed [7].

Currently, there are no national clinical guidelines for the perioperative management of patients with IT in THA. A systematic review of publications on the aspects of surgical interventions in patients with IT indicates the need to achieve good hemostasis during surgical interventions. Many publications are cited in the context of general surgery. With THA, it is impossible to achieve such a level of hemostasis. In this regard, Kojouri et al. warned of an increase in the expected perioperative blood loss [8]. Thus, to date, many issues related to THA remain unresolved, and there are no algorithms for perioperative management of patients with IT.

*The study aimed* to evaluate the mid-term results of total THA in patients with primary IT.

## METHODS

### Study design

The authors conducted a randomized monocenter clinical trial of 38 patients with IT, who underwent THA between 2015 and 2021. These patients constituted group I of the study. For group II (control), we analyzed the outcomes of hip arthroplasty in 40 patients without thrombocytopenia over the same period. The mean follow-up period was 4.3 (min 3; max 6) years in group I and 4.1 (min 3; max 6) years in group II.

For the representativeness of the analysis results, the patients of both groups were comparable in age, scope of the preoperative examination, nature of the THA pathology (Table 1), surgical interventions performed, type of hip endoprosthesis components, and postoperative management. All surgeries in both groups were performed by the same surgical and anesthetic teams.

The exclusion criteria for the study were heparin-induced thrombocytopenia, history of splenectomy, severe form of IT in the exacerbation phase, and platelet count less than $25\times10^9$/L in the blood serum in the preoperative period.

*Table 1*

**General characteristics of the patients in both groups**

| Parameter | Group I | Group II | *p* |
|---|---|---|---|
| Number of patients | 38 | 40 | |
| Mean age, Me (min/max) | 47.24 (19/84) | 45.38 (20/81) | 0.430 |
| Sex, M/F | 9/29 | 19/21 | |
| Body mass index, Me (min/max) | 23.33 (14.5/32.7) | 28.5 (23.2/31.7) | <0.001 |
| Diagnosis | | | |
| – avascular necrosis of the femoral head | 30 (79%) | 21 (53%) | |
| – dysplasia | 1 (3%) | 9 (23%) | |
| – coxarthrosis | 7 (18%) | 10 (24%) | |
| Follow-up period, Me (min/max) | 4.3 (3/6) | 4.1 (3/6) | 0.284 |

Standard cementless acetabular press-fit components were implanted in both groups, with the use of only cross-linked polyethylene liners of 32 mm in diameter and standard cementless femoral components of proximal fixation.

Avascular necrosis of the femoral head prevailed among the indications for total hip arthroplasty, whereas idiopathic and dysplastic coxarthrosis were less common. The average body mass index was significantly lower in group I (ME 23.3; min 14.5; max 32.7) than in group II (ME 28.5; min 23.2; max 31.7).

## Assessment of result

The surgery duration, volume of intraoperative blood loss, and the transfused components of erythrocyte suspension, fresh frozen plasma, and platelet suspension were evaluated. The frequency and structure of general somatic and orthopedic complications were also assessed in both groups. Functional results were assessed using the 48-point Oxford Hip Score (OHS) scale.

## Statistical analysis

Statistical processing of the research results was performed using the IBM SPSS Statistics for Windows, version 20 (IBM Corp., Armonk, NY, USA). The normality of quantitative values was tested based on the Shapiro-Wilk test as modified by Royston [9]. To identify significant differences in normally distributed indicators, Student's t-test was used for related and unrelated samples and the Mann-Whitney test for non-normally distributed indicators. The criterion $\chi 2$ was used to evaluate the qualitative indicators.

## RESULTS

The mean length of hospital stay was significantly longer in group I than in group II. In a more detailed study of the reasons for such a long period of hospitalization, significant differences were noted in the indicators of preoperative bed-days (Table 2). Such results indicate the need for longer preoperative preparation, including transfusion of hemocomponents with repeated clinical blood tests, coagulogram, and production of platelet concentrate for each patient.

When evaluating intraoperative parameters, no significant difference was found in the duration of surgery; however, significant differences were found in the amounts of intraoperative blood loss and blood transfusion (Table 3).

*Table 2*

**Length of hospital stay, bed-day, Me (min/max)**

| Parameter | Group I | Group II | *p* |
|---|---|---|---|
| Length of hospital stay | 11.10 (6/17) | 7.70 (4/12) | <0.001 |
| Preoperative period | 3.94 (1/9) | 1.20 (1/3) | <0.001 |
| Postoperative period | 7.16 (3/14) | 6.80 (4/10) | 0.144 |

*Table 3*

**Intraoperative parameters in patients of the study groups**

| Parameter | Group I | Group II | *p* |
|---|---|---|---|
| Surgery time, min (min/max) | 95 (45/100) | 100 (55/110) | 0.124 |
| Intraoperative blood loss, mL (min/max) | 339.7 (200/1300) | 213.0 (100/350) | 0.001 |
| Blood transfusion, mean volume in mL | 11 patients, 140 | 3 patients, 220 | |
| Platelet suspension, average volume in mL | 5 patients, 350 | 0 | |
| Fresh frozen plasma, mean volume in mL | 3 patients, m 420 | 0 | |
| Platelet count before surgery, $\times 10^9$/L | 85±13 | 168±38 | 0.001 |

## Functional outcomes

When evaluating functional results on a 48-point OHS scale, no significant difference in indices was found 12 months after the surgery. In group I, the average statistical indicators improved from 25.4±7.3 to 42.1±6.1 points, while in group II, these changed from 26.2±5.3 to 43±4.3 points (Fig. 1).

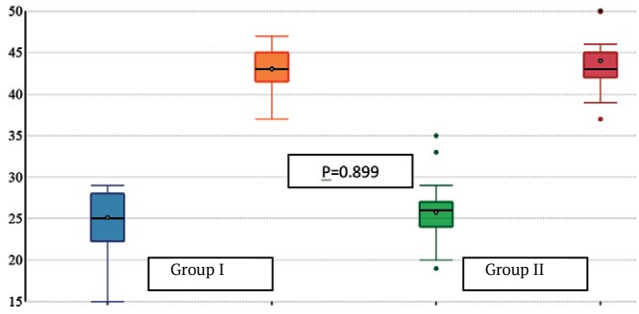


**Fig. 1.** Functional results on the Oxford Hip Score (48 points)

## Complications

Complications were registered in five patients in group I and in one patient in group II, which is not significantly different (p = 0.067). The relative risk (RR) for complications was 5.2 (95% confidence interval 0.64-43) in the IT group. Three (7.9%) patients in group I had intraoperative bleeding, two (5.27%) had postoperative hematoma, and one had superficial periprosthetic infection secondary to a postoperative hematoma, which did not require two-stage revision arthroplasty and was stopped by secondary surgical treatment of the wound. No complications associated with hip arthroplasty were recorded in group II.

As a result of the analysis of postoperative radiographs, no signs of aseptic loosening of the endoprosthesis components, osteolysis, or significant wear of the polyethylene liner in the average follow-up period of more than 4 years were found in both groups. Moreover, there were no cases of periprosthetic fractures and dislocations of the endoprosthesis. Thus, none of the patients in both groups underwent revision interventions for THA.

## DISCUSSION

Currently, insufficient attention is paid to the problems of surgical treatment of patients with IT in Russian and international literature. According to Wang et al., the incidence of thrombocytopenia among patients undergoing hip arthroplasty is 1.43% and increases annually [10]. Several authors report an increase in the number of complications and postoperative mortality among patients who undergo hip arthroplasty in the presence of thrombocytopenia. For example, in their major population meta-analysis, Chang et al. reported an increase in 30-day mortality up to 1.89% after surgery in patients with thrombocytopenia [11]. Monreal et al. argued that platelet count correction before hip arthroplasty reduces significantly the risk of postoperative blood loss [12].

Our results are comparable with the mid-term results of shoulder and elbow arthroplasty in 25 patients with clotting disorders and secondary thrombocytopenia [13]. Zorenko et al. reported one infectious complication, one intraoperative periprosthetic fracture of the humeral condyle, and one case of aseptic instability of the elbow arthroplasty in the period up to 9 years after surgery.

Wang et al. presented interesting data on the characteristics of patients with thrombocytopenia undergoing joint replacement. They

reported that IT is more common in older men and is associated with several somatic diseases. In our study, middle-aged women predominated (Me 47.24 years; min 19 years, max 84 years), which indirectly indicates different epidemiological indicators of the prevalence of IT in the population. The average length of hospital stay of patients with IT undergoing THA increases by 26% [10]. In our study, the average length of hospital stay in group I was 14.5% longer than that in group II, but significantly lower than the data presented in the literature. Such low rates of the average number of bed-days in patients with IT who undergo hip arthroplasty are due to the pharmacological correction of drugs and preparation of patients for surgery, which is performed in the R.M. Gorbacheva Research Institute of Pediatric Oncology, Hematology and Transfusiology, which is part of the structure of the Pavlov State Medical University (Saint Petersburg).

The literature reports a higher incidence of complications in large joint arthroplasty in patients with IT, both general somatic (pneumonia, infection of the urinary system, postoperative shock, and sepsis) and surgical (hemorrhagic anemia, hematoma and seroma of the postoperative wound, wound infection, and instability of endoprosthesis components) complications. Specifically, Malpani et al. provided data on a twofold increase in the risk of complications during THA in patients with IT [14]. According to our data, the RR of all complications in patients with thrombocytopenia was 5.2 times higher. Such a significant increase in risks may be due to the small number of cases; therefore, cohort multicenter studies are needed.

## Study limitations

The main limitation of the study was the small number of patients in group I, which was due to a rather rare combination of IT with deforming coxarthrosis requiring surgical interventions. Multicenter studies are necessary for more accurate study representativeness. Further prospects are associated with the formation of flows of such patients to specialized multidisciplinary centers.

## CONCLUSIONS

The mid-term outcomes of hip arthroplasty in patients with IT are comparable with the results of THA in the general population. A characteristic aspect of surgical intervention in patients with IT is an increase in the average volume of intraoperative blood loss and the need for a significantly larger amount of transfusion of blood components not only during arthroplasty but also in the preoperative period, which increases the length of hospital stay

## DISCLAIMERS

***Author contribution***

*Tsed A.N.* — the idea and design of the study, the collection and processing of material, writing the draft, editing.

*Mushtin N.E.* — data collection and analysis, manuscript writing, text editing.

*Dulaev A.K.* — research conception and design, analysis and statistical processing of 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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***Competing interests.*** The authors declare that they have no competing interests.

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# Salter vs Pemberton: Comparative Radiologic Analysis of Changes in the Acetabulum and Pelvis After Surgical Correction in Children with Hip Dysplasia

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***Background.*** Hip dysplasia, characterized by pronounced anatomical changes, continues to be one of the leading positions in the structure of all congenital malformations of the musculoskeletal system. Late diagnosis or ineffective conservative treatment leads to the need for surgical correction of congenital deformities of the proximal femur and acetabulum. The choice of the method of operational reconstruction of the latter remains a subject of discussion over the past decades.

***Aim of the study*** — a comparative X-ray analysis of surgical treatment outcomes of children with hip dysplasia type IHDI III-IV after Salter and Pemberton pelvic osteotomies.

***Methods.*** The study included 80 patients (80 hip joints) aged 2 to 4 years (3.1 ± 0.45) with hip dysplasia of the III-IV degree according to the IHDI. Patients were divided into two groups: group I consisted of 40 patients who underwent modified Salter osteotomy, group II — 40 patients who underwent Pemberton pericapsular acetabuloplasty. Radiometry of the following parameters was performed: acetabular index (AI), Wiberg angle, neck-shaft angle, anteversion angle of the proximal femur, degree of bone coverage, the depth of the acetabulum (AD) and pelvic height (PH)

***Results.*** The values of AI and Wiberg angle in patients in I group indicate that a greater correction was achieved ($p<0.05$) in contrast to patients who underwent Pemberton pericapsular acetabuloplasty. At the same time, the values of AD and PH in I group patients had pronounced differences ($p<0.05$) from those in II group patients, whose values were close to similar indicators in the contralateral hip joint.

***Conslusions.*** In the treatment of children with hip dysplasia IHDI III-IV degree performing a modified Salter osteotomy leads to a significant decrease in the values of AI and an increase in the values of the Wiberg angle, which corresponds to hypercorrection of the position of the acetabulum, does not affect the AD and contributes to the elongation of the hemipelvis by an average of 13.8 mm. Pemberton acetabuloplasty allows to achieve values of AI and Wiberg angle close to the age-related indicators of the norm, leads to an increase AD, approaching the contralateral joint in its value and does not significantly affect the PH.

**Keywords:** hip dysplasia, children, modified Salter's procedure, Pemberton's pelvic osteotomy.

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# Salter vs Pemberton: сравнительный рентгенологический анализ изменения вертлужной впадины и таза после хирургической коррекции у детей с врожденным вывихом бедра

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***Актуальность.*** Дисплазия тазобедренных суставов, характеризующаяся выраженными анатомическими изменениями, продолжает оставаться на одной из лидирующих позиций в структуре всех врожденных пороков развития костно-мышечной системы. Поздняя диагностика или неэффективное консервативное лечение приводят к необходимости хирургической коррекции врожденных деформаций проксимального отдела бедренной кости и вертлужной впадины. Выбор метода оперативной реконструкции последней остается предметом дискуссии на протяжении последних десятилетий.

***Цель исследования*** — провести сравнительный рентгенологический анализ изменения строения вертлужной впадины и таза у детей с врожденным вывихом бедра (III–IV степени по IHDI) после остеотомии таза по Salter и Pemberton.

***Материал и методы.*** В исследование вошли 80 пациентов (80 тазобедренных суставов) в возрасте от 2 до 4 лет (3,1±0,5) с дисплазией тазобедренных суставов III–IV степени по классификации IHDI, получавших лечение в период с 2020 по 2021 г. Все дети были разделены на две группы: I группу составили 40 пациентов (40 тазобедренных суставов), которым выполняли модифицированную подвздошную остеотомию таза по Salter, II группу — 40 пациентов (40 тазобедренных суставов), которым выполняли перикапсулярную ацетабулопластику по Pemberton. Проводили рентгенометрию следующих показателей: ацетабулярный индекс (АИ), угол Wiberg, шеечно-диафизарный угол, угол антеверсии проксимального отдела бедренной кости, степень костного покрытия, глубина вертлужной впадины (AD) и высота таза (PH).

***Результаты.*** Ближайшие результаты оценивались через 6 мес. Значения АИ и угла Wiberg у пациентов, которым была выполнена модифицированная остеотомия таза по Salter, говорят о достижении большей коррекции ($p$<0,05) в отличие от пациентов, которым была выполнена перикапсулярная ацетабулопластика по Pemberton. Вместе с тем значения AD и PH у пациентов I группы имели выраженные отличия ($p$<0,05) от таковых у пациентов II группы, значения которых были приближены к аналогичным показателям в контралатеральном интактном тазобедренном суставе.

***Заключение.*** При лечении детей с дисплазией тазобедренных суставов III–IV степени по классификации IHDI выполнение модифицированной остеотомии таза по Salter приводит к значительному уменьшению значений АИ и увеличению значений угла Wiberg, что соответствует гиперкоррекции положения вертлужной впадины, не влияет на глубину вертлужной впадины и способствует удлинению гемипельвиса в среднем на 13,8 мм. Перикапсулярная остеотомия таза по Pemberton позволят достичь значений АИ и угла Wiberg, близких к возрастным показателям нормы, приводит к увеличению глубины вертлужной впадины, приближающейся по своему значению к контралатеральному суставу, и не оказывает отрицательного влияния на высоту таза.

**Ключевые слова:** дисплазия тазобедренных суставов, дети, модифицированная операция Salter, остеотомия по Pemberton.

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## BACKGROUND

Hip dysplasia, characterized by pronounced anatomical changes that occurred during the ante- and postnatal periods of development, remains one of the most significant congenital malformations of the musculoskeletal system [1, 2]. Late diagnosis or inadequate use of conservative treatment methods results in the need for surgical correction of congenital deformities of both the proximal femur and acetabulum. The choice of methods for the surgical reconstruction of the latter has been the subject of discussion over the past decades.

To date, all pelvic osteotomies used in global and Russian orthopedic practice, aimed at achieving adequate stability of the hip joint and congruence of the articular surfaces of the femoral head and acetabulum, can be conditionally divided into two groups, namely, those accompanied by complete damage to the ilium and those without it. The former group of surgical methods includes osteotomies of the pelvis such as iliac (R. Salter), double (D. Sutherland, Yu.I. Pozdnikin, and M.M. Kamosko), and triple (H. Carlioz, H. Steel, D. Tönnis, and modifications by other authors). Essentially, these technologies involve the change in the spatial position of the acetabular fragment [3, 4, 5, 6]. The latter group of pelvic osteotomies includes acetabuloplasty (W. Dega, P. Pemberton, San Diego, E.S. Tikhonenkov, V.P. Melnikov, and modifications of other authors), which are mainly aimed at the change in the acetabulum shape [7, 8, 9 , 10, 11].

Despite the widespread application of triple pelvic osteotomy in clinical practice and the expansion of the age criteria for its implementation [12, 13], in pediatric patients aged <6 years with hip dysplasia of varying severities and functioning Y-shaped cartilage, currently, the most common treatment methods for dysplastic acetabulum is iliac pelvic osteotomy according to Salter, pericapsular acetabuloplasty according to Pemberton, and acetabuloplasty according to Dega. Moreover, Dega acetabuloplasty includes complete damage to the posterior pelvic column and, therefore, in our opinion, cannot be fully classified as true acetabuloplasty.

To date, the choice of a pelvic osteotomy technique for hip dysplasia in pediatric patients depends on the preferences of the operating surgeon, and modern Russian literature provides almost no comprehensive analysis of the surgical treatment results.

*This study aimed* to perform a comparative X-ray analysis of structural changes of the acetabulum and pelvis in pediatric patients with congenital hip dislocation (IHDI grades III and IV) following Salter and Pemberton pelvic osteotomy.

## METHODS

### Study design

A two-center cohort comparative controlled retrospective–prospective study was performed.

The *inclusion criteria* were as follows:

– Aged 2-4 years;

– unilateral dislocation of the hip (grades III and IV according to the IHDI classification [14]);

– absence of surgical interventions on the hip joint in history;

– absence of signs of aseptic necrosis of the femoral head according to the Tönnis classification [15];

– absence of confirmed neurological diseases;

– absence of genetic diseases and systemic skeletal dysplasia;

– consent of the patient's legal representatives to participate in the study;

The *exclusion criteria* were as follows:

– age of <2 years and >4 years;

– subluxation of the hip (grade II according to the IHDI classification).

– hip bilateral lesions;

– history of surgeries on the hip joint;

emerging or formed multiplanar deformity of the proximal femur;

– neurological, systemic, and genetic diseases;

– refusal to fill out informed consent to participate in the study.

The study included 80 patients (80 hip joints) aged 2-4 years (3.1 ± 0.5) with grade II-IV hip dysplasia according to the IHDI classification, who received treatment at the clinic of the H.I. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery and the Federal Center for Traumatology, Orthopedics, and Endoprosthetics (Barnaul) during the period from 2020 to 2021.

Patients were distributed into two groups depending on the technique used for pelvic osteotomy to correct the abnormal acetabulum.

Group I consisted of 40 patients (40 hip joints) who underwent the modified Salter iliac pelvic osteotomy. This pelvic osteotomy differed from the classical one by the rotation vector of the acetabular fragment, i.e., not isolated anteriorly, but more laterally, which enabled to increase the coverage of the femoral head and minimize the risk of acetabular retroversion. Group II also consisted of 40 patients (40 hip joints) who underwent Pemberton pericapsular acetabuloplasty, following the author's surgical technique. In both groups, tenotomy of the *m. iliopsoas* at the lower aperture of the acetabulum followed by capsulotomy and revision of the acetabulum was compulsory, and depending on the angular values of the proximal femur, intertrochanteric corrective osteotomy was also performed [16].

Patients of both groups underwent a clinical examination, typical for this orthopedic disease of the hip joint, and an X-ray examination, which consisted of performing radiography of the hip joints in the frontal view, Lauenstein position, and abduction and internal rotation of the lower extremities before and after surgical treatment. In this study, we focused on the assessment of the X-ray anatomical structure of the acetabulum after surgical correction. X-ray measurements were used to assess the acetabular index (AI), Wiberg angle, caput-collum-diaphyseal angle (CCDA), anteversion angle of the proximal femur (AA), bone coverage degree, acetabular depth (AD), and pelvic height (PH) (Fig. 1).

## Surgery technique

All patients underwent reconstructive surgery through the anterolateral approach. After performing intra-articular manipulations, osteotomy of the femur with excision of the bone autograft, and additional shortening of the femur in group I, a subperiosteal approach and osteotomy of the ilium body were performed. Thereafter, the acetabular fragment was rotated outward and anteriorly using a tenaculum. In the position of the achieved correction, an autograft from the femur was placed in the diastasis between the fragments of the ilium and fixed with 3-4 Kirschner wires (Fig. 2).

In group II, after identical manipulations both inside the joint and on the femur and a similar exposure of the ilium, an angular pericapsular section of the inner and outer cortical layers of the ilium was performed with chisels so that the vertical part of the section passed at a distance of at least 0.5 cm from the posterior column of the pelvis and strictly parallel to it. Subsequently, using spreaders, the acetabular hood was "folded" outward and anteriorly, whereas the posterior pelvic column remained intact (Fig. 3).

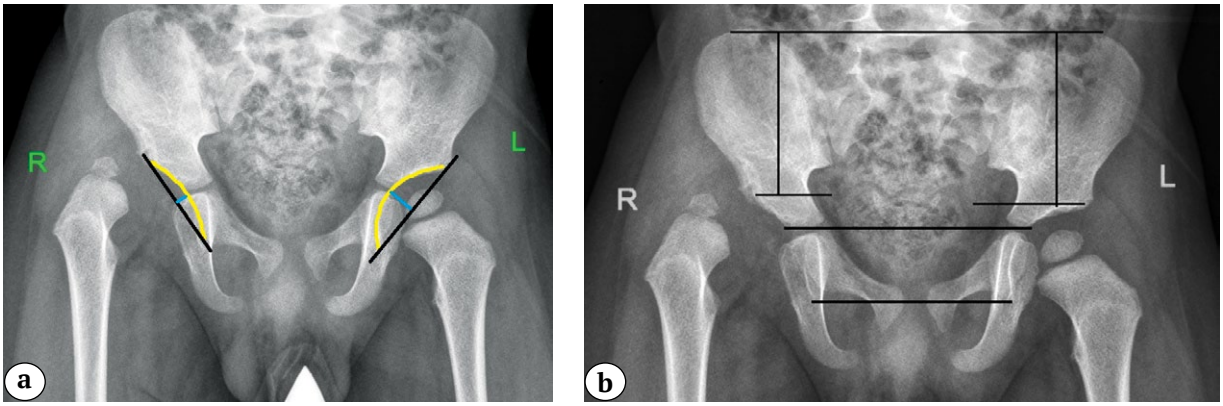


**Fig. 1.** Calculation of indicators in a patient with hip dysplasia IHDI type IV:
a — acetabular depth: yellow line — the inner contour of the acetabulum; black — the line connecting the lateral edge of the acetabulum with the lower edge of the "tear drop figure"; blue (the depth of the acetabulum) — perpendicular from the medial part of the acetabulum to the black line;
b — the pelvic height

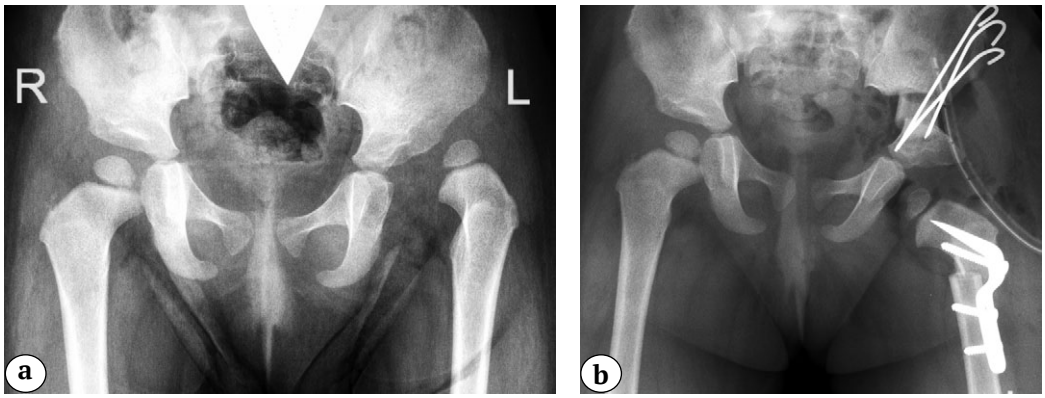


**Fig. 2.** X-rays of hip joints of patient born in 2018 with hip dysplasia IHDI type IV in an anterior-posterior projection:
a — before surgery;
b — after surgical treatment using Salter's osteotomy

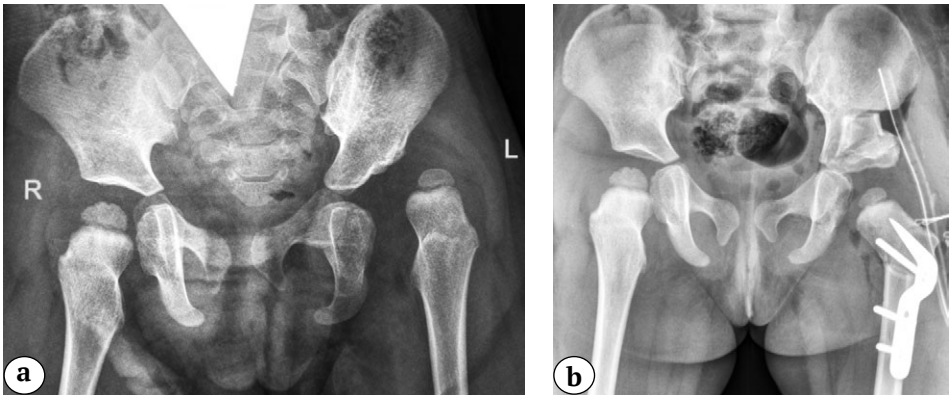


**Fig. 3.** X-rays of hip joints in an anterior-posterior projection of patient born in 2018 with hip dysplasia IHDI type III:
a — before surgery;
b — after surgical treatment using the Pemberton pelvic osteotomy

## Statistical analysis

Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 26 (IBM Corp. Armonk, NY, USA). Arithmetic mean values (M), standard deviation (SD), and median (Me) with quartiles (25%; 75%) were calculated. The analysis between the groups was performed according to the non-parametric Mann–Whitney *U*-test. The intragroup analysis was performed according to the Wilcoxon test. The result was considered significant at $p < 0.05$.

## RESULTS

Upon hospital admission, the legal representatives of the patients in both study groups complained of lameness. The relative shortening of the lower limb was 1.3±0.5 cm. In the course of goniometry, changes in the amplitude of hip joint movements, typical for the dysplastic nature of the disease, were observed, which consisted of moderate limitation of abduction (34±6°) and excessive internal (60±10°) and external rotation (50±10°) (Table 1).

As shown in Table 1, both groups exhibited pronounced underdevelopment of the acetabular hood with a decrease in its depth, decrease in the PH on the disease side, and increase in the CCDA and AA of the proximal femur. Negative values of the Wiberg angle and bone coverage coefficient are due to hip dislocation (grades III-IV according to IHDI). The values of the above indicators of the X-ray anatomical structure of the hip joint and its stability, confirmed by statistical data, allowed further comparative analysis of the surgical treatment results, which were evaluated 6 months after the reconstructive intervention.

During the examination, all patients followed a strict orthopedic regimen, which excluded the possibility of axial load on the lower limbs. As a result, gait was not assessed. Goniometric data are presented in Table 2.

As shown in Table 2, 6 months after the surgical intervention, the amplitude of movements in the operated hip joint in three planes in both groups almost reached physiological values. Indicators of internal and external rotation were significantly changed in comparison with preoperative values ($p < 0.05$) because of the correction of the angle of anteversion of the proximal femur.

The results of the radiological methods of examination of both groups 6 months after surgery are presented in Table 3.

As presented in Table 3, in both groups, the parameters characterizing the X-ray anatomical structure of both the acetabulum and proximal femur underwent significant changes compared with the values before surgery ($p < 0.05$). This indicates the restoration of hip joint stability. Moreover, the AI and Wiberg angle in patients who underwent the modified Salter pelvic osteotomy indicate a greater correction ($p < 0.05$) than those in patients who underwent Pemberton pericapsular acetabuloplasty.

The assessment of the AD and PH should receive special attention. Thus, in group I, no significant change was found ($p > 0.05$) in the AD indicator, both in comparison with the baseline and postoperative indicators, which is not related to the PH, which increased significantly ($p < 0.05$). Moreover, the AD and PH of group I had pronounced differences ($p < 0.05$) from those of group II, the values of which were close to those in the contralateral intact hip joint. Thus, Salter pelvic osteotomy in the above modification has a high corrective potential, but with the risk of hypercorrection of the acetabulum position compared with pericapsular acetabuloplasty, does not affect the shape of the pelvic component of the hip joint, and leads to an increase in the height of the hemipelvis. Pemberton pelvic osteotomy is an effective technique for achieving adequate correction of the dysplastic acetabulum, changes its shape by increasing the depth, and does not significantly affect the PH.

Complications such as aseptic necrosis of the femoral head, reluxation, or emergence of another type of instability in the operated joint, and malposition of the position of the surgical hardware were not noted in both groups.

*Table 1*

**Indicators of X-ray structure and stability of the hip joint before surgery, M ± SD, Me (25%, 75%)**

| Parameter | Group I | Group II | Contralateral joint |
|---|---|---|---|
| AI, deg. | 41.6±3.2<br>41.5 (40.0; 42.8) | 42.3±3.1<br>42.0 (40.0; 44.0) | 20.6±2.0<br>20.5 (19.0; 22.8) |
| Wiberg angle, deg. | Negative values | Negative values | 28.7±2.0<br>29.0 (27.0; 30.5) |
| AD, mm | 6.0±0.6<br>6.0 (5.6; 6.3) | 5.5±0.5<br>5.5 (5.2; 5.8) | 9.6±1.0<br>9.5 (9.0; 10.4) |
| PH, mm | 56.5±4.8<br>56.0 (52.8; 59.0) | 55.1±6.8<br>56.9 (50.0; 60.3) | 55.9±5.8<br>56.1 (51.3; 60.2) |
| CCDA, deg. | 142.5±4.3<br>142.5 (140.3; 144.8) | 141.9±4.0<br>142.0 (140.0; 144.0) | 142.2±4.1<br>142.0 (140.0; 144.0) |
| AA, deg. | 46.0±5.6<br>45.5 (40.3; 50.8) | 46.7±5.8<br>47.1 (41.5; 52.0) | 40.3±3.6<br>40.0 (37.9; 42.3) |
| BCD, % | 0 | 0 | 90.0±6.0<br>90.0 (85.0; 95.0) |

*Table 2*

**Range of motion of the hip joints in both groups after surgery, M ± SD, Me (25%, 75%)**

| Motion | Group I | Group II |
|---|---|---|
| Flexion, deg. | 112.8±6.2<br>112.5 (110.0; 120.0) | 115.0±3.7<br>115.0 (115.0; 120.0) |
| Abduction, deg. | 36.0±3.9<br>35.0 (35.0; 45.0) | 36.5±2.9<br>35.0 (35.0; 40.0) |
| Internal rotation, deg. | 18.5±4.3<br>20.0 (15.0; 20.0) | 18.5±4.3<br>20.0 (15.0; 20.0) |
| External rotation, deg. | 40.8±5.4<br>40.0 (35.0; 45.0) | 41.0±5.2<br>42.5 (35.0; 45.0) |

*Table 3*

**Indicators of X-ray structure and stability of the hip joint in both groups 6 months after surgery, M ± SD, Me (25%; 75%)**

| Parameter | Group I | Group II | Contralateral joint |
|---|---|---|---|
| AI, deg. | 12.6±1.6<br>12.0 (11.8; 14.0) | 15.4±1.9<br>16.0 (14.0; 17.0) | 20.6±2.0<br>20.5 (19.0; 22.8) |
| Wiberg angle, deg. | 38.1±3.5<br>39.0 (37.0; 40.0) | 31.0±2.6<br>31.0 (28.5; 33.0) | 28.7±2.0<br>29.0 (27.0; 30.5) |
| AD, mm | 6.4±1.3<br>6.1 (5.7; 6.7) | 9.8±0.8<br>9.9 (9.4; 10.4) | 9.6±1.0<br>9.5 (9.0; 10.4) |
| PH, mm | 69.7±5.3<br>70.0 (66.3; 72.6) | 57.9±6.7<br>59.0 (52.6; 64.0) | 55.9±5.8<br>56.1 (51.3; 60.2) |
| CCDA, deg. | 128.1±4.8<br>128.0 (124.5; 132.3) | 128.5±4.4<br>129.0 (124.5; 132.0) | 142.2±4.1<br>142 (140; 144) |
| AA, deg. | 14.9±3.3<br>15.0 (12.8; 18.0) | 15.9±2.5<br>16.0 (14.5; 17.5) | 40.3±3.6<br>40.0 (37.9; 42.3) |
| BCD, % | 101.6±5.2<br>100.0 (98.6; 105.0) | 98.6±3.2<br>100.0 (95.0; 100.0) | 90.0±6.0<br>90.0 (85.0; 95.0) |

## DISCUSSION

Late diagnostics, non-compliance with the basic therapeutic principles, and inadequate use of conservative methods of hip dysplasia in pediatric patients lead inevitably to the need for radical reconstructive plastic surgery aimed at achieving stable concentric reduction and retention of the femoral head in the acetabulum by changing the anatomical structure of the pelvic and femoral components of the joint. All this is necessary for further normal development of the hip joint and reduction of the risk of early coxarthrosis [17, 18, 19].

Nowadays, in the global orthopedic practice in young patients, the most common methods of surgical correction of the dysplastic acetabulum are pelvic osteotomies according to Salter in various modifications ad those according to Pemberton and Dega. Scientific publications reveal the high efficiency of these surgical treatment methods in the medium and long-term follow-up periods [21, 22, 23, 24]. Moreover, studies have focused on a comparative analysis of changes in the X-ray anatomical state of the hip joint after Salter and Pemberton pelvic oste-

otomies, despite their widespread use [25, 26, 27, 28]. For example, Dello Russo and Candia Tapia conducted a comparative analysis of the treatment of pediatric patients with grade II-IV hip dysplasia according to the Tönnis classification, which showed that AI correction was greater after Pemberton's pericapsular acetabuloplasty than after classical Salter osteotomy (24° and 13°, respectively). This led to a more significant increase in the Wiberg angle in the Pemberton acetabuloplasty group than in the Salter osteotomy group (35° and 27°, respectively) [25]. N. Ezirmik and K. Yildiz [28] presented similar data. In their study, the mean AI corrections for Pemberton and Salter pelvic osteotomies were 25.78° and 18.33°, respectively, and the Wiberg angles were 43.11° and 37.15°. Gharanizadeh et al. analyzed AI changes in patients who underwent Salter surgery in the Kalamchi modification and Pemberton acetabuloplasty and did not reveal significant differences in both groups. They concluded the identical efficiency of these two surgical methods for the correction of a dysplastic acetabulum [29]. In our study, we obtained a different result, that is, the average value of AI correction in patients who underwent the modified Salter pelvic osteotomy was 29.0° versus 26.9° in patients who underwent Pemberton pericapsular acetabuloplasty, and the postoperative values of the Wiberg angle were 39° and 31°, respectively. This fact can be due to the peculiarities of our modification of the Salter pelvic osteotomy, that is, the predominance of the lateral tilt of the acetabular fragment over the anterior rotation typical of the author's technique [30].

Moreover, hypercorrection may have negative consequences in the long-term due to the risk of femoroacetabular impingement [31, 32, 33]. Thus, pericapsular acetabuloplasty enables bringing the AI and Wiberg angle values closer to the age norm [34]. In our study, AD changes were detected only in patients with Pemberton pelvic osteotomy, which corresponds to literature data [25, 35]. Several authors analyzed changes in the length of the lower extremities after Salter and Pemberton pelvic osteotomies [28, 36]. Ezirmik and Yildiz analyzed the results of surgical treatment of 57 patients with bilateral hip dysplasia, who underwent classical Salter pelvic osteotomy on one joint, and Pemberton acetabuloplasty on the other joint, and revealed that on the side of Salter surgery, the lower limb was longer on average by 0.5 cm [28]. Moreover, radiometry of the PH and CCDA was not performed, which limits the value of this study. A group of surgeons from Taiwan performed a comparative analysis of the hemipelvis height in two groups of pediatric patients treated with the above surgical techniques and concluded that the PH increased in all patients on the intervention side, but with Salter pelvic osteotomy, it was two times greater than that with acetabuloplasty [36]. In our study, we did not reveal a significant change in this indicator in patients who underwent Pemberton pelvic osteotomy, whereas in group I, the PH increased by an average of 13.8 mm. In our opinion, this is caused by the acetabular fragment bringing down during the lateral tilt during the modified Salter pelvic osteotomy. This can lead to excessive compression of the articular surfaces, which, in turn, can lead to hip joint stiffness, and hemipelvis deformity can lead to biomechanical and structural disorders in both lower limb joints and lumbar spine. Moreover, Pemberton pericapsular acetabuloplasty does not cause changes in the anatomy of the pelvic ring and birth canal and does not require repeated surgical intervention to remove internal fixation devices, unlike Salter pelvic osteotomy, as confirmed by literature data [27, 28]. In addition, Pemberton pericapsular acetabuloplasty is a technically more complex surgery, and inappropriate technique can cause iatrogenic fracture of the posterior pelvic column, which will affect the primary fixation of the autograft with its possible migration and loss of surgical correction, as well as damage to the Y-shaped cartilage and its preterm closure [37, 38]. All this may require repeated reconstructive surgeries on the hip joint and negatively affect both the hip joint condition and the child's lifestyle.

## Study limitations

This study is limited by the follow-up period and by only performing X-ray assessment of the parameters of the pelvic and femoral components of the joint. Thus, further studies should examine the long-term treatment results of patients with a comprehensive clinical and radiological study of the state of the hip joint and spinal–pelvic ratios.

## CONCLUSIONS

In the treatment of pediatric patients with grade III-IV hip dysplasia according to the IHDI classification, Salter modified pelvic osteotomy leads to a significant decrease in AI values and an increase in the Wiberg angle, which correspond to hypercorrection of the acetabulum position, do not affect the AD, and contribute to hemipelvis lengthening by an average of 13.8 mm. Pemberton pericapsular osteotomy of the pelvis helps achieve AI and Wiberg angle values close to age norms, leads to an increase in the AD, approaching the contralateral joint in value, and does not significantly affect the PH.

The absence of an "ideal" pelvic osteotomy for the treatment of hip dysplasia of varying severities requires further comprehensive analysis of the results of surgical interventions in these patients; consequently, it will be possible to develop an algorithm for a differentiated approach to choosing a method for surgical correction of a dysplastic acetabulum.

## DISCLAIMERS

***Author contribution***

*Bortulev P.I.* — research conception and design, collection and processing of material, literature review, treatment the patients, manuscript writing.

*Baskaeva T.V.* — the collection and processing of material, treatment the patients, manuscript editing.

*Vissarionov S.V.* — text editing.

*Barsukov D.B.* — treatment the patients, manuscript editing.

*Pozdnikin I.Y.* — treatment the patients, manuscript editing.

*Kozhevnikov V.V.* — 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.*** The study was approved by the local ethics committee of H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, protocol No 21-1, 18.01.2021.

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

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Original Article
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# Microbiological Profile of the Implantation Zone under Different Mechanical Compression of Percutaneous Implants

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***Background.*** Infection of percutaneous implants in patients with limb amputation is the most common complication. ***This study aimed*** to evaluate the microbiological contamination of the implantation zone depending on the implant mechanical compression under the conditions of the additional external fixation.

***Methods.*** The study was performed on 36 male rabbits. The tibia of all the rabbits was sawn at the border of the upper and middle parts. The medullary canal was reamed and a percutaneous implant was placed in the tibial stump. The segment and the implant were fixed with an Ilizarov apparatus. An additional compression device was installed in 30 animals. We used 5 compression modes, accordingly, 6 experimental groups were formed, 6 animals in each: group 1 — without compression, group 2 — compression on the implant with force of 0.053 N/mm$^2$, group 3 — compression on the implant with force of 0.105 N/mm$^2$, group 4 — compression on the implant with force of 0.158 N/mm$^2$, group 5 — compression on the implant with force of 0.211 N/mm$^2$, group 6 — compression on the implant with force of 0.263 N/mm$^2$. The restraint was removed 6 weeks after implantation for a total follow-up of 26 weeks. The microflora of the place where the implant enters the skin (the implant / skin interface) was investigated, the level of blood leukocytes and the level of C-reactive protein in blood serum were determined.

***Results.*** On days 9-10 after implantation, significant differences in the microbial landscape were found at the site of the exit of the metal implant in animals of different groups. The largest number of strains was found in animals of groups 1, 5 and 6, the smallest in groups 2 and 3. The most frequently detected strains: *S. saprophyticus* and *Enterococcus* spp. It was found that the greatest statistically significant increase in the level of CRP in the blood serum was observed in animals of group 6. The level of leukocytes in animals of all groups did not change statistically significantly relative to preoperative values. Animals with better osseointegration (groups 2 and 3 — no cases of implant loss) showed a minimal number of growing strains.

***Conclusions.*** The microbiological profile of the implantation zone of percutaneous implants changes depending on the amount of mechanical compression. The optimal mode is 0.053-0.105 N/mm$^2$.

**Keywords:** prosthetics, osseointegration, implant, microflora, compression, Ilizarov apparatus.

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# Микробиологический профиль зоны имплантации в условиях различной механической компрессии чрескожных имплантатов

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***Актуальность.*** Инфицирование чрескожных имплантатов у пациентов с ампутациями конечностей является наиболее частым осложнением. ***Цель исследования*** — оценка микробиологического обсеменения зоны имплантации в зависимости от механической компрессии имплантата в условиях его дополнительной внешней фиксации.

***Материал и методы.*** Исследование выполнено на 36 самцах кроликов. Всем животным осуществляли распил большеберцовой кости на границе верхней и средней третей. Затем рассверливали костномозговой канал и устанавливали чрескожный имплантат в культю большеберцовой кости. Сегмент и имплантат фиксировали аппаратом Илизарова. Тридцати животным дополнительно устанавливали компрессионное устройство. Использовали 5 режимов компрессии, соответственно этому было сформировано 6 экспериментальных групп по 6 животных в каждой: группа 1 — без компрессии; группа 2 — компрессия на имплантат силой 0,053 Н/мм$^2$; группа 3 — компрессия на имплантат силой 0,105 Н/мм$^2$; группа 4 — компрессия на имплантат силой 0,158 Н/мм$^2$; группа 5 — компрессия на имплантат силой 0,211 Н/мм$^2$; группа 6 — компрессия на имплантат силой 0,263 Н/мм$^2$. Удерживающее устройство демонтировали через 6 нед. после имплантации, общий период наблюдения составил 26 нед. Исследовали микрофлору места вхождения имплантата в кожу (интерфейс имплантат/кожа), определяли уровень лейкоцитов в крови и уровень С-реактивного белка в сыворотке крови.

***Результаты***. На 9–10-е сут. после имплантации в месте выхода металлического имплантата у животных разных групп обнаруживались существенные отличия микробного пейзажа. Наибольшее количество штаммов обнаружено у животных групп 1, 5 и 6; наименьшее — в группах 2 и 3. Наиболее часто обнаруживаемые штаммы — *S. saprophyticus* и *Enterococcus* spp. Наибольшее статистически значимое повышение уровня С-реактивного белка в сыворотке крови отмечалось у животных группы 6. Уровень лейкоцитов у животных всех групп статистически значимо не изменялся относительно дооперационных значений. У животных с лучшей остеоинтеграцией (в группах 2 и 3 не было случаев выпадения имплантатов) наблюдалось минимальное число растущих штаммов.

***Заключение.*** Микробиологический профиль зоны имплантации в условиях различной механической компрессии чрескожных имплантатов изменяется в зависимости от величины нагрузок. Применение нагрузок в пределах 0,053–0,105 Н/мм$^2$ лучше сказывается на приживаемости имплантатов и обсемененности зоны имплантации, чем отсутствие компрессии.

**Ключевые слова:** протезирование, остеоинтеграция, имплантат, микробиологическое обсеменение, компрессия, аппарат Илизарова.

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## BACKGROUND

Osseointegration technology is recently widely used in clinical practice in patients with limb amputation, when a percutaneous implant integrated into the bone provides a direct mechanical connection between the bone and the external prosthesis [1]. The clinical application of this technology is increasing [2, 3, 4, 5]. In this case, the most frequent complications are implant instability and infection [6,7, 8].

Many authors regard a comprehensive solution to these problems mainly as an improvement of the characteristics of the implant primarily in surface modification to improve its biocompatibility and provide antibacterial characteristics [9, 10, 11, 12]. A certain solution to these problems can be an improvement of the implantation procedure, particularly by the transition from a two-stage technology that is currently the most recognized [13] to a one-stage one that has recently started to be developed [14]. In this field, we have developed a one-stage implantation technology with additional fixation of the implant having an external fixation device and the ability to perform compression (Utility Model Patent No. 185647, Invention Patent No. 2631631).

*This study aimed* to evaluate the microbiological contamination of the implantation zone depending on the implant mechanical compression under the conditions of the additional external fixation.

## METHODS

The experiment was performed on 36 male chinchilla rabbits aged 6–11 months, with an average weight of 3.6 ± 0.4 kg. Animals were received from a nursery. They were conventional animals according to their microbiological status.

The study was performed in accordance with GOST R ISO 10993-1-2011, GOST 33215-2014, and GOST 33216-2014.

In all rabbits, the tibia was cut at the interface of the upper and middle thirds using a Gigli saw in the operating room. Then, the medullary canal was reamed to 4.0 or 4.5 mm, and the implant (RF Patent No. 152558) with a diameter of 4.5 or 5.0 mm (depending on the diameter of the medullary canal), respectively, was screwed into the tibial stump (Fig. 1). Soft tissues were sutured in layers. An incision was made in the skin flap to remove the outer part of the implant, and a stump was formed. Then, the Ilizarov apparatus was mounted. For this purpose, wires were passed at an angle of 90° through the proximal tibia and the distal part of the abutment, which comprised a thrust platform. Then, a compression device (Patent No. 2631631) was installed on the bone and prosthesis (30 rabbits). Five compression modes were used.

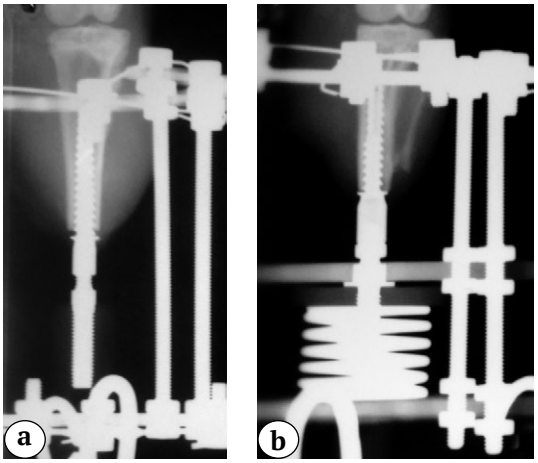


**Fig. 1.** Postoperative X-rays. Tibial implant:
a — without compression device (group 1);
b — with compression device

In total, six experimental groups were formed, with six rabbits in each group: group 1 without compression, group 2 with compression on the implant with a force of 0.053 N/mm$^2$, group 3 with compression on the implant with a force of 0.105 N/mm$^2$, group 4 with compression on the implant with a force of 0.158 N/mm$^2$, group 5 with compression on the implant with a force of 0.211 N/mm$^2$, and group 6 with compression on the implant with a force of 0.263 N/mm$^2$. Before the surgery, the animals were randomized into groups.

### Postoperative follow-up and maintenance of animals

The retainer was removed 6 weeks after implantation. The total follow-up period was 26 weeks. In the first 3 days, all animals received antibiotics (Enroxil 5 mg/kg); additionally, in the first 5 days after the surgery, antiseptic treatment was performed through the hole in the implant with 3 ml of 1% chlorhexidine solution. The wound

was treated with 0.05% chlorhexidine solution for 10 days. The exit sites of the retainer wire were treated with a 3% hydrogen peroxide solution for 10–14 days.

During the study, the animals were kept in a specialized vivarium of the research center. The rabbits were kept in cages, with one animal in each cage. The cages were equipped with containers for food and water. The flooring was sawdust of coniferous trees. Wet cleaning of the cages was performed daily. Food was given once a day, and drinking water was given without restrictions. Before the experiment, the animals were quarantined for 21 days.

Planned euthanasia of animals was performed 26 weeks after implantation by introducing repeatedly excess doses of barbiturates. If the implant fell out, the animals were sacrificed unscheduled, immediately after the fallout detection.

## Evaluation of results

The implant survival rate was assessed by the absence of its loss at the final follow-up period, i.e., at week 26 after implantation. X-ray control was performed at weeks 3, 6, 9, 12, 15, 18, 21, and 26 of implantation. After removing the compression device, a daily clinical test was performed to assess the implant mobility.

Laboratory studies included bacteriological examination of the site of the implant entry into the skin (implant/skin interface), counts of leukocytes in the blood, and blood serum level of C-reactive protein (CRP) at the time of the experiment.

Samples for microbiological examination were collected from wounds intraoperatively in compliance with asepsis rules and on days 9–10 after device implantation, from the site of the implant entering the skin. The samples selected were immediately delivered to the laboratory. To isolate aerobic and facultative anaerobic bacteria, inoculation was performed on the nutrient media of nutrient agar containing 5% blood, yolk-salt agar, Levin medium, and Sabouraud's medium. The inoculations were incubated at 37°C for 24–48 h. To determine the degree of contamination, the inoculation was divided into sectors. After incubation, the number of colonies of each type in sectors was counted, and the result was expressed in terms of the decimal logarithm of the size of the grown colonies (CFU/ml). Generic and species identification of isolated bacterial cultures was performed by the traditional method by studying their tinctorial, cultural, and biochemical properties. The antibiotic susceptibility of the isolated strains was determined by the disk diffusion method on the Muller–Hinton broth. The tested drugs were chosen according to clinical guidelines*. The tested drugs included cefoxitin, gentamicin, clindamycin, erythromycin, ciprofloxacin, and vancomycin for gram-positive microorganisms; ampicillin, amoxicillin/claulanate, ceftazidime, ceftriaxone, meropenem, ciprofloxacin, and gentamicin for *Enterobacteriaceae*; and cefepime, imipenem, meropenem, ciprofloxacin, amikacin, gentamicin, and ceftazidime for nonfermenting gram-negative bacteria.

Leukocyte counts were determined on a ProCyte Dx automatic hematological analyzer (IDEXX Lab., Netherlands). CRP concentration was determined on a Hitachi/BM 902 automatic biochemical analyzer (F. Hoffmann-La Roche Ltd., Italy) using reagent kits from Vital Diagnostic (Russia).

## Statistical analysis

The results of quantitative analyses are presented as a median and 1-3 quartiles (Me; Q1–Q3). The normality of the samples was determined using the Shapiro-Wilk test. The statistical assessment of the significance of differences among parameters during the experiment with preoperative values was performed using the Wilcoxon W-test. The significance of intergroup differences was assessed using the nonparametric Kruskal-Wallis test. The minimum significance level ($p$) was equal to 0.05. Statistical analysis was performed using the AtteStat 13.1 add-in for Excel spreadsheets.

## RESULTS

In this study, a single growth of microorganisms in wound samples was taken intraoperatively (Table 1). In four animals of groups 1, 4, 5, and 6, single bacterial cells were found in the samples, which were representatives of the normal microflora of the skin of animals, belonging to *Staphylococcus epidermidis* ($n$ = 2) and *Enterococcus* spp. ($n$ = 2). Microbial content for these strains was less than $10^3$ CFU/ml.

* Clinical guidelines. Determination of the sensitivity of microorganisms to antimicrobial drugs. Version 2021-01:225.

On days 9–10 after implantation, at the metal implant exit site, animals of different groups showed significant differences in the microbial landscape (Table 2). The largest number of strains was detected in groups 1, 5, and 6, whereas the smallest number was registered in groups 2 and 3. The most common strains were *Staphylococcus saprophyticus* and *Enterococcus* spp. When analyzing the antibiograms of bacteria isolated from the wounds of experimental animals, the predominance of several resistant isolates of gram-positive microorganisms was established. In group 6 on days 9–10 after implantation, the microbial landscape was the most specific compared with other groups. Four strains were not detected in animals of other groups, namely, *Staphylococcus warneri, Staphylococcus haemolyticus, Enterobacter* spp., and *Acinetobacter* spp. This pattern indicated that high values of compression, as well as its absence, were associated with an increase in the infection of the implant exit zone.

*Table 1*

**Species composition of bacteria isolated intraoperatively from animal wounds**

| Range of isolated bacteria | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|---|---|---|---|---|---|---|
| Staphylococcus epidermidis (+) | – | – | – | <103 | – | <103 |
| Enterococcus spp. (+) | <103 | – | – | – | <103 | – |
| Total<br>Number of strains<br>Number of animals | 1<br>1 | 0<br>0 | 0<br>0 | 1<br>1 | 1<br>1 | 1<br>1 |

(+) Gram-positive bacteria.

*Table 2*

**Species composition of bacteria isolated from animal wounds on days 9–10 after implantation**

| Range of isolated bacteria | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|---|---|---|---|---|---|---|
| *Staphylococcus aureus* (+) | 4 ($10^5$)* | – | – | – | 2 ($10^5$) | 1 ($10^6$) |
| *Staphylococcus saprophyticus* (+) | 3 ($10^5$) | 1($10^5$) | 2($10^5$) | – | 1 ($10^5$) | 1 ($10^6$) |
| *Staphylococcus epidermidis* (+) | 2** ($10^5$) | – | – | – | 2** ($10^5$) | 1** ($10^6$) |
| *Staphylococcus warneri* (+) | – | – | – | – | – | 4($10^4$) |
| *Staphylococcus haemolyticus* (+) | – | – | – | – | – | 1($10^6$) |
| *Streptococcus* spp. (+) | 1 ($10^4$) | – | – | – | 1 ($10^4$) | – |
| *Corynebacterium* spp. (+) | 1 ($10^5$) | – | – | – | 1 ($10^5$) | – |
| *Enterococcus* spp. (+) | 2 ($10^5$) | – | – | 2 ($10^4$) | 1 ($10^5$) | 2 ($10^6$) |
| *Enterobacter* spp. (–) | – | – | – | – | – | 1 ($10^6$) |
| *Enterobacter cloacae* (–) | 1 ($10^6$) | – | – | 1 ($10^5$) | 1 ($10^6$) | – |
| *Acinetobacter* spp. (-–) | – | – | – | – | – | 1 ($10^6$) |
| *Pseudomonas aeruginosa* (–) | – | – | – | 1 (106) | – | 1 ($10^5$) |
| *Proteus mirabillis* (–) | 1 ($10^4$) | – | – | – | 1 ($10^4$) | – |
| *Citrobacter* spp. (–) | 1 ($10^6$) | – | – | – | 1 ($10^6$) | – |
| *Escherichia coli* (–) | 1 ($10^7$) | 1 ($10^4$) | – | – | 1 ($10^7$) | – |
| Total<br>Number of strains<br>Number of animals<br>Loss of implants<br>Purulent inflammation of the tissues around the implant | 10<br>4<br>1<br>1 | 2<br>1<br>0<br>0 | 1<br>2<br>0<br>0 | 3<br>2<br>1<br>0 | 10<br>4<br>2<br>1 | 9<br>5<br>4<br>1 |

* Here and below: 4 is the number of animals with the strain detected; 105 the average value of bacterial contamination for this strain;
** presence of methicillin-resistant *Staphylococcus* epidermidis (MRSE) strains; (+), (–) gram-positive and gram-negative bacteria, respectively.

The determination of antibiotic sensitivity showed that some strains of *Staphylococcus* spp. were resistant to the action of β-lactam drugs. Specifically, our study revealed methicillin-resistant *S. epidermidis* resistant to cefoxitin and, consequently, to all antibiotics belonging to the β-lactam group (groups 1, 5, and 6). Ciprofloxacin and clindamycin had pronounced activity against staphylococci. Strains of *Enterococcus* spp. were sensitive to gentamicin and ciprofloxacin. Vancomycin-resistant enterococci were not detected. Ceftriaxone and gentamicin showed maximum activity in relation to representatives of the *Enterobacteriaceae* family. Ciprofloxacin was the most effective drug for non-fermenting gram-negative bacteria.

In two animals of group 5 and four animals of group 6, signs of the implant instability (loosening) were noted immediately after the removal of the retainer, and on days 3–4, the implant fell out. In one animal each of groups 1 and group 4, signs of instability were recorded on days 8–9 after the retainer was removed; in these cases, implants fell out on days 13–14 after the retainer removal.

We separately analyzed the microbiocenosis of animal wounds after the implant loss (eight cases in all groups). The microbial landscape of samples taken from these animals intraoperatively was similar to other experimental groups. Gram-negative microorganisms *Proteus mirabilis, Enterobacter cloacae, Citrobacter* spp., and *Escherichia coli* were detected in the species composition after the implant loss, and microbial content was $10^6$ CFU/ml. Purulent discharge during implant loss was not detected.

The largest significant increase in the blood serum level of CRP was revealed in animals of group 6 (Table 3). For other groups, no obvious relationship was found between the magnitude of compression with an increase in CRP level. This finding probably indicates the absence of development of systemic infection in groups 1–5 because the leukocyte count in all groups did not change significantly relative to preoperative values.

Nevertheless, acute purulent inflammation of the soft tissues around the implant was detected in one animal each of groups 1, 5, and 6 on days 12–16 after implantation. Purulent inflammation was stopped by antibiotic therapy for 7–10 days (cefazolin 0.05 g/kg). In addition, in six rabbits (2 from group 1 and one each from groups 2, 4, 5, and 6), inflammation of the soft tissues around the wires of the external fixation device was noted, which disappeared following treatment with antiseptic agents.

*Table 3*

**Dynamics of C-reactive protein (mg/L) in the blood serum of rabbits during the experiment, Me (Q1–Q3)**

| Term, weeks | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|---|---|---|---|---|---|---|
| 0 | 0 (0–2) | 0 (0–1) | 0 (0–1) | 0 (0–4) | 0 (0–3) | 0 (0–2) |
| 1 | 15* (9–20) | 7* (4–11) | 13* (6–22) | 20* (17–30) | 12* (5–18) | 33* (22–38) |
| 2 | 21* (10–28) | 11* (8–22) | 10* (4–17) | 12* (5–16) | 12* (9–14) | 36* (23–44) |
| 6 | 19(9–24) | 2 (0–17) | 2 (0–3) | 18* (9–23) | 9* (7–19) | 8* (6–10) |
| 20 | 7* (5–11) | 7* (4–15) | 10* (6–19) | 10* (5–24) | 11* (7–14) | 8* (7–12) |
| 26 | 7* (4–10) | 11* (7–30) | 4* (2–21) | 18* (6–27) | 8* (7–10) | 5* (4–6) |

* Significantly different from preoperative (term 0) values at $p < 0.05$;
bold type indicates significant differences between the groups ($p < 0.05$).

## DISCUSSION

The study demonstrated varying degrees of growth of microbial flora around the percutaneous implant in all experimental groups. These data are quite consistent with clinical cases when the growth of microbial flora around percutaneous implants, despite antimicrobial measures, is observed in more than half of the patients [8, 15].

The species composition of the microorganisms detected in the implantation site indicates that the landscape was formed due to the growth of opportunistic microflora, which is also noted in the clinical presentation after surgery [16]. Although the increase in the number of bacteria on the skin near the implant is not equivalent to the clinical manifestation of infection (in our case, an increase in contamination was found in 18 of 30 animals, while a purulent-inflammatory process developed in 3 animals), the high frequency of microbial colonization, providing a high bacterial load, can potentially provoke the development of not only a superficial infectious process but also deep infection [17]. The latter is also contributed by the formation of bacterial biofilms on the implant surface, which ensures the dissemination of pathogens into the soft tissues and the bone [18, 19, 20].

In our study, we did not observe substantial signs of a systemic reaction in experimental animals, associated with the release of bacteria into the blood, as evidenced by a relatively low level of CRP; a significant increase in this marker indicates the presence of bacteria in the blood [21]. All processes were localized in the vicinity near the contact zone, and the absence of cases of deep infection in animals supports the fact that the implant was not a source/gateway for the penetration of microorganisms from outside. Indeed, in clinical practice, deep infection, including osteomyelitis, develops rarely in patients with percutaneous implants [22, 23].

Based on the comparison results of these data, we can conclude that the presence or absence of implant compression is not associated with the development of deep infection. However, the association of the implant mechanical compression with the growth of microbiological contamination at the implant–skin interface is obvious. Specifically, our results indicate that both the absence and presence of implant compression in the range of 0.158–0.211 N/mm$^2$ were accompanied by a significant increase in the contact zone contamination. The minimal compressive loads studied in the range of 0.053–0.105 N/mm$^2$ were accompanied by minimal contamination.

If the causes of changes in the contamination of the implantation zone and on the implant surface are described and confirmed in the literature [24], then the relationship we detected between the implant compression value and the contamination of the implant–skin interface has not been previously described.

This phenomenon can be explained by the concept described by A. G. Gristina [25]. According to this concept, during implantation into living tissues, competition between bacteria and tissue cells for adhesion occurs on the implant surface. Moreover, if osteoblasts are the first to colonize the surface of the product, then implant integration occurs; if tissue cells cannot displace bacterial colonies, implant integration decreased and infection developed. Subsequently, the applicability of this concept was confirmed by several works. Specifically, experimental models confirmed that early osseointegration of the implant into the tissue prevents the attachment of bacteria and, consequently, the formation of biofilms [25, 26, 27, 28]. This concept is complemented by the possibility of direct interaction between osteoblasts and microbial flora [29, 30]. Consequently, the adhesion process between osteoblasts and microbial flora is competitive in nature, which determines not only further osseointegration but also the possibility of implant infection.

This concept can explain our results as well. No implant loss occurred in animals with better osseointegration (groups 2 and 3), and the minimum amount of growing strains at the implant–skin interface was noted. The positive effects of compression in stimulating osteogenesis are described in detail in the literature [31, 32, 33]. These data suggest that the minimal compression of percutaneous implants under the conditions of the experimental model studied stimulates the differentiation of osteoblasts, which creates a competitive advantage for them in the implant surface adhesion. This not only promotes better device integration but also prevents the formation of biofilms and a significant increase in microbiological contamination in the implantation site.

The implantation technology, which includes additional fixation of the implant with an external fixation device, also implies the presence of a new adverse response, namely, an inflammatory reaction near the retainer wires. This is the most common reaction in the application of the Ilizarov apparatus, and the methods of its relief are described and are not difficult [34].

## CONCLUSIONS

Thus, the results of this study demonstrated that the microbiological profile of the implantation site under conditions of various mechanical compressions of percutaneous implants changes depending on the magnitude of the loads. The optimal modes of mechanical compression of the percutaneous implants under additional fixation can be identified. The discovery of a relationship between the implant survival rate and the growth of microbiological contamination is related to the fact that loads ranging from 0.053 to 0.105 N/mm$^2$ have better effects on the implant survival rate and implantation site contamination than the absence of compression. The latter finding suggests that percutaneous implant integration is more effective in the presence of a certain level of compression.

## DISCLAIMERS

### *Author contribution*

*Stogov M.V.* — research concept and design; writing the text of an article.

*Emanov A.A.* — research concept and design; collection, analysis or interpretation of data.

*Godovykh N.V.* — collection, analysis and interpretation of data; editing the text.

*Ovchinnikov E.N.* — research concept and design; collection, analysis and interpretation of data.

*Tushina N.V.* — collection, analysis and interpretation of data; editing the text.

*Kuznetsov V.P.* — research concept and design.

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.*** Approval from the local ethics committee was obtained before the start of the study. The study was conducted in compliance with the principles of humane treatment of laboratory animals in accordance with the requirements of the European Convention for the Protection of Vertebrate Animals used for Experiments and other Scientific Purposes and Directive 2010/63/EU of the European Parliament and the Council of the European Union of September 22, 2010 on the protection of animals used for scientific purposes.

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

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# Different Models of Dual-Energy Bone DXA Scanners: A Comparative Study

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***Background.*** Dual-energy X-ray absorptiometry (DXA) is an effective method for bone mineral density (BMD) and subcutaneous fat percentage estimation. The constant development of new densitometry techniques, the demographic change and the higher potential of artificial intelligence in healthcare enhance requirements for the high-quality measurements in DXA.

***This study aimed*** to develop a quality control method for DXA scanners and compare four DXA systems with different X-ray geometries and manufacturers when simulating fat-water environments.

***Methods.*** We evaluated the accuracy (relative error (ε%) and precision (CV%)) of the bone mineral density (BMD) measurements, performed by the four DXA scanners: 2 with narrow-angle fan beam (64- and 16-channel detectors (DXA-1, DXA-2)); 1 with wide-angle fan beam (DXA-3); 1 with pencil beam (DXA-4). We used a PHK (PHantom Kalium) designed to imitate spine. The PHK contained four vertebras filled with a $K_2HPO_4$ solution in various concentrations (50-200 mg/ml). The PHK also included paraffin patches (thickness 40 mm) to simulate the fat layer.

***Results.*** DXA-1 and DXA-2 demonstrated the best CV% ranged from 0.56% to 1.05%. The least ε% was observed when scanning PHK with fat layer on DXA-1 and DXA-2 (1.74% and 0.85%) and DXA-4 (1.47%). DXA-3 produced significantly lower BMD (ε = -14.56%, p = 0.000). After removing the fat layer, we observed reduction (p = 0.000) of BMD for DXA- 1 and DXA-2 (ε = -5.11% and -6.12% respectively) and weak deviation (p = 0.80) for DXA-4 (0.87%). For DXA-3, removal of the fat layer also resulted in a significant reduction in BMD (ε = -16.44%, p = 0.000). The subcutaneous fat modeling showed that all these DXA systems automatically determine the percentage of fat in the scanned area with weak underestimation: for DXA-1, DXA-2 and DXA-4 the ε% were -5,9%, -6,3% and -2,3% respectively. CV% were 0.15%; 0.39%; 1.6%, respectively.

***Conclusions.*** We proved a significant underestimation of the BMD measurements across the entire range of simulated parameters for the DXA scanners when the model did not include the subcutaneous fat layer. All models demonstrated high accuracy in measuring the fat layer, with the exception of the DXA-3 model, which was not assessed in these studies.

**Keywords:** DXA, dual-energy X-ray absorptiometry, densitometry, bone mineral density, osteoporosis, precision, relative error.

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# Сравнение двухэнергетических денситометров различных моделей

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***Актуальность.*** Двухэнергетическая рентгеновская абсорбциометрия (ДРА) — это эффективный метод оценки минеральной плотности костной ткани (МПК) и подкожно-жировой клетчатки (ПЖК). Постоянное развитие новых методов денситометрии, старение населения и высокий потенциал применения технологий искусственного интеллекта в здравоохранении усиливают потребности в получении высококачественных измерений МПК в ДРА.

***Цель исследования*** — разработать средства и методы контроля ДРА сканеров и провести сравнение четырех денситометров разной геометрии и фирм-производителей при моделировании различного водно-жирового окружения.

***Материал и методы.*** В ходе работы проведена оценка точности (относительной погрешности (ε%) и воспроизводимости (CV%)) измерений МПК четырех рентгеновских денситометров: два — с узковеерным пучком рентгеновского излучения с 64- и 16 рядами детекторов (DXA-1, DXA-2), один — с широковеерным пучком (DXA-3); один — с пучком карандашного типа (DXA-4). Для сравнения использовался фантом РНК (PHantom Kalium), моделирующий МПК поясничной области: четыре модели позвонков от нормы до остеопороза, содержащие гидрофосфат калия в различной концентрации — 50–200 мг/мл. РНК также включал парафиновые накладки (толщиной 40 мм), имитирующие ПЖК.

***Результаты.*** DXA-1 и DXA-2 имеют наилучшую CV%, определенную в диапазоне от 0,56% до 1,05%. Наименьшая ε% отмечена при сканировании РНК с ПЖК для DXA-1 и DXA-2 (1,74% и 0,85%) и DXA-4 (1,47%). При исключении ПЖК наблюдаются снижение МПК для DXA-1 и DXA-2 (ε = -5,11% и -6,12% соответственно) и небольшое отклонение ($p$ = 0,80) для DXA-4 (ε = 0,87%). DXA-3 демонстрирует существенно заниженные данные измеренной МПК (ε = -14,56%; $p$ = 0,000) при сканировании РНК с ПЖК. Однако исключение ПЖК также приводит к значительному ($p$ = 0,000) снижению МПК (ε = -16,44%; $p$ = 0,000). При анализе точности определения жирового слоя для DXA-1, DXA-2, DXA-4 отмечалась незначительная недооценка заданных показателей на -5,9%, -6,3% и -2,3% соответственно. При этом CV результатов составила 0,15%; 0,39%; 1,6%.

***Заключение.*** Результаты исследования подтвердили значительную недооценку МПК для всего диапазона возможных значений при сканировании РНК без ПЖК. Модели продемонстрировали высокую точность измерения жирового слоя за исключением DXA-3 сканера, для которого этот параметр в исследовании не оценивался.

**Ключевые слова:** ДРА, двухэнергетическая рентгеновская абсорбциометрия, денситометрия, минеральная плотность кости, остеопороз, воспроизводимость, относительная погрешность.

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## BACKGROUND

Dual-energy X-ray absorptiometry (DXA) is an effective method for bone mineral density (BMD) and subcutaneous fat percentage estimation. High-accuracy measurement of BMD is considered an important criterion to diagnose osteoporosis and to monitor the treatment progress [1]. The International Society for Clinical Densitometry (ISCD 2019) suggests assessing the precision in volunteer studies by calculating the least significant change (LSC) using the ISCD calculator [2]. A similar approach (involving the LSC calculation) was suggested for cross-calibration of various scanner models. The suggestions also addressed phantom studies, recommending to assess the stability of the scanner performance in general and when replacing scanners with similar models. Fat layer measurements are relevant for body composition estimation that is recommended for children, the diagnosis of sarcopenia, and other diseases [3].

The comparison of DXA scanners about the measurement accuracy and phantom studies designed to assess various scanner models has been conducted during the entire DXA history [2, 4, 5, 6]. However, recently, there has been growing interest in precision assessment. Firstly, it is associated with the constant development of new densitometry techniques that requires providing comparisons with previous methods [7]. Secondly, the population becomes older, and with that, the distribution of this technique and its application rise [8]. The suggested resupply of the DXA equipment to meet the European targets (1 scanner per 100 thous. people) would secure population coverage with the screening measures based on the risk factors and treatment monitoring needs [9]. Thirdly, the higher potential of artificial intelligence in healthcare requires receiving robust medical data for using it in a decision support system, to provide patient-oriented medicine [10, 11], and for providing the population studies by osteoporosis.

Following the European Union initiative, the Committee d'Actions Concertes — BioMedical Engineering (COMAC-BME) developed a procedure to improve cross-calibration and enhance the BMD measurement standards that utilize semi-anthropomorphic phantoms (ESP — European Spine Phantom) [12, 13]. Some phantoms contain as well as test objects for BMD modelling, a permanent fat layer. For example, the standard ESP configuration is designed to simulate a 9% fat layer [14], whereas Bona Fide Phantom, BFP simulates a 26% fat layer [15]. However, the embedded fat layer of these phantoms cannot be modified. Although this phantom was presented in many studies, its construction doesn't allow adding or deleting a fat layer. The above makes it reasonable to compare the measurement technique of various DXA scanners to assess the impact produced by the fat layer and to obtain data on CV precision and accuracy when modelling fat-water environments.

Our study aimed to compare the accuracy and precision parameters for BMD and fat percentage measures acquired by four DXA scanners using a self-developed phantom solving the describing above limitations. During our study, the alternative phantom was presented and the precision and accuracy parameters of four DXA scanners were measured and compared.

## METHODS

### PHK phantom

A detailed description of the PHK (Phantom Kalium) is available in the previous paper [7] (Fig. 1).

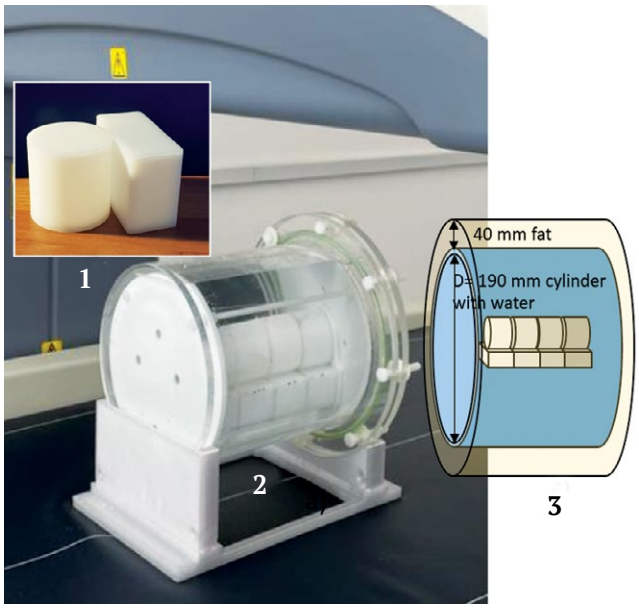


**Fig. 1.** PHK design:
1 — vertebrae section made of a cylinder that simulates the vertebra body, and a parallelepiped imitating a cortical layer;
2 — during the w/ fat scan the 'vertebrae' were placed inside a cylinder with a diameter of 190 mm filled with water;
3 — around the cylinder walls it was possible to place 40 mm thick paraffin patches to simulate the fat layer

The phantom is designed to simulate the lower back region. Depending on the configuration, the phantom body can be made of polypropylene or polymethyl methacrylate (to results presented in this paper were obtained using a polypropylene phantom. The phantom is cylinder in shape with an internal diameter of d = 190 mm and length 230 mm. Wall thickness — 5 mm. Using high-precision milling on ultra-high-molecular-weight polyethylene fiber we made 4 vertebra models consisting of a cylinder (a vertebra body) and a parallelepiped (a cortical layer).

The vertebrae sections are filled with a dipotassium phosphate solution ($K_2HPO_4$) in various concentrations. Table 1 contains set values of volumetric BMD and projected areal density (cylinder + cortical layer). The "vertebra" area of 17.5 $cm^2$ is defined by the area of a parallelogram pertaining to a denser cortical layer. According to the evaluation of the expanded uncertainty for the set values the error for the set volumetric BMD is ± 0.21%; projected areal density — ±0.9%. The highest difference between the volumetric and set BMD values for both L1 sections is 0.26%. The accuracy of the set BMD values for this phantom is as good as that for ESP phantoms. The PHK phantom can be used both for DXA measurement accuracy evaluation and for QCT. To simulate the fat layer, we used 40 mm thick circular paraffin patches that covered completely the phantom outer side (See Fig. 1). During the imaging with fat condition, the fat percentage was 32.14%; for scanning without fat, it was 5%, due to consideration of the thickness of the polypropylene wall in the fat percentage.

*Table 1*

**The PHK features for set volumetric and projected BMD**

| Vertebra | Set volumetric BMD (cylinder), mg/mL | Set volumetric BMD (cortical layer), mg/mL | Set projected BMD, $g/cm^2$ | Set T-score for Lunar DXA, SD |
|---|---|---|---|---|
| L1 | 50.13 | 250.65 | 0.586 | -5.08 (osteoporosis) |
| L2 | 100.19 | 350.79 | 0.886 | -2.58 (osteoporosis) |
| L3 | 150.38 | 450.10 | 1.177 | -0.16 (normal) |
| L4 | 200.49 | 551.21 | 1.475 | 2.33 (normal) |

## Scanning technique

The phantom study was performed using DXA scanners with four different types of fan beam:

– two DXA scanners with narrow-angle beam and a detector array: 64-channel detector Lunar iDXA (hereinafter – DXA-1) (GE HealthCare, USA); 16-channel detector (DXA-2) (Lunar Prodigy, GE HealthCare, USA);

– one DXA scanner with wide-angle beam (DXA-3) (Discovery, Hologic Inc., USA);

– one DXA scanner with pencil beam (DXA-4) (DEXXUM-3, OsteoSys Co., Ltd., Republic of Korea).

The imaging was performed using the standard clinical protocol. The phantom scanning technique is described in previous studies [4, 16]. Each phantom scan was repeated five times for each of the two configurations: with (w/) and without (w/o) fat layer.

During the image processing, the automated segmentation was corrected manually (since there was no high X-ray density layer, the automated segmentation showed lower reliability) which eliminated the possible bias [7]. The rectangular configuration of the cortical block allowed to perform the correction effectively (Fig. 2). In addition, as per the DXA scanning procedures, we have been recording the results of the fat percentage estimation in the regions that imitated soft tissues.

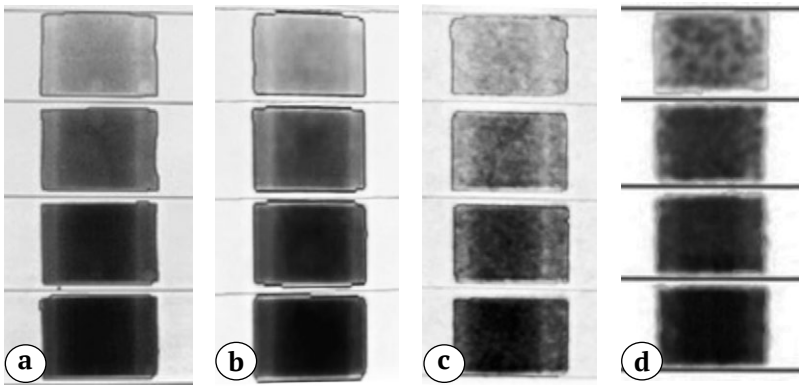


**Fig. 2.** The images were obtained from a PHK phantom w/o fat using the following DXA scanners:
a — DXA-1; b — DXA-2;
c — DXA-3; d — DXA-4

### Evaluation of accuracy (precision and relative error)

When comparing the DXA scanners, we analyzed the following results of the DXA study: the area, the bone mineral composition (BMC), and the derived areal BMD (calculated as the ratio between BMC and the object area). The measurement was performed for each vertebra section and the average scores for L1–L4.

Following the results of the five-fold scanning, we calculated an average value ($\overline{BMD}_{L1-4}$) and a standard deviation ($SD_{L1-4}$) that were later used to access the study accuracy scores: precision (CV%, formula 1) and relative error (ε%, formula 2):

$$CV = \frac{SD_{L1-4}}{\overline{BMD}_{L1-4}} \times 100\%, \quad (1)$$

where:

$SD_{L1-4}$ — standard deviation,

$\overline{BMD}_{L1-4}$ — average BMD values for L1-4;

$$\varepsilon = \frac{\overline{BMD}_{L1-4} - BMD_0}{BMD_0} \times 100\%, \quad (2)$$

where:

$BMD_0$ — average BMD values for L1-4 set during the making of the phantom;

$\overline{BMD}_{L1-4}$ — average BMD values for L1-4.

Considering that the measured BMD, BMC, and the area values are linearly dependent from the set values, to compare the measurements from different DXA scanners we analyzed the corresponding linear approximation parameters. The comparison was performed using the generalized linear model (GLM) method for w/ and w/o fat conditions. A significance level was set to <0.05.

## RESULTS

Figure 2 shows images, obtained from a PHK phantom w/o fat. The borders that surround the BMD measurement area were corrected manually.

Figure 3 shows graphs of BMD measured with different DXA scanners using the PHK phantom in w/ and w/o fat configurations. It shows the mean values, which are ± 2 SD for each L1-4 vertebra model.

For the Lunar DXA scanners (DXA-1 and DXA-2), the CV,% during the scanning w/ fat was 0.68% and 1.0%, and 0.56% and 1.05% w/o fat, respectively. The mean ε,% for the DXA-1 and DXA-2 w/ fat was 1.74% and 0.85% (Table 2). The measured BMD values were lower w/o fat and the average ε values were -5.11% and -6.12% for the DXA-1 and DXA-2, respectively. The lower BMD for the DXA-1 and DXA-2 were significant (p = 0.000 for both models), as determined by the multiple regression for w/ fat scans. This underestimation was caused by a significant decrease in BMC measurements (p = 0.000 for both models), while no significant differences in the area measurements were observed (p = 0.430 for the DXA-1 and p = 0.360 for the DXA-2).

The Hologic DXA scanner (DXA-3) generated reproducible data during w/o fat scans (CV = 0.91%) and less precise data for w/ fat scans (CV = 2.60%) (See Table 2). Assessment of the relative error for the DXA-3 indicates a significantly lower BMD across the entire range of values: the mean ε% were (-16.44%) w/o fat and (-14.56%) w/ fat (See Fig. 3c). This model showed a significantly lower BMD (p = 0.000) w/o fat, due to a significant decrease in BMC (p = 0.000), without a significant underestimation of the measured area (p = 0.220).

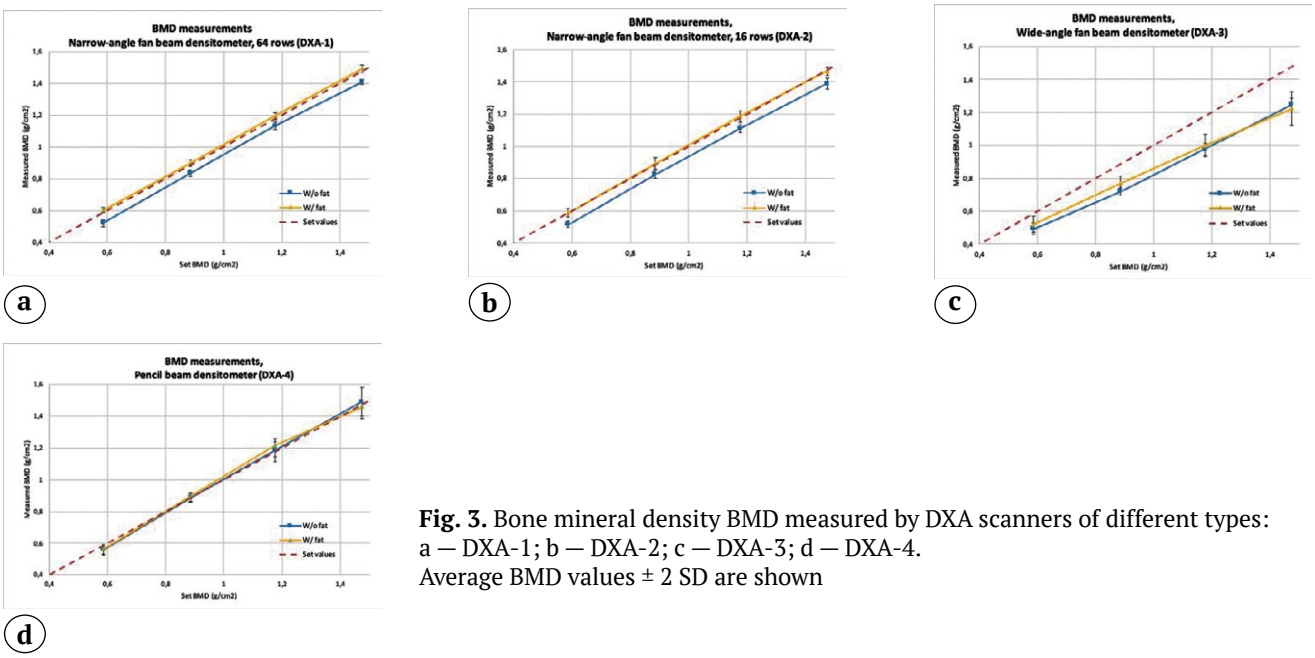


**Fig. 3.** Bone mineral density BMD measured by DXA scanners of different types:
a — DXA-1; b — DXA-2; c — DXA-3; d — DXA-4.
Average BMD values ± 2 SD are shown

*Table 2*

**Specified values, precision (coefficient of variation CV), accuracy (relative error ε) of BMD, BMC, and areas for various models of DXA scanners (mean values for L1-4), calculated using the formulas 1, 2**

| Set values | DXA scanner | Measured mean values (L1-4) | | Precision, CV% L1-4, % | | Accuracy, relative error (ε), % | |
|---|---|---|---|---|---|---|---|
| | | W/o fat | W/ fat | W/o fat | W/ fat | W/o fat | W/ fat |
| BMD, g/cm$^2$ 1.031 | DXA-1 | 0.978 | 1.049 | 0.56 | 0.68 | -5.11 | 1.74 |
| | DXA-2 | 0.968 | 1.039 | 1.00 | 1.05 | -6.12 | 0.85 |
| | DXA-3 | 0.861 | 0.881 | 0.91 | 2.60 | -16.44 | -14.56 |
| | DXA-4 | 1.038 | 1.040 | 2.10 | 1.47 | 0.71 | 0.87 |
| BMC, g 72.17 | DXA-1 | 67.73 | 72.86 | 0.34 | 0.85 | -6.16 | 0.95 |
| | DXA-2 | 66.11 | 71.47 | 0.47 | 0.87 | -8.40 | -0.97 |
| | DXA-3 | 58.21 | 60.91 | 1.33 | 1.31 | -19.35 | -15.6 |
| | DXA-4 | 67.64 | 67.88 | 0.86 | 0.57 | -6.29 | -5.95 |
| Area, cm$^2$ 70 | DXA-1 | 69.18 | 69.45 | 0.44 | 0.97 | -1.16 | -0.78 |
| | DXA-2 | 68.51 | 68.74 | 0.70 | 0.67 | -1.01 | -1.78 |
| | DXA-3 | 67.57 | 69.17 | 1.26 | 2.90 | -2.5 | -1.18 |
| | DXA-4 | 65.18 | 65.29 | 2.37 | 1.40 | -6.90 | -6.73 |

The OsteoSys DXA scanner (DXA-4) produced fairly low-reproducible results. The CV was 2.10% for w/o fat, and 1.47% for w/ fat condition. At the same time, the measured BMD values closely corresponded with the set values (See Fig. 2 d) for L1-L4: the relative error (ε%) was 0.71% and 0.87% w/o fat and w/ fat, respectively. It should be noted that these scanning modes showed no significant differences in BMD measurements ($p = 0.800$). Also, no differences were observed in BMC values ($p = 0.48$), and in the vertebrae area ($p = 0.870$).

At the same time, both the measured area (on average) and BMC values (6.8%) were underestimated for both scanning options (see Table 1), while the calculated BMD value was close to the set one.

The accuracy of the fat percentage estimation was compared for three devices. The subcutaneous fat modeling showed that all these DXA systems automatically determine the percentage of fat in the scanned area quite well: 30.24 ± 0.05% for the DXA-1; 30.53 ± 0.12% for the DXA-2 and 31.4 ± 0.54% for the DXA-4 (CV% were 0.15%; 0.39%; 1.6%, respectively) for a given 32.14% fat environment, including the paraffin patches and the polypropylene casing. We obtained identical results by scanning the phantom without the patches for all three DXA scanners: 4% with a relative error of 20%.

## DISCUSSION

Analysis of the precision (CV%) showed that the lowest CV values (the best reproducibility) were observed for both Lunar DXA scanners: from 0.56% (for the DXA-1 w/o fat) to 1.05% (the DXA-2 w/ fat). The presence of the fat layer simulant contributed to lower precision for the DXA-1 and the DXA-2, an even more significant decrease for the DXA-3 DXA scanner, and a decrease for the DXA-4 DXA scanner (Table 2). Previously we obtained comparable results. Scanning an ESP phantom with similar DXA scanners produced: 0.78% for the DXA-3 (80 measurements, 10 DXA scanners); 2.46% for the DXA-4 (50 measurements, 10 DXA scanners) [4].

According to other data, when scanning the ESP phantom with the DXA-1 and the DXA-2, we obtained the coefficients of variation of 0.42% and 0.50%, respectively [15], which also matches well with our data. In-vivo measurements (30 patients) by Krueger D. et al. produced slightly larger coefficients of variation for these DXA scanner models: 1.81% for the DXA-1 and 1.41% for the DXA-2 [5].

Scanning of the PHK phantom using various DXA scanners showed that the BMD parameters correspond the most with the set values when measured using the DXA-1 and the DXA-2 in the w/ fat mode. According to the scientific papers, scanning of the ESP phantom

produced overestimated BMD values in comparison to the set values for the Lunar DXA scanners, so according to different authors, the BMD value was 11.75% [4], 4.08% [17] in the L1- L3 section. We noted a slight relative overestimation of the measured BMD values (by 0.85% w/o fat and 1.01% w/fat) for the measurements using the DXA-1 DXA scanner compared to the DXA-2 DXA scanner. A similar overestimation by 1.5% was observed for the DXA-1 compared to the DXA-2 in the study in phantoms and in patients earlier [3].

The DXA-3 DXA scanner also showed a significant underestimation of the BMD measurements compared to the set values, both when scanning with and without subcutaneous fat (See Fig. 3c). Without subcutaneous fat, the measured BMD values were slightly lower (-1.9%) compared to the Lunar DXA scanners. According to the scientific papers, the average relative error for the ESP phantom was -3.91% in the L1-L3 section [4].

We obtained relatively elevated (13.71%) BMD measurements for the DXA-2 DXA scanner in comparison to the DXA-3 DXA scanner in the L1-L4 sections. This is in good agreement with the 15.66% difference [4] in the results for similar DXA scanners.

The difference in relative errors for the DXA-1, the DXA-2 and the DXA-3 may be caused by different technologies for bone structure contouring [4]. According to our data, this discrepancy is largely caused by different methods for BMC measurements (See Table 2): the MSC values for the Hologic DXA scanner are lower by 10.9% (without subcutaneous fat) and 14.6% (with subcutaneous fat) compared to the Lunar DXA scanners, although the difference in the determined area is insignificant.

According to our data, the Osteosys DXA scanners ensure the most accurate BMD measurements, regardless of whether the fat simulant was there. However, this was achieved by a systematic decrease both of the area and the BMC values by about 6% with manual adjustments (Table 2). Without an automated adjustment of the area measurements, the ESP scanning with this DXA scanner model produced lower BMC values (by 7%) for the L1-L3 section [2]. This can be explained by an increased area of objects with automatic segmentation and lower BMC values.

A study of 102 patients showed a relative underestimation of the BMD values measured using the DXA-4 DXA scanner compared to the DXA-2 DXA scanner (the same models) [18].

Elevated measured BMD values with an increased fat environment were recorded for DXA scanners when scanning the phantoms [19]. We observed a significant decrease in BMD in patients after different types of weight reduction surgeries [20]. A true decrease in BMD, which may cause fractures as a complication from the obesity treatment, must be differentiated from an artifact decrease in BMD when measuring the volume of fat tissue [21]. Therefore, it is important to determine the relative error when modeling the fat environment.

The study showed that all DXA scanners determine the percentage of fat in the scanned area quite well. When scanning with subcutaneous fat, the volume of adipose tissue is slightly lower by -5.9%, -6.3%, and -2.3% when using the DXA-1, the DXA-2 and the DXA-3 DXA scanners, respectively. When scanning without subcutaneous fat the results were the same across all the devices and studies, therefore the underestimation is 20%. These studies are relevant for estimating the human body composition accuracy (fat, muscles, bones) using modern DXA scanners [14]. This technology is used in paediatrics [22, 23], and the diagnosis of sarcopenia [24]. Cross-calibration of DXA scanners when determining the composition of the human body [25] may be feasible when using a special phantom that simulates the shape of the human body.

The results of this study are perspective also for providing ex-vivo samples experiments based on DXA [26]. On the other hand, the high-accuracy measurements of BMD and fat percentage are seemed to be applied in the decision-making systems including systems based on the artificial intelligence. Robust data develop the prognosis accuracy that is actually in the situation of the life duration increasement.

The developed PHK phantom is limited by its inability to correctly outline the edges of vertebra models in an automatic mode when using the phantom, which calls for manual adjustment. A promising idea is adding high- density boundary inserts to the cortical block models. The study is also limited to four devices. Different devices of these models are required for a more comprehensive understanding of the observed differences.

## CONCLUSIONS

The study showed the effectiveness of the developed PHK phantom based on vertebra models using potassium hydrogen phosphate and modeled subcutaneous fat for determining the accuracy of the densitometry studies.

The impact of the fat environment on the DXA studies was evaluated for four DXA scanners (various models and manufacturers). We proved a significant underestimation of the BMD measurements across the entire range of simulated parameters for the iDXA, Prodigy (Lunar GE), and Discovery (Hologic) DXA scanners when the model did not include the subcutaneous fat layer. The Discovery model (Hologic) underestimates BMD compared to the iDXA and Prodigy (Lunar GE) models, which is consistent with

the results of other studies. The BMD values obtained using the Dexxum 3 DXA scanner (Osteosys) showed they were close to the standard, while the BMC and the area were systematically underestimated.

All models demonstrated high accuracy in measuring the fat layer, with the exception of the Discovery (Hologic) model, which was not assessed in these studies.

The best precision was demonstrated by the iDXA and Prodigy (Lunar GE) models (below 1%).

## DISCLAIMERS

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***Author contribution***

*Petraikin A.V.* — concept and methodology, consulting during experiments, preparing and review of the manuscript.
*Akhmad E.S.* — data analysis, preparing and editing of the manuscript.
*Semenov D.S.* — performing experiments, participation in the development of the phantom.
*Artyukova Z.R.* — accumulate and processing the data of the study, preparing of the manuscript.
*Kudryavtsev N.D.* — accumulate and processing the data of the study.
*Petriaikin F.A.* — concept of the study and data analysis.
*Nizovtsova L.A.* — editing the manuscript.
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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# Pathomorphological Changes in Vater-Pacinian Corpuscles in Palmar Fascial Fibromatosis Depending on the Dupuytren's Contracture Degree

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***Background.*** World literature data indicate the involvement of Vater-Pacinian corpuscles in the pathogenesis of palmar fascial fibromatosis, but the information about their pathomorphological changes and histomorphometric characteristics is contradictory.
***Purpose*** — a comparative analysis of qualitative and quantitative changes in Vater-Pacinian corpuscles in patients with Dupuytren's contracture of varying degrees.
***Methods.*** The analysis of case histories and material resected during operations from 100 patients with Dupuytren's contracture, was made. The patients were divided into two groups: group 1 — those with degree I-II contracture (n = 31), group 2 — those with degree III-IV (n = 69). Histomorphometry of 122 Vater-Pacinian corpuscles, in which the cut plane passed through the central nucleus, was performed in paraffin and semi-thin sections of the patients' surgical material.
***Results.*** At the time of the disease onset, the difference in age medians in the groups was not statistically significant. The age median at the time of surgery (group 1 — 56.0 years; group 2 — 61.0 years, p = 0.001) and the median of the disease duration (group 1 — 5.0 years; group 2 — 9.0 years, p = 0.006) were higher in group 2, the variability in the disease duration was comparable. As it has been established, Vater-Pacinian corpuscles undergo successive reactive-destructive changes in the form of death of the central axon, stratification of the capsule, inflammation, fibrosis, deformation and destruction. The number of corpuscles is greater (p = 0.040) in group 1 — 1 (0; 3) than in group 2 — 0 (0; 6). In group 2, the corpuscles have larger diameters (group 1 — 0.85 mm; group 2 — 0.96 mm, p = 0.072), more layers of the outer capsule (group 1 –17; group 2 — 20, p = 0.032).
***Conclusions.*** In patients with Dupuytren's contracture, along with compensatory and adaptive changes in Vater-Pacinian corpuscles (hyperplasia and hypertrophy), their irreversible destructive changes develop, which, when the disease progresses to grade 3-4, lead to a loss in the number of bodies.

**Keywords:** Dupuytren's contracture, Vater-Pacinian corpuscles, morphology, morphometry.

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# Патоморфологические изменения телец Фатер-Пачини при ладонном фасциальном фиброматозе в зависимости от степени контрактуры Дюпюитрена

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***Введение.*** Данные мировой литературы свидетельствуют о вовлечении телец Фатер-Пачини в патогенез ладонного фасциального фиброматоза, но сведения об их патоморфологических изменениях и гистоморфометрических характеристиках противоречивы.
***Цель исследования*** — сравнительный анализ качественных и количественных изменений телец Фатер-Пачини у пациентов с контрактурой Дюпюитрена разной степени.
***Материал и методы.*** Проведен анализ историй болезни и резецированного во время операций материала от 100 пациентов с контрактурой Дюпюитрена, распределенных на две группы: группа 1 — с контрактурой I–II ст. ($n$ = 31), группа 2 — III–IV ст. ($n$ = 69). В парафиновых и полутонких срезах операционного материала пациентов проведена гистоморфометрия 122 телец Фатер-Пачини, в которых плоскость среза прошла через центральное ядро.
***Результаты.*** На момент начала заболевания различие медиан возраста в группах статистически незначимо. Медиана возраста на момент операции (группа 1 — 56,0 лет; группа 2 — 61,0 год; $p$ = 0,001) и медиана давности заболевания (группа 1 — 5,0 лет; группа 2 — 9,0 лет; $p$ = 0,006) больше в группе 2, вариативность давности заболевания сопоставима. Установлено, что тельца Фатер-Пачини претерпевают последовательные реактивно-деструктивные изменения в виде гибели центрального аксона, расслоения капсулы, воспаления, фиброза, деформации и деструкции. Количество телец больше ($p$ = 0,040) в группе 1 — 1 (0; 3), чем в группе 2 — 0 (0; 6). В группе 2 тельца имеют большие диаметры (группа 1 — 0,85 мм; группа 2 — 0,96 мм; $p$ = 0,072) и большее количество слоев наружной капсулы (группа 1 — 17; группа 2 — 20; $p$ = 0,032).
***Заключение.*** У пациентов с контрактурой Дюпюитрена наряду с компенсаторно-приспособительными изменениями телец (гиперплазия и гипертрофия) развиваются их необратимые деструктивные изменения, которые при прогрессировании заболевания до III–IV ст. приводят к потере численности телец.

**Ключевые слова:** контрактура Дюпюитрена, тельца Фатер-Пачини, морфология, морфометрия.

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## BACKGROUND

Palmar fascial fibromatosis is a connective tissue disease [1, 2]. It is characterized by a predominant lesion of the palmar aponeurosis in the projection of rays IV-V of the hand, starting with the emergence of nodules and strands [3, 4], which eventually cause limited extension of the fingers and subsequent flexion deformity of the hand [5, 6, 7].

Mikusev recognized the polyetiological nature of the disease due to the interaction of exogenous and endogenous factors [8, 9, 10] and suggested that microcirculation disorders in Vater-Pacinian corpuscles are the primary link in its pathogenesis [11]. Vater-Pacinian corpuscles are sensitive receptors for vibration and deep pressure, important for proprioception, and located in all parts of the human body, but are most numerous on the hand [12, 13, 14]. The ulnar edge of the hand of healthy people contains the largest counts of Vater-Pacinian corpuscles, which are characterized by a major variability in size; the largest corpuscles (up to 5 mm in diameter) are localized in the superficial layers of the aponeurosis, where the capillaries form a denser network. Already at the initial stages of Dupuytren's contracture, deformity and degenerative-dystrophic changes in Vater-Pacinian corpuscles can be detected, and in the most severe cases, contractures of the Vater-Pacinian corpuscles are absent [11].

Subsequent studies have increased the uncertainty of ideas about the morphological characteristics of the Vater-Pacinian corpuscles in healthy people and in patients with Dupuytren's contracture. Data on the size of the Vater-Pacinian corpuscles in the fingers of healthy people are contradictory. Thus, according some authors, they had a length of 1.5 mm and widths of 0.78 mm [15], 1.0-2.5 mm, and 0.2-0.5 mm [16], and the sizes varied from 2×1 to 5×5 mm [17]. According to other authors, the diameters of the corpuscles varied from 1.0 to 5.0 mm [14] and from 0.8 to 2.2 mm (average transverse diameter of 1.40±0.23 mm) [18]. Józsa et al. described hypertrophy of Vater–Pacinian corpuscles and an increase in collagen deposits around them in Dupuytren's contracture [19]. Akyurek et al. and Yenidunya et al., in isolated clinical cases of Dupuytren's contracture, revealed hyperplasia of corpuscles, i.e., the formation of corpuscle clusters with size that did not differ from normal ones [20, 21]. Campe et al. examined the histological correlates of the pain form of Dupuytren's contracture in samples from 10 patients and revealed enlarged Vater-Pacinian corpuscles in only one patient [22]. Ehrmantant et al. compared the counts of the Vater-Pacinian corpuscles in five patients with Dupuytren's contracture and in 17 healthy individuals and revealed that in Dupuytren's contracture, Vater-Pacinian corpuscles are more numerous than normal, have larger sizes due to an increase in the number of layers, and have more intense reaction with nerve growth factor [15].

Qualitative and quantitative immunohistochemical studies of the topography and density of nerve structures (using antibodies to the S100 protein and tubulin) of normal palmar aponeurosis and in patients with Dupuytren's contracture also demonstrated a higher density of free nerve endings in pathological samples, which indicates the involvement of nerve structures in enhanced fibrosis in this pathology [23].

Contradictory data on the histomorphometric characteristics of Vater-Pacinian corpuscles under normal conditions, direction of their changes in Dupuytren's contracture, and opinions of the authors concerning the key role of Vater-Pacinian corpuscles in the pathogenesis of fascial fibromatosis indicate the need for further relevant studies of these structures using more clinical materials.

The study aimed to perform a comparative analysis of qualitative and quantitative changes in the Vater-Pacinian corpuscles in patients with Dupuytren's contracture of various grades.

## METHODS

An analysis was made of case histories and material resected during surgeries from 100 patients with Dupuytren's contracture, operated on in the period from 2015 to 2020. The age of patients varied from 22 to 70 years.

The inclusion criteria were Dupuytren's contracture, histologically confirmed palmar fascial fibromatosis. The exclusion criteria were concomitant injuries and a history of hand injuries in patients with Dupuytren's contracture.

Two comparison groups were distinguished, namely, patients with disease grades I-II (n=31) and disease grades III-IV (n=69).

The criteria for comparison were the recentness of palmar fascial fibromatosis (from the moment of the emergence of areas of the palm skin com-

paction), age at disease onset, age at the time of surgery, grade of Dupuytren's contracture according to the Tubiana classification [24], counts of the Vater-Pacinian corpuscles in the surgical material, and their histomorphometric characteristics.

Fragments of the pathologically altered palmar aponeurosis with adjacent areas of subcutaneous adipose tissue and superficial fascia, resected during partial fasciectomy surgeries, were fixed in 4% formalin and embedded in paraffin blocks according to the standard method. Longitudinal and transverse sections (5-7 μm) were obtained on a microtome (Reichert Technologies, Buffalo, NY, USA) and stained with hematoxylin and eosin and Masson's three-color method. A part of the material was fixed in a mixture of solutions of glutaric aldehyde and paraformaldehyde and then in a solution of osmium (VIII) oxide, poured into araldite. Semi-thin sections were obtained on a Nova ultramicrotome (LKB, Sweden), and stained with methylene blue and basic fuchsin. Images of micropreparations for morphometric studies were obtained using an AxioScope.A1 microscope and an AxioCam digital camera (Carl Zeiss MicroImaging GmbH, Germany). In the program "VideoTesT Master-Morphology, 4.0" (Russia), a histomorphometric study of 122 Vater-Pacinian corpuscles was performed, in which the cut plane passed through the central nucleus. Their average diameter, average number of layers of the outer capsule, and shape factor were determined.

### *Statistical analysis*

Quantitative data were processed in Microsoft Excel using the Attestat program (version 9.3.1). The nonparametric Wilcoxon test (significance level $p<0.05$) was used to calculate significant differences, since the distribution of data in some samples differed from normal. Tabular data were presented as medians (Me) and quartiles (Q1; Q3).

## RESULTS

An analysis of the main clinical and demographic characteristics of the comparison groups presented that at disease onset, the groups were comparable in age, and the difference in median age was not significant (Table 1). The median age at the time of surgery and the median disease duration were greater in group 2 than in group 1 by 5 ($p=0.001$) and 4 ($p=0.006$) years, respectively, but the variability in the disease duration was comparable.

A morphological study of the fragments of the palmar aponeurosis resected during a partial fasciectomy revealed the presence of encapsulated nerve endings of complex structure (Vater-Pacinian corpuscles) in many samples.

Patients with Dupuytren's contracture rarely have Vater-Pacinian corpuscles of normal structure. In group 1, there are clusters of corpuscles surrounded by a common perineurium, which include corpuscles with varying degrees of severity of perineuritis (Fig. 1).

Pronounced reactive-destructive changes are detected not only in the corpuscles but also in the nerves and arteries located in their immediate vicinity. In nerve stems, perineuritis naturally accompanies axonal and Wallerian degeneration of myelinated nerve fibers (Fig. 2 a). In most blood vessels (arterioles and capillaries), obliteration of the lumen, wall thickening, and necrobiotic changes in the cellular elements of the vascular walls are noted (Fig. 2 b).

*Table 1*

**Main clinical and demographic characteristics of the studied groups of patients, Me (Q1; Q3)**

| Parameter | Group 1 (grade I-II contracture) n = 31 | Group 2 (grade III-IV contracture) n = 69 | *p* Wilcoxon's test |
|---|---|---|---|
| Age at disease onset, years | 32–68<br>49.0 (45.5; 54.0) | 22–70<br>53.5 (47.0; 59.0) | 0.079 |
| Age at the time of surgery, years | 39–71<br>56.0 (51.0; 58.0) | 37–77<br>61.0 (56.0; 67.0) | 0.001* |
| Disease duration, years | 1–30<br>5.0 (2.0; 9.5) | 0.5–30<br>9.0 (5.0; 15.0) | 0.006* |

* Intergroup differences are significant.

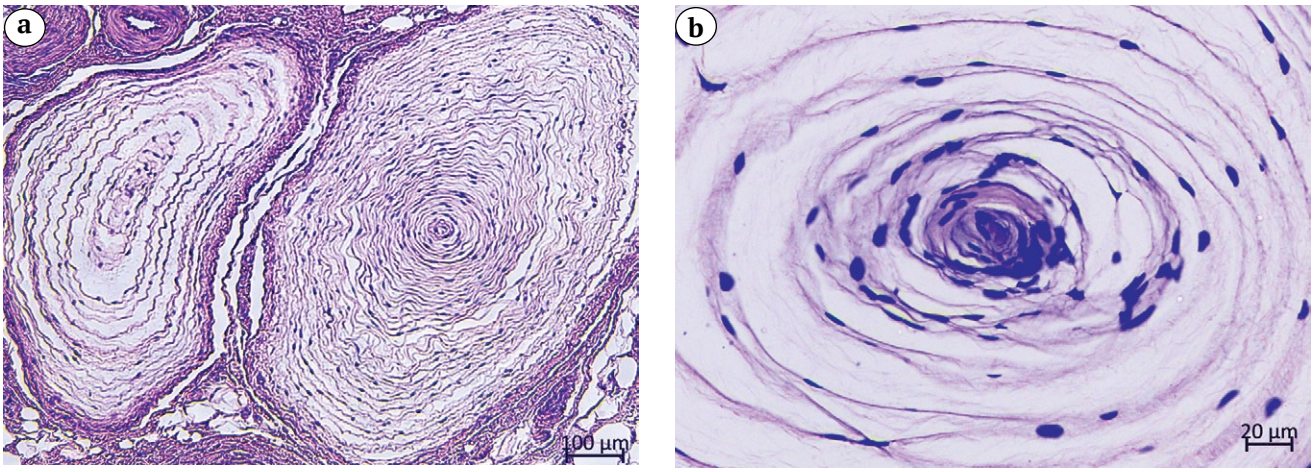


**Fig. 1.** Vater-Pacinian corpuscles in paraffin sections of the palmar aponeurosis of patients with grade II Dupuytren's contracture. Cluster of two corpuscles with uneven corrugation of layers of perineural cells and with uneven distances between layers. Stained with hematoxylin and eosin. Mag.: a — ×50; b — ×400

*Table 2*

**Histomorphometric characteristics of the Vater-Pacinian corpuscles of the palmar aponeurosis in patients with Dupuytren's contracture, Me (Q1; Q3)**

| Parameter | Group 1 (grade I-II contracture) n = 53 | Group 2 (grade III-IV contracture) n = 69 | *p* Wilcoxon's test |
|---|---|---|---|
| Number of corpuscles | 0–5<br>1 (0; 3) | 0–6<br>0 (0; 6) | 0.040* |
| Corpuscle diameter, mm | 0.05–2.29<br>0.85 (0.54; 0.97) | 0.32–1.76<br>0.96 (0.63; 1.29) | 0.072 |
| Number of outer capsule layers | 9–29<br>17 (14; 21) | 10–38<br>20 (16; 26) | 0.032* |
| Corpuscle shape factor | 0.590–0.980<br>0.820 (0.770; 0.920) | 0.370–0.990<br>0.800 (0.680; 0.870) | 0.016* |

* Intergroup differences are significant.

Moreover, a cascade of successive reactive-destructive changes can be detected in Vater-Pacinian corpuscles. Thus, at first the corpuscle, the central part becomes empty because of the destruction of the nerve terminal (Fig. 2 c, d). The circular regularity of the lamellar layers of the inner nucleus and outer capsule begins to deteriorate, pronounced waviness appears, and corpuscle contours start to deform (Fig. 2 c, d).

Further, local discontinuities in the individual layers of the outer capsule are noted, but the lamellar structure of the outer capsule and inner nucleus remains intact, and the nuclei of the cells forming lamellae are clearly visible. In sites with impaired integrity of the layers of the outer capsule in the interlamellar spaces, macrophages migrating into the corpuscles and penetrating to the inner nucleus are detected (Fig. 3 a). They have a very dark, often vacuolated cytoplasm, and some become racket-shaped. The outer capsule is delaminated, and the layers become looser.

Subsequently, the signs of the inflammatory reaction intensify; capillaries grow into Vater-Pacinian corpuscles up to the inner bulb. Fibroblast-like cells of the outer capsule start active production of collagen in the interlamellar spaces (Fig. 3 b), the corpuscles become fibrotic (Fig. 3 b, c), their contours begin to deform and wrinkled (Fig. 3 c), some of them acquire a tortuous shape, and finally, they are destroyed (Fig. 3 d).

Histomorphometric studies of the Vater-Pacinian corpuscles of the palmar aponeurosis of patients with Dupuytren's contracture revealed that the counts of corpuscles in the group with

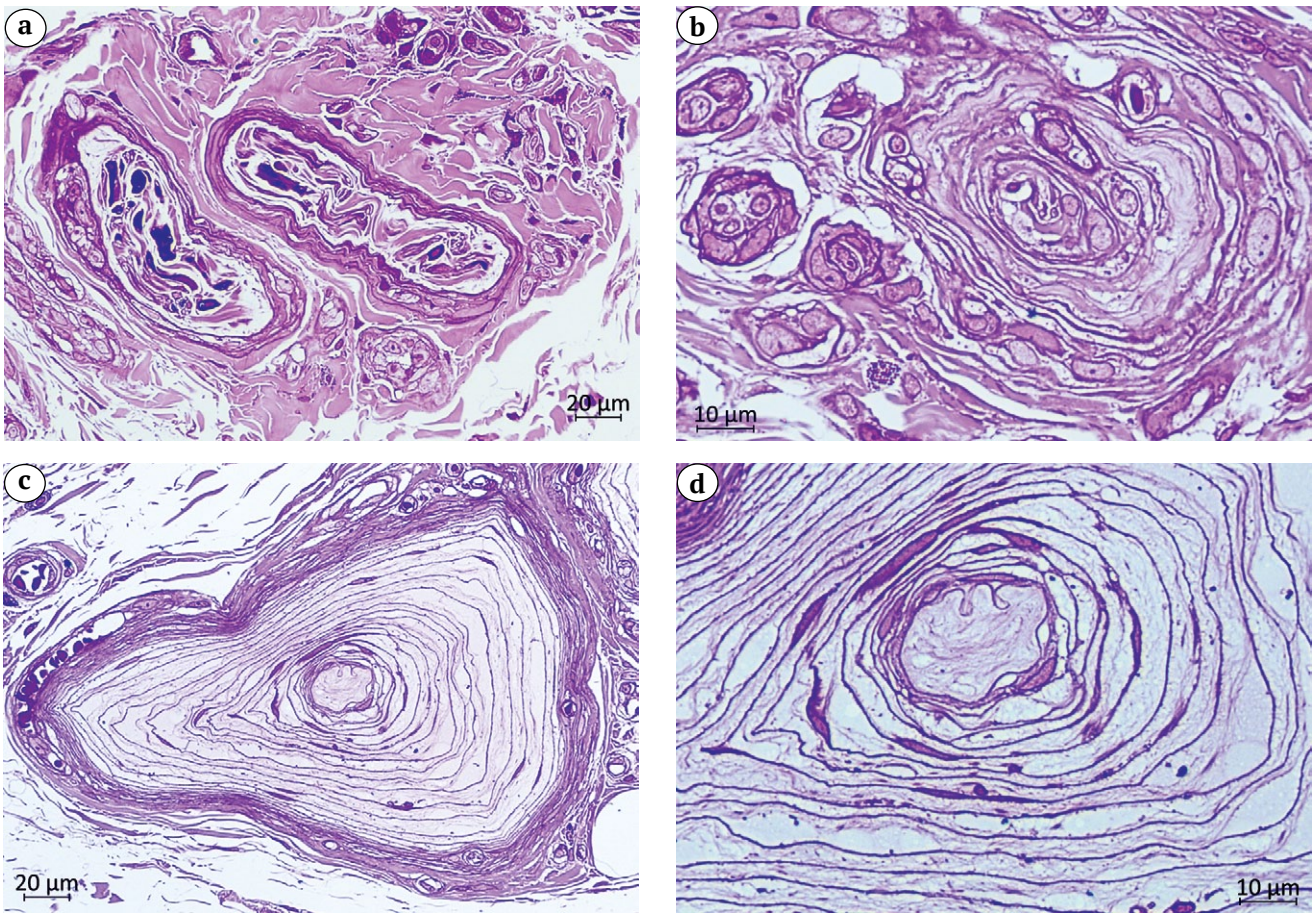


**Fig. 2.** Nerves (a), blood vessels (b) and Vater-Pacinian corpuscles (c, d) in semi-thin sections of the palmar aponeurosis of patients with grade III Dupuytren's contracture. Stained with methylene blue and basic fuchsin. Mag.: a, c — ×400; b, d — ×1000

disease grades I-II were higher (p=0.040) than that of patients with grades III-IV (Table 2). The shift in the dimensional characteristics toward larger diameters in group 2 is expressed at the tendency level (p=0.072). In group 2, the corpuscles have numerous outer capsule layers (p=0.032) and lower values of the shape factor (0.016), which indicates greater fibrosis and deformation.

## DISCUSSION

In patients with Dupuytren's contracture, the Vater-Pacinian corpuscles in palmar aponeurosis undergo successive reactive and destructive changes in the form of central axon death, capsular delamination, inflammation, fibrosis, deformation, wrinkling and, ultimately, necrobiosis, which confirms the results of Mikusev who revealed their degenerative and dystrophic changes and subsequent disappearance in this pathology [11]. The reactive and destructive changes in Vater-Pacinian corpuscles are apparently caused by not only microcirculatory disorders [11, 25] but also denervation due to pathomorphological changes in nerves [26, 27]. Similar changes in Vater-Pacinian corpuscles were registered in an experimental model of rat sciatic nerve transaction, where within a week after the nerve transection, axon terminals are destroyed, and after 8 weeks, the lamellae of perineural cells became wavy, their circularity was disturbed, and over time, the production of collagen fibrils increased [28].

The discovery of a clustered arrangement of corpuscles in the analyzed materials is consistent with literature data on Vater-Pacinian corpuscle hyperplasia, which can occur in various diseases, including Dupuytren's contracture. The pathogenesis of hyperplasia has not been elucidated, but hand trauma is thought to be a potential un-

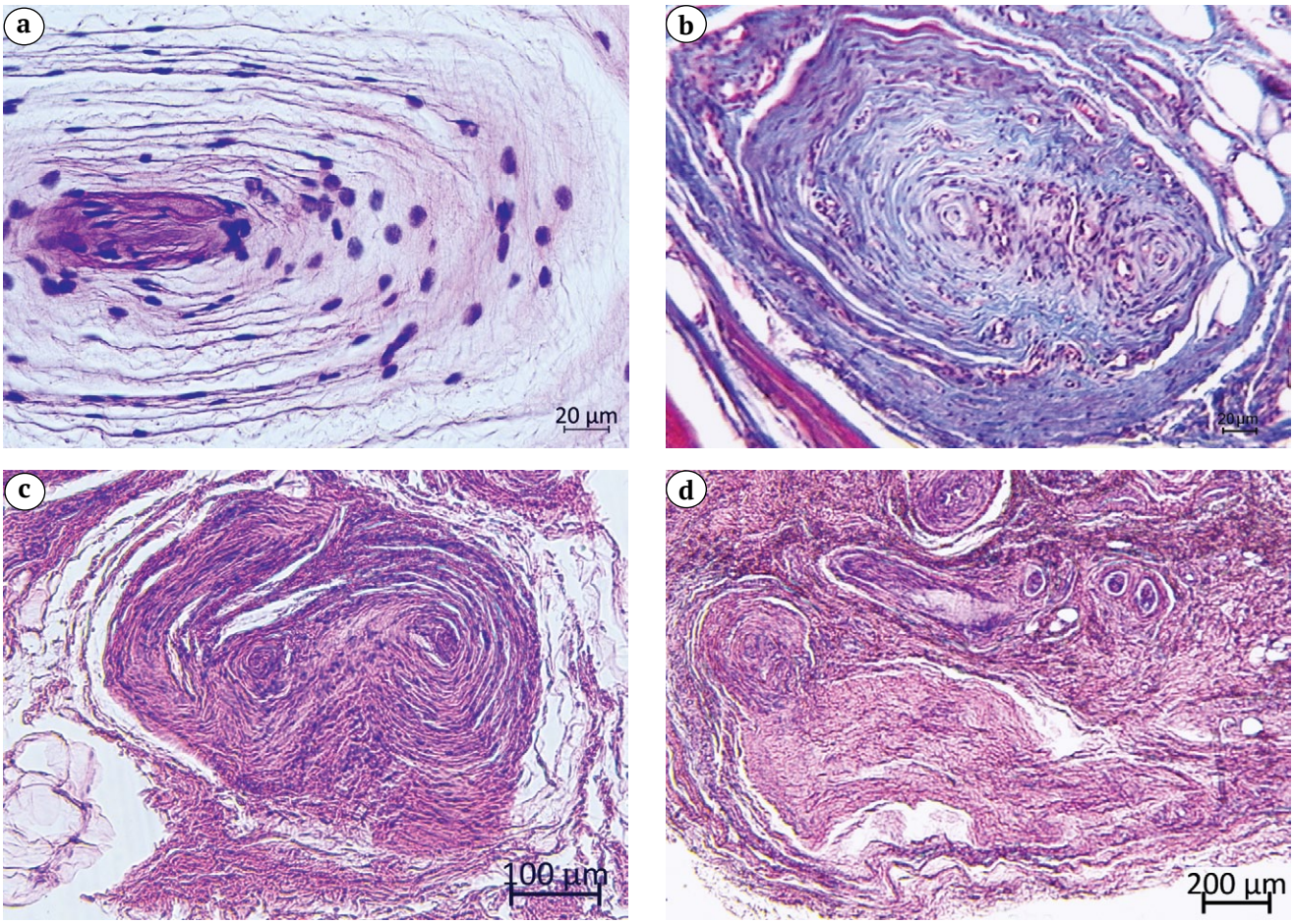


**Fig. 3.** Vater-Pacinian corpuscles in paraffin sections of the palmar aponeurosis of patients with grade II Dupuytren's contracture (a, b), grade III (c) and grade III–IV (d): a — macrophages in the interlamellar spaces of the outer capsule;
b, c — fibrosis and deformation of the contours; d — destruction of the corpuscles.
Stained with hematoxylin and eosin (a, c, d), Masson's trichromic method (b).
Mag.: a — ×400; b, d — ×40; c — ×100

derlying cause [29]. Apparently, the hyperplasia of Vater-Pacinian corpuscles compensates to some extent for their dysfunctions, destruction, and decrease in counts. In our study of the surgical material of patients with Dupuytren's contracture, clusters of corpuscles were detected already at the initial disease stages; however, in patients with grade III-IV contracture, the counts of corpuscles was significantly less than in grades I-II.

The tendency identified toward an increase in the diameter of the corpuscles and a significant increase in the number of outer capsule layers in patients with Dupuytren's contracture grades III-IV compared with those with grades I-II is consistent with the findings of Ehrmantant et al. who revealed an increase in similar parameters in patients with Dupuytren's contracture compared with healthy individuals [15]. These changes can also be classified as compensatory-adaptive, as an increase in the number of layers of perineural cells increases the barrier properties of the perineurium [30]. On the contrary, according to Ehrmantant et al., excess cell growth of the fibrous capsules of Vater-Pacinian corpuscles generates cells that develop into fibromatous nodules [15]. This concept is indirectly confirmed by the fact that clusters of Vater-Pacinian corpuscles are localized at the level of the metacarpophalangeal joints in the same place where fibromatous nodules are most often formed [14]. However, in our study, the registered increase in the number of outer capsule layers of Vater-Pacinian corpuscles can be considered moderate, since the number of layers is normally 13-15, and

with their hypertrophy in an elderly patient who has worked as a mechanic for many years, it is 35-60 [31].

Our study also established that the progression of Dupuytren's contracture to grades III-IV accompanied by a significant decrease in the shape factor of Vater-Pacinian corpuscles and complete destruction. These data are consistent with the results of sensitivity studies in patients. According to Engstrand et al., in patients with Dupuytren's contracture with extension deficiency of 60, the normal level of sensitivity before surgery was registered only in 28% of cases, tactile sensitivity disorders were noted in 66%, and those of protective sensitivity were revealed in 6% [32].

## CONCLUSIONS

For the first time, a study of qualitative and quantitative changes in Vater-Pacinian corpuscles in patients with Dupuytren's contracture was performed on a large clinical material, depending on the disease grade. Along with compensatory-adaptive changes (hyperplasia and hypertrophy of corpuscles), their reactive and destructive changes occur, which, with the disease progression to grades III-IV, lead to the irreversible loss of corpuscle counts. The new data obtained eradicate the contradictions in the global literature about the direction of changes in lamellated corpuscles and represent the actual confirmation of the role of these changes in the pathogenesis of palmar fascial fibromatosis.

## DISCLAIMERS

### *Author contribution*

*Shchudlo N.A.* — research conception and design, writing the draft.

*Varsegova T.N.* — the collection and processing of material, writing the draft.

*Stupina T.A.* — the collection and processing of material, writing the draft.

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 the National Ilizarov Medical Research Centre for Traumatology and Orthopedics (protocol No 4 (68), 11.11.2020).

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

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Original Article
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# Radiometric Parameters of the Forearm in Traumatic Instability of the Distal Radioulnar Joint in Children

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***Background.*** At present, the literature describes in sufficient detail the use of various methods of X-ray examination of the bones of the forearm in the diagnosis of distal radioulnar joint instability (DRUJI), but there are no data on radiometric parameters for DRUJI of traumatic origin in children. Quantitative diagnostics becomes mandatory for determining the tactics of treating DRUJI of traumatic origin in children.

***The purpose of study*** — to analyze the radiometric parameters of the distal forearm in case of DRUJI of traumatic origin in children to plan the method of surgical treatment.

***Methods.*** The paper presents an analysis of the results of X-ray examination of 23 children with instability of the distal radioulnar joint of traumatic origin aged 9 to 17 years (mean age — 14.21±2.5 years) — the main group. For comparison, radiographs of the contralateral forearms of the same patients were analyzed — the comparison group (23 children), and radiographs of the forearm of 69 pediatric patients without signs of DRUJI (control group). On radiographs in the anteroposterior and lateral projections, the following radiometric parameters were evaluated: radioulnar and volar angles, radioulnar index, radioulnar distance, and the difference between the radioulnar distances of both forearms.

***Results.*** In 19 patients of the main group, a «positive variant» of the radioulnar index with dislocation of the head of the ulna was revealed, while the indicators of the radioulnar and volar angle were characterized by variability in values. The average values of radiometric parameters of DRUJI in children without bone-traumatic changes of the forearm are comparable to normal values in adults.

***Conclusions.*** In children with DRUJI of traumatic origin, various changes were revealed radiometric indicators of the distal parts of the bones of the forearm, which depend on the type of forearm fracture. In a particular pediatric patient with DRUJI of traumatic origin, these indicators reflect the biomechanical features of the wrist joint, which must be taken into account when planning surgical intervention and predicting the recovery of the anatomy and function of the forearm.

**Key words:** distal radioulnar joint, children, instability, trauma, radiography.

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# Оценка рентгенометрических показателей костей предплечья при травматической нестабильности дистального лучелоктевого сустава у детей

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***Актуальность.*** В настоящее время в литературе достаточно подробно описано применение различных методик рентгенологического исследования костей предплечья при диагностике нестабильности дистального лучелоктевого сустава (ДЛЛС), но отсутствуют сведения о рентгенометрических показателях при нестабильности ДЛЛС травматического генеза у детей. Квантитативная диагностика приобретает обязательный характер для определения тактики лечения нестабильности ДЛЛС травматического генеза у детей.

***Цель исследования*** — проанализировать рентгенометрические показатели дистальных отделов костей предплечья при нестабильности ДЛЛС травматического генеза у детей для планирования хирургического лечения.

***Материал и методы.*** В работе представлен анализ результатов рентгенологического исследования 23 детей с нестабильностью ДЛЛС травматического генеза в возрасте от 9 до 17 лет (средний возраст — 14,2±2,5 года) — основная группа. Для сравнения анализировали рентгенограммы контралатеральных предплечий этих же пациентов — группа сравнения (23 ребенка) и рентгенограммы костей предплечья 69 пациентов детского возраста без признаков нестабильности ДЛЛС (контрольная группа). На рентгенограммах в передне-задней и боковой проекциях оценивали следующие рентгенометрические показатели: лучелоктевой и волярный углы, лучелоктевой индекс, радиоульнарное расстояние и разницу между радиоульнарными расстояниями обоих предплечий.

***Результаты.*** У 19 пациентов с нестабильностью ДЛЛС травматического генеза был выявлен положительный вариант лучелоктевого индекса с вывихом головки локтевой кости, в то время как показатели лучелоктевого и волярного угла характеризовались вариабельностью значений. Средние рентгенометрические параметры ДЛЛС у детей без костно-травматических изменений костей предплечья сопоставимы с нормальными значениями у взрослых.

***Заключение.*** У детей с нестабильностью ДЛЛС травматического генеза выявлены различные изменения рентгенометрических показателей дистальных отделов костей предплечья, которые зависят от типа перелома. У конкретного пациента детского возраста с нестабильностью ДЛЛС травматического генеза эти показатели отражают биомеханические особенности кистевого сустава, что необходимо учитывать при планировании хирургического вмешательства и прогнозировании восстановления анатомии и функции предплечья.

**Ключевые слова:** дистальный лучелоктевой сустав, дети, посттравматическая нестабильность, рентгенометрия.

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## BACKGROUND

Fractures of the distal forearm bones is one of the most common causes of post-traumatic instability of the distal radioulnar joint (DRUJ) [1, 2, 3, 4]. Before the completion of the ossification process in traumatic injury, the distal epiphysis of the radius and/or ulna is displaced along the growth zone relative to the metaphysis, which is associated with greater elasticity and strength of the capsular–ligamentous apparatus compared with that of the growth cartilage [5].

The greatest potential for the remodeling of the residual deformity was noted in younger children with fractures of the forearm bones in the distal third. This determines the values of the allowable displacement depending on the patient's age and fracture location [6]. The values of these parameters are controversial and vary widely in the literature [7]. The critical age at which only a small corrective potential can be expected ranges from 9 to 12 years. With the inaccurate prediction of this potential, partial remodeling can lead to incorrect fracture consolidation with deformity formation [8]. An improperly consolidated fracture of one or both forearm bones causes a disorder of the ratio of bone structures in the DRUJ, resulting in the restriction of the forearm rotation [1, 3, 4]. Nevertheless, the soft tissue stabilizers of the DRUJ have a certain elasticity that can compensate for the residual displacement of the radius in the distal third. However, after repeated minor trauma, the function of the stabilizers becomes insufficient, resulting in the subluxation or dislocation of the ulnar head in the DRUJ.

With the same mechanism of damage in adolescents who have reached bone maturity and in adult patients, a distal radius fracture occurs in combination with a traumatic dislocation of the ulnar head in the DRUJ following damage to the soft tissue stabilizers of the joint (Galeazzi fracture dislocation). An accurate assessment of the damage is necessary to detect such injuries and minimize any dysplasia of the radius and ulna [9].

DRUJ instability of traumatic origin is clinically determined in the presence of a history of trauma, including fractures of the forearm bones, wrist joint pain, subluxation or dislocation of the ulnar head, and limited forearm rotational function [10]. Examinations of patients with DRUJ instability of traumatic origin include diagnostic tests such as a stress test and a press test [4, 11, 12].

The main method of radiodiagnostics for traumatic DRUJ instability in pediatric patients is standard radiography of the forearm bones with the capture of the elbow joints and hands in two views [2, 13]. In adult patients, the radioulnar angle, volar inclination of the radius, radioulnar index (RUI), and radioulnar distance are assessed on radiographs to objectify the radiological data obtained in case of instability of traumatic DRUJ [14].

Currently, no information is available in the literature about the radiometric parameters of the distal structures of the forearm bones in pediatric patients with DRUJ instability of traumatic origin and the anatomical and physiological aspects of the forearm bones during the growth period.

*This study aimed* to evaluate radiometric parameters of the forearm bones in traumatic DRUJ instability in pediatric patients to plan surgical treatment.

## METHODS

### Study design

This prospective and retrospective cohort study was performed based on the X-ray examination data of 23 pediatric patients (11 boys and 12 girls) with traumatic DRUJ instability, who were examined and treated at the H.I. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery in the period from 2009 to 2021. These patients constituted the main study group.

In the main group, patients aged 18 years with DRUJ instability after fractures of the forearm bones were included. Pediatric patients with DRUJ instability of non-traumatic origin (congenital, infectious, or tumor) were excluded.

Patients aged 9–17 (mean age 14.2±2.5) years were examined. All patients had a history of traumatic injuries in the distal forearm. Patients complained of wrist joint pain during movement and/or physical activity. The clinical examination revealed signs of subluxation/dislocation of the ulnar head and limited forearm rotational function.

To compare the radiological parameters, we analyzed similar radiometric parameters of the contralateral forearms of the same 23 patients included in the comparison group.

In the control group, frontal (anteroposterior) and lateral radiographs were analyzed in 69 patients who were examined in 2021 for various reasons, including suspected traumatic injuries of the forearm bones. The patients were 9–17 years old (mean 13.7±2.5 years) at the time of examination.

By the age of 12 years, the ossification process of the ulnar head is completed, and the development of the carpal articular surface of the radius terminates, which enables the assessment of all radiometric parameters of the anatomical structure of this section of the osteoarticular system [15, 16]. Considering account the age characteristics of the wrist joint structure, all study groups were distributed into subgroups (Fig. 1).

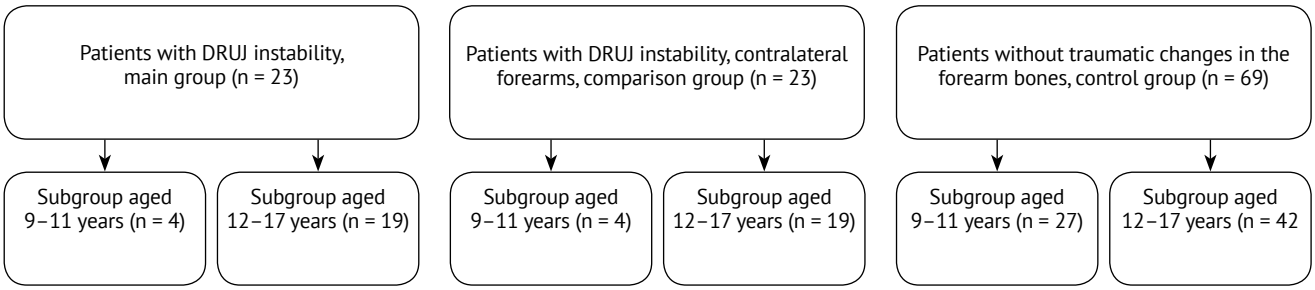


**Fig. 1.** Study flowchart

## Research technique

X-ray examination was performed using Philips X-ray diagnostic devices at the H.I. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery of the Ministry of Health of Russia and on a Samsung device at the K.A. Rauhfus Children's City Multidisciplinary Clinical Center for High Medical Technologies. Images in the anteroposterior and lateral views were obtained. In the main group, a functional radiographic examination of the wrist joint with instability at the site of the ulnar head dislocation was also performed.

Digital and analog X-ray images were analyzed, and linear indicators were determined using measuring tools in Sectra version 16.2.4.2112, Radiant DICOM Viewer version 2021.1, stationary ruler, and angle protractor.

Frontal images were obtained with the patient sitting or standing facing a table. The forearm was bent at the elbow joint up to 90°, the hand and forearm were adjacent to the table with the palmar surface, and the axes of the fingers II–V were a continuation of the forearm axis. The X-ray tube was centered at the ulnar head (projection of the wrist joint), with a focal distance to the joint of 100 cm perpendicular to the long axis of the forearm.

On a lateral radiograph, the child was positioned sideways to the table in a sitting position or facing the table in a standing position. The forearm and hand were adjacent to the table with the ulnar surface. The X-ray beam centering and focal length were set in the same way as when performing radiography in the anteroposterior projection [17].

The functional X-ray examination at the site of the ulna dislocation was performed with the child's limbs at the same position as for the lateral projection. The difference was that the forearm was placed in pronation or supination, depending on the dislocation direction.

In the analysis of radiographs, the following parameters were calculated to characterize the spatial position of the distal parts of the forearm bones:

1. The *radioulnar angle* (inclination of the radius in the frontal plane) is formed by two intersecting lines, namely, a line perpendicular to the long axis of the radius and a line drawn from the top of the radial styloid process to the ulnar edge of the articular surface of the radius, which were measured on images in frontal view (Fig. 2). According to the literature, the value varies from 13° to 30° and averages 22–24° [17]. The spread of values is largely due to the choice for measuring the surfaces of the radius (dorsal or palmar).

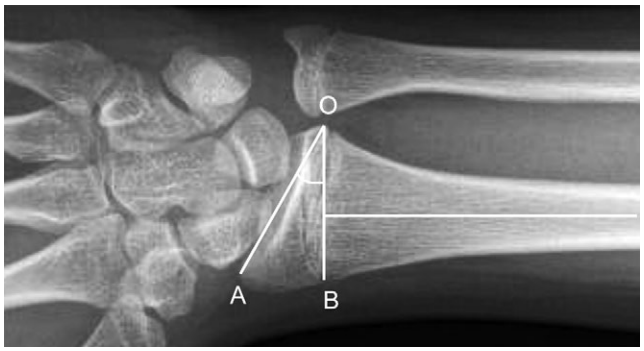


**Fig. 2.** X-ray of the wrist joint in direct projection. The radioulnar angle (∠AOB) is formed by line BO, perpendicular to the long axis of the radius, and line AO, drawn from the apex of the styloid process of the radius to the ulnar edge of the articular surface of the radius

2. The *volar angle* (inclination of the radius in the sagittal plane) is measured on lateral radiographs. This angle is formed by two lines, namely, a line perpendicular to the long axis of the radius and a line drawn between the two edges (dorsal and palmar) of the articular surface of the radius (Fig. 3 a). According to the literature, this indicator is normally 10–12° [3, 18].

3. The *radioulnar distance* is the distance between the dorsal contours of the epiphyzes of the radius and ulna on radiographs in the lateral view. It is measured in millimeters; according to the literature, it averages –2 to +17 mm in the adult population [19]. A negative radioulnar distance value indicates that the ulna is located dorsal to the radius (Fig. 3 b).

4. The *RUI* enables the correlation to the length of the ulna and radius bones on radiographs in the frontal view. It is measured as the distance between two lines drawn in parallel, with one of them along the articular surface of the ulna, and the other at the level of the proximal surface of the sigmoid notch of the radius in the images in the frontal view (Fig. 4). On average, this indicator ranges from –2.5 mm to +3.1 mm [14].

Zero variant, or neutral variant (the levels of the distal articular surfaces of the radius and ulna coincide); positive variant, or "ulna-plus' (the articular surface of the ulna is located distal to the radius); negative variant, or "ulna-minus" (the articular surface of the ulna is located proximal to the radius), were used.

In pediatric patients aged 9–11 years, we measured the Hafner RUI [20], and in pediatric patients aged 12–17 years, the measurement was performed as in the adult population (Fig. 5).

## Statistical analysis

Statistical processes were performed in Microsoft Office Excel 2019 and IBM SPSS Statistics for Windows, version 23 (IBM Corp., Armonk, NY, USA). Using descriptive statistics, arithmetic means (M), standard deviations (σ), and median (Me) with the 25$^{th}$ and 75$^{th}$ percentiles (Q1; Q3) were calculated. Differences were assessed using the nonparametric Mann–Whitney test.

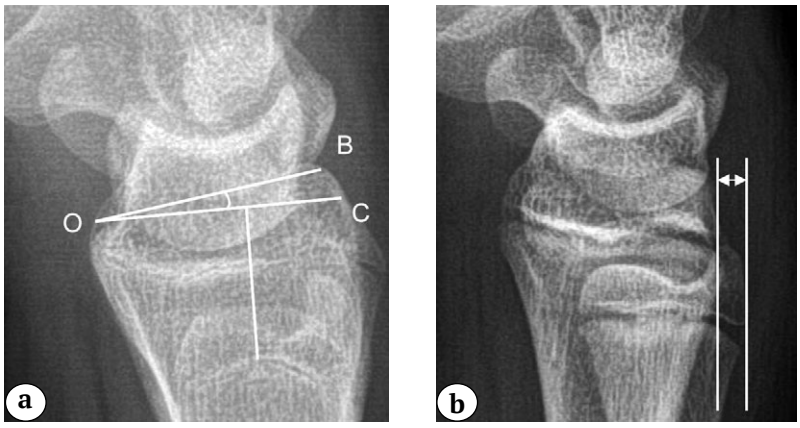


**Fig. 3.** X-ray of the wrist joint in lateral projection: a — volar angle (∠BOC) formed by line CO, perpendicular to the long axis of the radius, and line BO, connecting the two edges (dorsal and volar) of the articular surface of the radius; b — radioulnar distance between the dorsal contours of the epiphyses of the radius and ulna

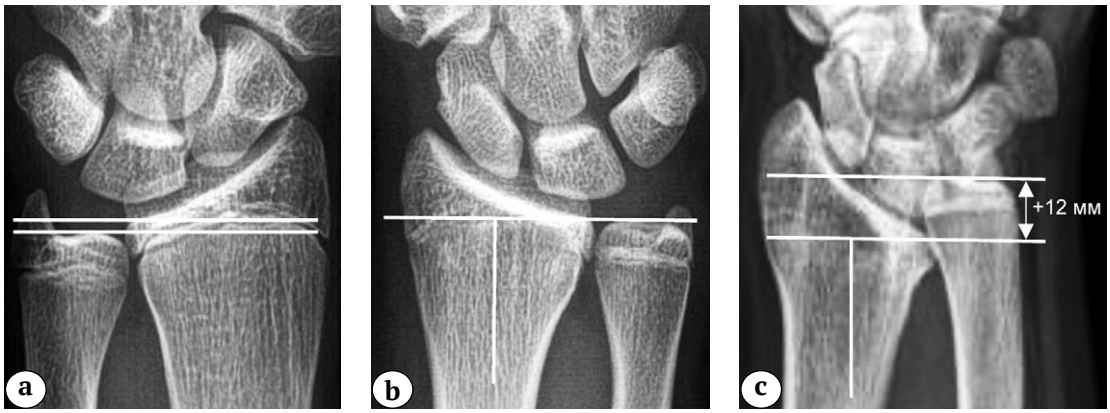


**Fig. 4.** X-ray of the wrist joint in direct projection. Radioulnar index — the ratio of the lengths of the ulna and radius:
a — the negative version of the index (normal version);
b — neutral variant of the index (norm variant); c — positive version of the index

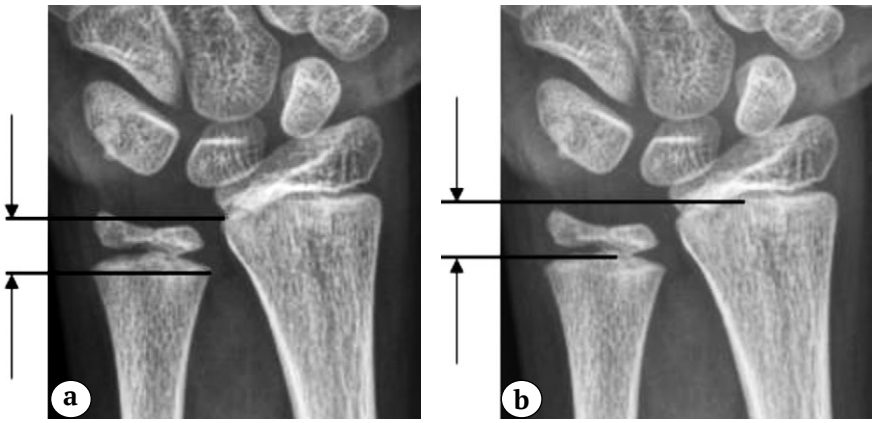


**Fig. 5.** X-ray of the wrist joint in direct projection. Radial-ulnar index (measurement according to Hafner):
a — distance from the most proximal point of the metaphysis of the ulna to the most proximal point of the metaphysis of the radius;
b — distance from the most distal point of the metaphysis of the ulna to the most distal point of the metaphysis of the radius

## RESULTS

All patients with traumatic DRUJ instability had a history of various injuries to the forearm distal structures; as a result, the radiometric parameters were characterized by pronounced variability in values owing to the types of post-traumatic deformity of the distal epimetaphyzes of the radial and ulnar bones.

Table 1 presents the radiometric parameters of the structures of the DRUJ in pediatric patients of the control group, comparison group, and average values of these parameters in the adult group according to the literature.

Intergroup differences in the radioulnar angle, volar angle, RUI, and radioulnar distance were determined using the Mann–Whitney U-test in the comparison and control groups.

The radioulnar angle in the control group increased significantly with age ($p < 0.001$ for 9–11 years old vs. 12–17 years old). A tendency of an age-related increase in this indicator was noted in the comparison group ($p > 0.05$). However, no significant differences were found between the comparison group and the control group within the age groups (Fig. 6).

Regarding the volar angle, an insignificant increase was found with age in the control and com-

parison groups, which did not reach significance. In patients aged 12–17 years, a significant decrease in the volar angle was observed in the comparison group compared with the control group ($p < 0.01$) (Fig. 7).

In our study, standard values of the radioulnar distance were determined in all 69 patients of the control group. The difference between the radioulnar distances in both limbs was determined only in eight patients of the control group owing to the lack of clinical material (absence of lateral radiographs of both limbs in 61 patients).

No significant differences were noted between the control and comparison groups in terms of the RUI and radioulnar distance (Fig. 8).

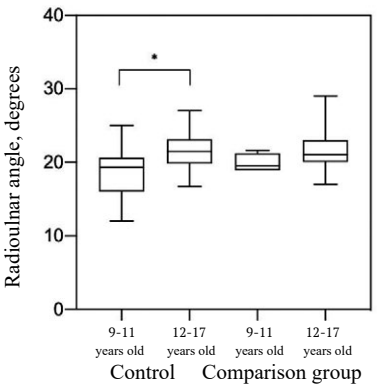


**Fig. 6.** Box plot: radioulnar angle.
Data are presented as min-max. * — $p<0.001$

*Table 1*

**Average values of the radiometric parameters of the distal forearm bones in healthy pediatric patients (control group), contralateral forearms of patients with DRUJ instability (comparison group), and adult population**

| Indicator | Adult patients (according to the literature) [18, 24] M | Comparison group (n = 23) | | Control group (n = 69) | |
|---|---|---|---|---|---|
| | | 9–11 years old (n = 4) M ± σ/Me* | 12–17 years old (n = 19) M ± σ/Me (Q1; Q3) | 9–11 years old (n = 27) M ± σ/Me (Q1; Q3) | 12–17 years old (n = 42) M ± σ/Me (Q1; Q3) |
| Radioulnar angle, degrees | 22–24 | 20.73±2.89/19.50 | 21.63±2.79/ 21.00 (20.00; 23.00) | 18.69±3.30/ 19.3 (16.0; 20.6) | 21.41±2.29/ 21.45(19.80; 23.10) |
| Volar angle, degrees | 10–12 | 9.25±1.03/9.25 | 9.79±1.79/ 10.00 (9.00; 11.00) | 10.30±3.09/ 11.00 (7.30; 11.70) | 11.21±1.52/ 11.00 (7.30; 11.70) |
| Radioulnar distance, mm | -2...+17 | -1.32±2.19/-1.30 | -2.23±3.57/ -2.40 (-5.20; 2.00) | -2.45±3.40/ -2.90 (-4.70; 0.90) | -2.65±3.86/-2.95 (-5.40; 0) |
| Radioulnar index, mm | -2.5...+3.1 | 1.08±1.99/1.95 | 1.25±1.86/ 1.5 (0; 2.5) | -0.19±1.09/ 0 (-0.82; 0) | -0.13±1.25/0 (0; 0) |
| Difference between radioulnar distances in both limbs, mm | 2.0±1.7 | – | – | 2.09±1.67/1.75** | 1.42±0.53/1.25** |

* The quartile interval in this column is not indicated because of the small sample of this age group.
** Calculated in four patients from the control subgroup aged 9–11 years and in four patients from the subgroup aged 12–17 years.

In this study, when measuring the radioulnar angle and volar angle in patients aged 9–11 years, difficulties arose due to the incompletely formed bone model of the radial epiphysis. The indices of the difference between radioulnar distances in both limbs in four pediatric patients from the control group corresponded to those in adults.

In this study, most patients with DRUJ instability had an altered radioulnar angle, that is, it decreased in five patients and increased in 15 patients. In three patients, the radioulnar angle was within the range of the values obtained in the analysis of the contralateral forearm (comparison groups) and healthy limbs in the control group (Table 2).

A decrease in the volar angle was noted in the majority of patients (18% or 78.3%), including the presence of negative values, which indicates a dorsal inclination of the distal articular surface of the radius because of post-traumatic deformity. In 2 (8.7%) patients, no change was found in the volar angle, and in 3 (13%) pediatric patients, the value of this radiometric indicator was higher than the average values of patients from the control and comparison groups (an increase in the palmar inclination of the articular surface of the radius) (Table 3).

The measurement of the RUI helped establish that the positive variant prevailed over the neutral and negative ones. The positive RUI in the comparison and control groups was within the reference values, whereas in the DRUJ traumatic instability group, this indicator was beyond the normal range (>3.1 mm).

A null variant was detected in 2 (8.7%) pediatric patients, and a negative variant without a decrease in the RUI in comparison with healthy children was noted in another 2 (8.7%) patients.

In the analysis of standard indicators of the radioulnar distance in the affected limbs in pediatric patients with DRUJ instability, negative values of this parameter were detected in 18 (78.3%) pediatric patients, which ranged from –4.2 mm to –12.8 mm, whereas 5 (21.7%) pediatric patients had positive values, which ranged from 2 mm to 12 mm.

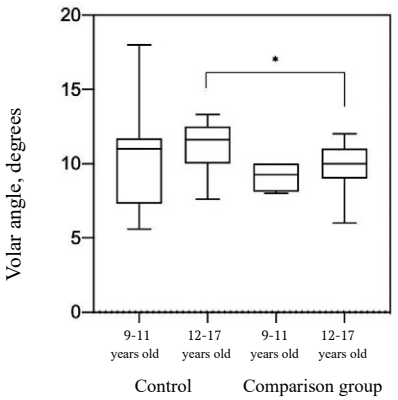


**Fig. 7.** Box plot: volary angle.
Data are presented as min-max. * — $p<0.01$

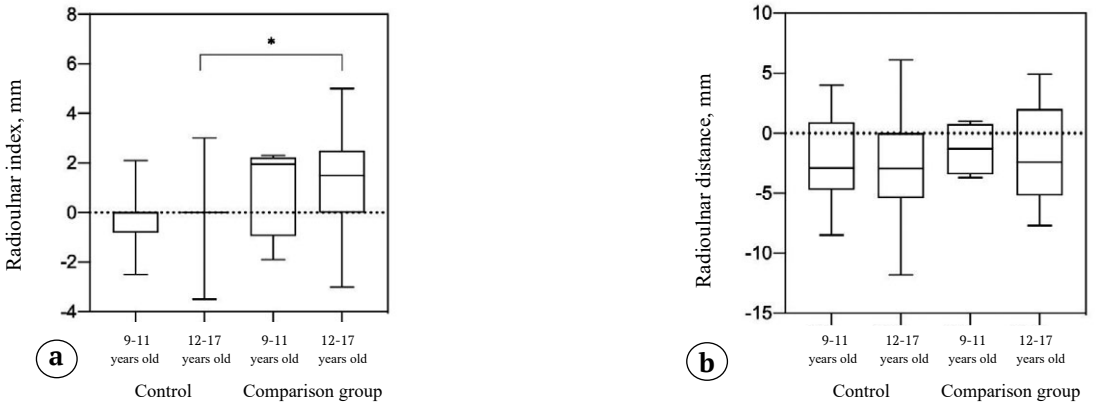


**Fig. 8.** Box plots: a — radioulnar index, mm; b — radioulnar distance. Data are presented as min-max

*Table 2*

**Radioulnar angle in patients with traumatic instability of the distal radioulnar joint**

| Number of patients | Radioulnar angle value, deg. |
|---|---|
| 2 | 8–12 |
| 3 | 13–17 |
| 3 | 18–22 |
| 4 | 23–24 |
| 8 | 25–29 |
| 3 | 30–45 |

*Table 3*

**Volar angle in patients with traumatic instability of the distal radioulnar joint**

| Number of patients | Volar angle value, deg. |
|---|---|
| 7 | –18.7–0 |
| 6 | 1.0–5.0 |
| 5 | 6.0–9.0 |
| 2 | 10.0–12.0 |
| 3 | 13.0–18.5 |

When assessing the difference between the radioulnar distances in both limbs, the value in 15 (65.2%) patients increased from 4.7 mm to 12.7 mm, and in 8 (34.8%) pediatric patients, this indicator was within the normal range.

Considering the predominance of the negative values of the standard indicator of the radioulnar distance in most pediatric patients with DRUJ instability, the results indicate the prevalence of the dorsal dislocation of the ulnar head, which is comparable to findings of the clinical examination.

An X-ray functional study (radiography in the site of the ulnar head dislocation) enabled analysis of the change in the position of the ulna in the case of a clinically detectable subluxation/dislocation of the ulnar head, whereas on standard radiographs in the lateral projection, we did not reveal significant changes in the radioulnar distance in the affected limb (Fig. 9).


**Fig. 9.** X-ray of the wrist joint of a 13-year-old patient with a diagnosis of posttraumatic dislocation of the ulnar head. Instability of the distal radioulnar joint: a — lateral projection; b — X-ray functional examination in the position of dislocation of the head of the ulna (volar type)

## DISCUSSION

Clinical examination is of paramount importance for the functional evaluation of DRUJ and its stability. Moreover, X-ray examination with the determination of radiometric indicators is the most objective method for determining the relationship between the bone structures of the DRUJ. According to many authors, a change in any radiometric indicator can lead to a change in the functional state of the wrist joint and hand [18, 21, 22].

According to the literature, a decrease in the radioulnar angle is observed in patients with fractures of the distal metaepiphysis of the radius, whereas radial deviation of the hand may occur with limitations in the range of motion in the wrist joint [18, 23].

Changes in the volar angle in patients with DRUJ instability of traumatic origin were caused by the deformity of the distal epimetaphysis of the radius. According to Medoff and Koehler, a change in the volar angle in adult patients leads to an impairment in the congruence of the distal articular surfaces of the forearm bones and, consequently, DRUJ instability with a decrease in the amplitude of rotational movements, mainly supination of the forearm, and limited dorsal and palmar flexion of the hand [18].

Normally, 80% of the axial load in the wrist joint accounts for the radial bone and 20% for the ulnar bone. The load distribution varies depending on the relative position of the distal sections of the radius and ulna [24]. However, as the positive version of the RUI increases, the load on the distal ulna increases, which leads to impingement syndrome of the ulna with carpal bones (semilunar and triquetral) and infringement, thinning, and degeneration of the triangular fibrocartilaginous complex [25, 26, 27]. The opposite option, when the RUI decreases, leads to a decrease in the ulnar load, increasing it to the "radial" side. In such patients, ulnar deviation of the hand develops, and pain occurs following the discongruence of the ulnar head with the radial bone proximal to the level of its sigmoid notch, followed by a decrease in the fist-grip strength [28]. Both options for changing the RUI ultimately lead to a limitation of the pronation–supination function of the forearm and early formation of the wrist joint arthrosis [2].

Hafner et al. proposed a method for determining the RUI in pediatric patients aged 1.5–15 years by measuring the distance between the most proximal and most distal points of the growth zones of the distal forearm bones. This measurement method is ideal for children without epiphyseal ossification, but has limitations in older pediatric patients [20].

Goldfarb et al. stated that the method of measuring the RUI in adolescents aged >12 years using the standard adult technique is accurate and reliable, and the mean readings are close to those in adult patients [29].

Clinical examination to determine ulnar head dislocation is of paramount importance in the evaluation of DRUJ in patients with traumatic instability. The measurement of the radioulnar distance in patients with DRUJ instability enables confirmation of the severity of the pathological changes in DRUJ. However, Nakamura et al. showed that a more accurate estimate of the radioulnar distance is obtained through a comparison of this indicator of both limbs in one patient than using one standard value. On average, the difference between radioulnar distances on both limbs is 2.0±1.7 mm. The authors indicate the need for the most accurate position of the forearm in the lateral projection, for which they recommend using special retaining devices that fix the hand [19].

Back in 1983, Mino et al. first reported the importance of radiography of the wrist joint in the lateral view to detect dislocation or subluxation of the ulnar head, emphasizing the need for accurate positioning of the forearm to perform this projection. However, the authors emphasized that the correct position of the limb for obtaining images in the lateral view is not always possible, including that caused by pain syndrome [30]. These reasons may have led to the very variable range of the radioulnar distance index in different authors. Thus, the measurement of the radioulnar distance in patients with DRUJ instability only in the affected limb is not appropriate for assessing the severity of changes. It is worth agreeing with the recommendations of Schachinger et al., who indicated the need to calculate precisely the difference between radioulnar distances in two limbs [31].

To objectify a clinically detected dislocation in the DRUJ, X-ray functional examination of the forearm bones at the site of the ulnar head dislocation should be performed in pediatric patients.

## CONCLUSIONS

The analysis of the radiometric parameters of the distal structures of the forearm bones without traumatic changes in pediatric patients allowed us to confirm the comparability of values with the adult population, except for the radioulnar angle indicators in pediatric patients aged 9–11 years, which is due to the anatomical aspects of the epiphysis shape in patients of this age group. X-ray diagnostics of DRUJ instability of traumatic origin allows for an objective assessment of structural changes, taking into account the disease etiopathogenesis. The radiometric parameters described should be used when planning surgical treatment. Knowledge of the anatomical, physiological, clinical, and radiological aspects of the distal structures of the forearm bones in case of DRUJ instability of traumatic origin in pediatric patients is the basis for correct X-ray diagnostics. The interaction between the radiologist and the orthopedic traumatologist plays a decisive role in the correct interpretation of radiographic findings, which must be evaluated in conjunction with clinical results.

## DISCLAIMERS

### *Author contribution*

*Semenov S.Yu.* — collection, analysis and interpretation of data, description of the article.

*Proshchenko Ya.N.* — research concept and design, article editing.

*Baindurashvili A.G.* — text editing.

*Braylov S.A.* — data selection and processing.

*Semenova E.S.* — data processing, preparation and writing of the text of the article.

*Trufanov G.E.* — 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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Original Article
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# Strategies of Osteosynthesis: Problems and Perspectives

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***Background.*** Urgent osteosynthesis requires number of organizational, material, technical and staff resources.
***Aim of the study*** — to determine advantages and disadvantages of existing strategies for osteosynthesis basing on literature data and comparative analysis of organization of osteosynthesis on the first day after injury and at a later time.
***Methods.*** Data were collected through review of medical records from first half of 2021 calendar year and consist of the patients have been treated by different types of osteosynthesis on the first day after admission to the hospital and later. Average length of hospital stay (LOS) for surgical procedures and duration of the operative time were compared.
***Results.*** In total 266 osteosynthesis of the extremities immediately after admission to the hospital were performed in the first half of 2021 in 260 patients. The most frequently performed ankle fractures fixation (20.7%) and clavicle fractures surgical repairment (13.9%). Cases of early infections complications and no revision surgeries required due to unstable fixation after urgent osteosynthesis were excluded. In the same period 659 delayed osteosynthesis were performed. Mean value of inpatient day in patients, who underwent urgent surgery, was 8.40±16.67 days, while patients, who underwent delayed surgery, spent significantly greater ($p<0.05$) amount of time in the hospital — 12.98±6.28 days in average.
***Discussion.*** Three strategies of osteosynthesis exist: urgent surgeries, delayed surgeries in daytime in operating rooms for planned surgeries and combination of these approaches. Urgent osteosynthesis surgeries do not lead to infectious complications or unstable fixation, what makes them viable option while choosing treatment tactics in case of some injuries. Precise determination of patient groups according to fracture pattern and its localization, that can be operated on in urgent manner, is necessary. Moreover, introduction of urgent osteosynthesis requires serious organizational measures. It is also necessary to perform economical assessment of described approach. Only after solving these questions, it will be possible to make final conclusions about optimal strategy for performing osteosynthesis.

**Keywords:** osteosynthesis, urgent osteosynthesis, urgent surgeries, planned surgeries, delayed surgeries.

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# Стратегия выполнения остеосинтеза: проблемы и перспективы

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***Актуальность.*** Для выполнения операций остеосинтеза переломов в неотложном порядке необходимо выполнение ряда организационных, материально-технических и кадровых требований.
***Цель исследования*** — на основании сравнительного анализа структуры операций остеосинтеза, произведенных в первые сутки после травмы и в более позднее время, а также изучения данных литературы определить преимущества и недостатки существующих стратегий выполнения операций остеосинтеза.
***Материал и методы.*** По материалам первичной медицинской документации, операционным журналам и базе рентгенологических исследований определены пациенты, которым в первом полугодии 2021 г. были выполнены операции остеосинтеза в течение первых 24 ч. после поступления в стационар, и пациенты с аналогичной патологией, остеосинтез которым выполнен в отсроченном порядке с определением среднего времени нахождения пациента в стационаре с момента поступления до и после операции, а также средней длительности хирургического вмешательства.
***Результаты.*** Всего за первое полугодие 2021 г. было выполнено 266 операций остеосинтеза костей конечностей непосредственно при поступлении в стационар у 260 пациентов. Наиболее часто выполнялся остеосинтез переломов лодыжек (20,7%) и ключицы (13,9%). После выполнения операций остеосинтеза в неотложном порядке случаев ранней инфекции и/или ревизионных операций по причине некачественного выполнения первичного остеосинтеза в период госпитализации не было. За тот же период было выполнено 659 отсроченных операций остеосинтеза. Средний койко-день у пациентов, прооперированных в неотложном порядке, составил 8,40±16,67 дней, в то время как пациенты, перенесшие отсроченное хирургическое вмешательство, находились в стационаре в среднем 12,98±6,28 дней ($p$<0,05).
***Обсуждение.*** Существует три стратегии выполнения операций остеосинтеза: неотложные операции, отсроченные операции в дневное время в плановых операционных и комбинация этих подходов. Операции остеосинтеза в неотложном порядке при определенных повреждениях безопасны в плане качества их выполнения и инфекционных осложнений и имеют право на жизнь. Необходимо четкое определение групп больных в зависимости от характера и локализации перелома, которым целесообразно выполнение подобных операций. Кроме того, внедрение практики выполнения остеосинтеза в неотложном порядке требует проведения серьезных организационных мероприятий. Крайне важно также провести экономическое обоснование целесообразности изложенного подхода. Только после решения всех этих вопросов можно будет сделать окончательные выводы о предпочтительной стратегии выполнения операций остеосинтеза.

**Ключевые слова:** остеосинтез, остеосинтез в неотложном порядке, неотложные операции, плановые операции, отсроченные операции.

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## BACKGROUND

The relevance of the problem of providing specialized inpatient care to patients with trauma is beyond doubt. Thus, in each first-level trauma center in St. Petersburg, more than 800 surgeries are performed per year for limb fractures. Moreover, over time, in the absence of significant changes in the number of patients in need of hospital care, the share of those with multisystem and concomitant injuries increases, as well as the severity of polytrauma and both the total proportion of open fractures of the long bones and degree of damage to the soft tissues of the extremities [1]. These changes also affect the structure of surgical interventions. Specifically, analysis of the structure of surgeries shows a significant increase in the proportion of surgeries for near- and intra-articular fractures in 2010 compared with the beginning of the first decade of the XXI century. Moreover, the share of minimally invasive osteosynthesis surgeries increased, which was accompanied by a decrease in the number of preoperative bed-days and, consequently, the total hospital stay after such surgeries [2].

Theoretically, to improve the work of a trauma hospital, all patients with trauma requiring surgical treatment, should undergo definitive osteosynthesis surgeries immediately upon admission to the hospital, except for patients with severe polytrauma, open fractures, high-energy peri- and intra-articular fractures, and other fractures accompanied by significant closed soft tissue injuries. In such cases, primary extrafocal osteosynthesis with external fixation devices should be performed [3]. However, to organize work in accordance with these principles, several requirements must be observed. First, a team of traumatologists should be on duty around the clock, which can physically form a surgical team without disrupting the reception of patients entering the admission and diagnostic department. Second, this team should have a high-level traumatologist on a 24-h basis, who cannot only perform complex surgeries but can also make decisions about treatment approach and the choice of the osteosynthesis technique. In addition, a 24-h trauma operating room equipped with a basic set of instruments for performing trauma surgeries, necessary supply of sterile consumables for osteosynthesis, and an X-ray electron-optical image intensifier (EOII) should be available. Finally, an on-duty team is required, consisting of an anesthesiologist, a nurse anesthesiologist, a surgical nurse, and an aide, who will ensure the work of the trauma team. Therefore, ensuring adequate work of the inpatient trauma service in accordance with modern standards for the provision of specialized trauma care requires significant additional costs for the hospital to increase the staff schedule, equip additional operating rooms, and purchase additional consumables for osteosynthesis. This is a complex problem and cannot be fully resolved in a single hospital without revising the standards for staffing and financing trauma care in the system of compulsory medical insurance. Nevertheless, this problem can be solved to a large extent even under these conditions.

The experience of international hospitals demonstrates the possibilities and prospects of emergency surgery with the competent organization of the process of providing emergency medical care and clear patient routing [4, 5, 6, 7, 8]. However, most first-level Russian trauma centers do not have algorithms for providing emergency trauma care, particularly for performing emergency osteosynthesis surgeries. On the contrary, the delayed performance of osteosynthesis surgeries in elective operating rooms during daytime and a combination of emergency and delayed options for surgical treatment of fractures are possible.

*This study aimed* to determine the advantages and disadvantages of existing strategies for performing osteosynthesis surgeries based on a comparative analysis of the structure of osteosynthesis surgeries performed on day 1 after injury and at a later time. Literature data were also analyzed.

## METHODS

According to the primary medical documentation, dictated procedure reports, and X-ray database of the I.I. Dzhanelidze Research Institute of Emergency Medicine, patients who underwent osteosynthesis surgeries within the first 24 h after admission to the hospital in the first half of 2021 were identified. Surgical interventions were performed in an antishock operating room equipped with an orthopedic table and an X-ray EOII and in an emergency operating room of the operating unit

equipped with a surgical table without an X-ray EOII. Accordingly, surgeries that required an orthopedic table and/or direct intraoperative radiological control could only be performed in an antishock operating room. Surgeries were grouped according to the localization of injuries and type of osteosynthesis. Surgeries in patients with multiple and concomitant traumas were singled out separately. Using the same method, patients with a similar pathology, whose osteosynthesis was performed on a delayed basis for the same period, were identified.

We determined the average hospital stay from the time of admission and after the surgery and the average duration of the surgical intervention, presence or absence of revision surgeries, and early infectious complications of osteosynthesis.

## Statistical analysis

Statistical processing of quantitative data was performed using Excel and basic statistics/tables modules of the Statistica for Windows software package. The nature of the distribution of the studied data was determined using the Shapiro-Wilk test. In the statistical analysis of changes in the studied parameters, the nonparametric Mann-Whitney test was used. Differences in indicators were considered significant at $p<0.05$. The frequency of the studied phenomena was analyzed by calculating the relative values expressed as a percentage. Moreover, using the above programs, the average indices were calculated, including their standard deviation, median, quartiles, and maximum and minimum values.

## RESULTS

In total, for the first half of 2021, at the I.I. Dzhanelidze Research Institute of Emergency Medicine, 266 osteosynthesis surgeries of the limbs immediately were performed on 260 patients upon admission to the hospital. During 236 surgical interventions (88.7%), internal osteosynthesis was performed, whereas in the remaining 32 (11.3%) cases, an external fixation apparatus was applied. Surgical stabilization of the fracture was performed in 114 and 152 cases in the antishock operating room and emergency operating room, respectively. Data for individual locations and segments are presented in Table 1.

For patients who underwent osteosynthesis surgeries in the antishock operating room of the trauma center, the osteosynthesis surgery was performed after an average of 6 h 56 min±3 h 52 min from the time of hospital admission. The average duration of surgical intervention was 1 h 28 min ± 47 min. Moreover, patients with multisystem and concomitant injuries underwent surgery in the same operating room after an average of 3 h 20 min±1 h 43 min, and their average duration was 1 h 24 min±51 min.

Patients who underwent osteosynthesis surgeries in the emergency operating room of the surgery unit stayed in the hospital for an average of 6 h 27 min±3 h 01 min from the time of admission to the start of the surgery. The duration of surgery in this group was 2 h 11 min±41 min.

During the study period, osteosynthesis surgery was performed on 18 patients with multisystem and concomitant injuries upon admission to the hospital, including those with fractures of the bones of the extremities. Moreover, in 14 (77.8%) patients with an injury severity of <25 points on the ISS scale, primary internal osteosynthesis was performed in accordance with the protocol of early total care. In 4 (22.2%) patients with more severe injuries, the fractures were immobilized with external fixation apparatus in accordance with the damage control protocol and Yu.N. Tsibin – A.N. Keyer medical approach-tactical prediction method [9].

An analysis of the surgeries performed revealed that osteosynthesis of fractures of the ankles (20.7%) and collarbone (13.9%) was most often performed. After emergency osteosynthesis surgeries, there were no cases of early infection and/or revision surgeries because of poor quality of primary osteosynthesis during hospitalization.

In the first half of 2021, 659 elective osteosynthesis surgeries were performed, along with 266 emergency ones, on patients who were not operated on urgently (925 surgeries in total). Moreover, the average number of bed-days in patients who underwent emergency surgery was 8.40±16.67 days, whereas patients who underwent delayed surgery had a longer hospital stay ($p=0.025$) for an average of 12.98±6.28 days. The distribution of two independent data samples does not correspond to the normal one; therefore, the nonparametric Mann-Whitney test was used to assess the significance of differences. For individual localizations, the sample sizes of bed-day values (with non-normal distribution) enabled statistical analysis using the nonparametric Mann-Whitney test.

*Table 1*

**Number, type, and location of emergency surgical interventions depending on the fracture location**

| Segment | Osteosynthesis | Antishock operating room | Emergency operating room | Total | |
|---|---|---|---|---|---|
| | | n | n | n | % |
| Collarbone | Internal | 1 | 36 | 37 | 13.9 |
| Humerus | Internal | 6 | 5 | 11 | 4.1 |
| Bones of the forearm, including the distal metaepiphysis of the radial bone | Internal | 6 | 20 | 26 | 9.8 |
| Proximal femur | Internal | 16 | 0 | 16 | 6.0 |
| Diaphysis and distal segment of the femoral bone | Internal | 11 | 2 | 13 | 4.9 |
| | External fixation | 4 | 5 | 9 | 3.4 |
| Patella | Internal | 0 | 2 | 2 | 0.8 |
| Lower leg bones | Internal | 24 | 3 | 27 | 10.2 |
| | External fixation | 5 | 8 | 13 | 4.9 |
| Ankle | Internal | 5 | 50 | 55 | 20.7 |
| Foot bones | Internal | 1 | 2 | 3 | 1.1 |
| Hand bones | Internal | 6 | 19 | 25 | 9.4 |
| Polytrauma | Combined | 18 | 0 | 18 | 6.8 |
| Pelvis | Internal | 8 | 0 | 8 | 3.0 |
| | External fixation | 3 | 0 | 3 | 1.1 |
| Total | | 114 | 152 | 266 | 100.0 |

The calculated *p* values in all cases were less than the accepted significance level of 0.05.

The shortest hospital stay was registered for patients who underwent osteosynthesis of the foot bones, and it averaged 2.66±2.52 days. The highest indicator of the average number of bed-days was expectedly noted in patients with pelvic fractures and polytrauma (30.07±39.92 days). The maximum number of bed-days among patients in this group was 136 days, which was explained by the development of postoperative infectious complications in a patient with polytrauma, which required multiple repeated surgical interventions. If we consider the average hospital stay in all patients who underwent osteosynthesis, then this value was 11.80±10.70 bed-days (Table 2). Thus, we can state a significant decrease in the hospital stay of patients with the injuries under study in the case of emergency osteosynthesis surgeries upon admission.

## DISCUSSION

The problem of organizing surgeries for osteosynthesis of bone fractures in an emergency hospital is long overdue. Unfortunately, the transition to modern standards of specialized trauma care is hindered by several factors. First, most hospitals were designed and built more than 20-30 years ago and are oriented toward the extensive model of care that was implemented at that time; these hospitals do not have the number of operating rooms necessary to work in the new conditions. Second, the current procedures for providing specialized trauma care to patients with both isolated and multisystem and concomitant injuries do not provide a suffi-

*Table 2*

**Number of surgical interventions and average number of bed-days depending on the fracture location**

| Fracture location | Emergency surgery | | Elective surgery | | *p* | Total | |
|---|---|---|---|---|---|---|---|
| | Number | Bed-days | Number | Bed-days | | Number | Bed-days |
| Collarbone | 21 | 2.40±1.14 | 50 | 10.88±7.33 | 2.4×10-10 | 71 | 8.46±7.31 |
| Collarbone—dislocation | 16 | 3.81±2.59 | 0 | 0 | – | 16 | 3.81±2.59 |
| Proximal humerus | 5 | 2.40±1.34 | 67 | 10.95±4.47 | – | 72 | 10.30±4.83 |
| Humeral diaphysis | 6 | 8.67±10.52 | 39 | 13.10±5.34 | – | 45 | 12.50±6.29 |
| Olecranon | 16 | 4.81±6.10 | 37 | 10.59±5.93 | 0.00054 | 53 | 8.85±6.56 |
| Bones of the forearm, including the distal metaepiphysis of the radial bone | 10 | 4.70±5.60 | 53 | 10.57±6.51 | – | 63 | 9.63±6.69 |
| Femoral neck | 0 | 0 | 130 | 15.11±6.57 | – | 130 | 15.11±6.57 |
| Pertrochanteric fracture of the femoral bone | 16 | 10.63±4.44 | 149 | 14.67±5.98 | 0.000798 | 165 | 14.30±5.96 |
| Subtrochanteric fracture of the femoral bone | 0 | 0 | 20 | 14.85±5.67 | – | 20 | 14.85±5.67 |
| Femoral shaft | 4 | 11.50±8.39 | 8 | 9.50±2.62 | – | 12 | 10.20±4.95 |
| Distal femur | 18 | 6.78±6.84 | 15 | 13.47±7.09 | 0.00179 | 33 | 9.82±7.64 |
| Patella | 2 | 1.00±1.41 | 14 | 11.36±3.71 | – | 16 | 10.10±4.96 |
| Proximal tibia | 0 | 0 | 21 | 15.14±6.19 | – | 21 | 15.14±6.19 |
| Diaphysis and lower third of the tibia | 40 | 7.95±9.28 | 6 | 16.50±12.86 | – | 46 | 9.09±10.10 |
| Ankles | 55 | 5.16±9.11 | 50 | 10.16±3.59 | 4.9×10-15 | 105 | 7.52±7.43 |
| Foot | 3 | 2.66±2.52 | 0 | 0 | – | 3 | 2.66±2.52 |
| Hand | 25 | 5.48±11.50 | 0 | 0 | – | 25 | 5.48±11.50 |
| Pelvis and polytrauma | 29 | 30.07±39.92 | 0 | 0 | – | 29 | 30.07±39.92 |
| Total | 266 | 8.40±16.67 | 659 | 12.98±6.28 | 1×10-17 | 925 | 11.80±10.70 |
| min/max | – | 0/136 | – | 3/46 | – | – | 0/136 |
| Q1/Me/Q3 | – | 2/3/8.75 | – | 9/12/15 | – | – | 6/10/15 |

min — minimum value, max – maximum value, Q1 – first quartile, Me – median, Q3 – third quartile.

cient number of personnel to perform surgeries at night. To ensure such work, the heads of hospitals are forced to search out reserves and increase the staff schedule with the introduction of additional doctors and operating nurses*. This is a global problem and has not yet been resolved even in developed countries.

Van der Wee et al. reviewed the provision of emergency surgical care in different countries and indicated great heterogeneity in the struc-

* The procedure for providing medical care to the population in the field of Traumatology and Orthopedics (approved by order of the Ministry of Health of the Russian Federation of November 12, 2012, No. 901n) and the procedure for providing medical care to patients with concomitant, multiple, and isolated injuries accompanied by shock (approved by order Ministry of Health of the Russian Federation dated November 15, 2012, No. 927n).

ture and components of the acute care surgery system worldwide [8]. Indeed, undoubtedly, high-quality osteosynthesis, upon admission of a patient to a hospital, reduces significantly the duration of hospital stay and thereby helps reduce the number of beds without reducing surgical activity. On the contrary, this practice requires the availability of round-the-clock specialized operating rooms with qualified personnel and therefore a significant increase in funding, which is not offset by a decrease in the bedspace capacity of the trauma service.

Thus, various trauma pathologies and the unpredictability of the number of patients with fractures of varying severity who will be admitted to the clinic should be considered. All these patients are traditionally hospitalized to await surgery. This means that during periods of significant workload, the expectation of surgery lasts for several days, the duration of the patient's hospital stay increases, the excessive burden falls on the operating room staff, and the satisfaction of patients with the availability (efficiency) and quality of medical care decreases. The problem is solved by introducing additional surgical teams and even working at night. Moreover, in recent years, surgeries performed at night have increased the risk of complications, treatment costs, and risks of loss of health by hospital staff [10].

Furthermore, the vast majority of traumatological surgeries can be performed on a delayed basis without compromising their quality. For example, in Finland, performing surgeries has four categories of urgency, namely, extremely urgent surgeries must be performed immediately, category 1 surgeries must be performed within 3 h, category 2 must be performed within 8 h, and category 3 must be performed within 24 h. In addition, in the range of osteosynthesis surgeries, only fixation of femoral fractures is included in category 3; therefore, other osteosynthesis surgeries are not performed on an emergency basis. According to Oulu Level 1 Trauma Center, extremely urgent surgeries (4.5% of all surgeries) were started in an average of 26 min after admission, and category 1 surgeries (9.7%) were started after 59 min. Moreover, the target indicator was achieved in 93% of cases. Category 2 surgeries (23.3%) were started after an average of 337 min with the achievement of the target value in 86% of cases, and category 3 surgeries (62.5%) were started in an average of 830 min after admission to the hospital with the achievement of the target value in 62.5% of cases. As the urgency of surgeries decreases, the proportion of interventions performed in compliance with the target indicators decreases. Furthermore, as the urgency decreases, surgeons choose the most suitable patients for themselves, and haste often has a negative effect. This leads to the postponement of surgeries at the lowest category of urgency, which include most osteosynthesis surgeries. These patients often expect surgery at home [4, 6].

FitzPatrick et al. also reported the need for gradation of surgeries depending on the urgency of performing them. They provide data on the introduction in 2003 of the concept of "emergency surgical patient" at the level 1 trauma center of the University of Pennsylvania. This patient needs surgery within 24 h. Moreover, courses in traumatology for general surgeons were organized; subsequently, the Trauma Case Management Team was created. When comparing 1999 and 2003, the number of patients remained approximately the same, but the proportion of older patients increased. The severity of injuries on the ISS scale slightly increased, amounting to more than 13 points. The duration of hospital stay varied from 5.5 to 6.9 days. The rate of refusal to pay for treatment decreased from 4.6% in 1998 to 2.8% in 1999 after the Trauma Case Management Team was established. This figure continued to decrease and reached 0.5% in 2004. In 2004, the rehospitalization rate was 1.8% compared with 4.0% in 1998 [5].

Among the systems that take into account the priority categories of patients expecting surgeries, the so-called traffic-light coding system is noteworthy [6]. According to this system, emergency surgeries are coded red and must be performed within the first 8 h. Surgeries coded orange are performed within 8–24 h, and those in the yellow code must be performed within 24–48 h. Other interventions, which include most osteosynthesis surgeries for isolated fractures, are coded green and can be delayed for a longer time. These patients, after first aid and examination, are discharged home to wait for the surgery that is scheduled for a certain time. Given the limited resources of operating rooms, the wait-

ing time is often longer than previously planned because of injuries that need to be treated first, such as femoral fractures. This causes dissatisfaction among the patients and staff, overloads the wards, and forces surgeries to be performed at night. The results of surgeries for proximal femur fractures are significantly worse when they are performed later than 48 h after the injury; however, there are no reliable data on the deterioration of the treatment results of patients with other traumatological pathologies requiring surgical treatment, when the surgery is performed later than 48 h. This is true for fractures of the upper limbs. Outcomes of surgeries performed beyond the working hours, including at night, are the subject of long-lasting discussions. However, night-time surgeons make more mistakes than daytime surgeons. The risks of complications after surgeries performed on weekends are higher than on weekdays [11]. The quality and safety of surgical treatment performed by on-duty personnel are lower than those of interventions performed during the daytime by surgeons who were not on duty the previous night [12, 13]. In this regard, the traffic-light coding system enables distinguishing priority surgeries (proximal femur) and less urgent surgeries that are included in the operating plan and performed during the daytime in specialized operating rooms by experienced surgeons [10].

In this aspect, the experience of Sweden is interesting, where the model of emergency assistance ensures its high level for all citizens. However, even there, the greatest organizational difficulties are caused by emergency surgeries that cannot be planned. Consequently, emergency surgeries may be performed in an elective operating room and conflict with elective surgeries when the operating room capabilities are limited. This is true for very urgent surgeries. In some cases, the postponement of the surgery leads to additional patient suffering, a longer rehabilitation period, and a deterioration in the final functional result. Moreover, studies on the cancellation or postponement of surgeries reveal suboptimal use of hospital resources and a decrease in its income [7].

When analyzing the experience of Sweden, Bhattacharyya et al. stated that despite the improvement of the material base and resources of clinics and the introduction of new technologies, delays in surgeries in trauma departments occur every day. They are usually explained by a large flow of patients with a wide range of injuries in need of emergency care [14]. However, the real emergency conditions in traumatology requiring immediate intervention are acute compartment syndrome, such as fractures, dislocations, and other injuries accompanied by vascular damage. Most other surgeries can be postponed without harm; however, they should be performed as quickly, as the patient's condition is stabilized and the hospital resources enable them to do it [15]. Thus, emergency osteosynthesis surgeries should be performed depending on the severity of injuries, general status of the patient, and availability of the operating room. Moreover, in some cases, elective orthopedic surgeries can be postponed to perform emergency ones.

All reasons for delaying surgeries can be divided into patient-related and organizational ones. A study of one of the centers in Sweden, which included 9,500 traumatological and orthopedic surgeries (46% elective and 54% emergency), revealed that the priority in surgical treatment was distributed as follows: fractures of the femur (osteosynthesis in the first 24 h), emergency patients admitted to the hospital and awaiting surgery, and patients who received primary care and awaited a call for surgery (home pathway surgery). The system of registration for the operating room and calling patients from home was organized well; however, a large number of delays in performing osteosynthesis surgeries were identified, which can be divided into organizational and medical ones.

The organizational causes of the delays are as follows:

– Admission of patients with severe trauma, who have priority in surgical treatment.

– An increase in the time of the previous surgery relative to that planned previously.

– Change or cancellation of indications for surgery.

– A decrease in the number of available intensive care beds or departments.

– Lack of staff in the operating room and intensive care unit, surgeons, or anesthesiologists.

In addition, organizational problems include refusal of treatment in the clinic and transfer of the patient to another hospital. Medical causes of delays in surgical treatment are the aggravation

of the patient's condition, development of infectious complications, and desire of the patient to undergo the surgery later or refuse it.

Consequently, surgery was postponed once in 18% of patients, twice in 4%, three times in 1%, and four times in less than 1%. In addition, the proportion of surgeries postponed and performed on time did not change for 7 years; 21% of all postponed surgeries were performed within 24 h after cancellation, 41% of patients waited up to 3 days, 17% waited from 3 days to a week or longer, and 6% of patients refused surgery in this clinic. Specifically, 80% of causes of cancellations and delays of surgeries were organizational, whereas only 20% were due to medical reasons [7].

Another problem is that trauma clinics traditionally face a shortage of operating rooms for osteosynthesis of fractures. Thus, such surgeries are often postponed and performed at night. Moreover, the proportion of complications in patients operated on during non-working hours is significantly higher than that in patients whose surgery was performed in daytime, and the duration of the same surgeries performed at night is significantly longer than that performed during the day. The solution can be the organization of the work of one operating room reserved for performing trauma surgeries. This was implemented in 1999 at Massachusetts Hospital where this operating room is open from Monday to Saturday from 7:45 to 17:00 and is under the supervision of traumatologists who determine the sequence of surgeries depending on their urgency. Other types of surgical and orthopedic surgeries are not performed there. The priority indications for the use of this operating room are fractures of the ankles, lower leg, femur, and hip joint, as well as open fractures. As a result, the proportion of night surgeries decreased from 28% to 9%. Moreover, the waiting list for representatives of other subspecialties has significantly decreased [14]. The desire to postpone the majority of surgeries for fractures to working hours is understandable; however, another important aspect of this problem should be considered. The inability to perform surgeries reduces the job satisfaction of a surgeon who deals with non-surgical treatment of closed blunt injuries. To increase job satisfaction, a rational combination of surgical and non-surgical treatment of fractures is required, but this requires extensive skills in the personnel [16].

The international community has also not resolved the issue of who should provide emergency trauma care to patients with fractures. In different countries of the European Union, to provide care to patients with skeletal trauma, different training is required and appropriate certificates obtained, namely, orthopedic surgery (Finland, France, Italy, Norway, Portugal, Romania, Spain, Turkey, Great Britain, Czech Republic, and Germany), trauma surgery (Croatia, Luxembourg, Netherlands, Czech Republic, and Germany), and general surgery (Croatia, Luxembourg, Netherlands, Greece, and Switzerland) [17]. The modern trend in surgery is an increase in the number of subspecialties and, accordingly, a decrease in the number of surgeries and manipulations performed by doctors providing emergency care. The more highly specialized the surgeon, the less competent he/she is in issues of emergency care, while emergency surgery and traumatology require constant training [18]. Moreover, there is a steady increase in the age of patients, financial problems of hospitals, decrease in the number of trained doctors, increase in specialization, and unavailability of consultants 24/7. Physicians do not have enough opportunities for training, which leads to a lack of specialists with a certificate in traumatology. Duty traumatologists usually have a large amount of night work while experiencing a shortage of elective surgery. Therefore, in recent years, the problem of centralization of trauma care and subspecialization of emergency trauma and surgical care has become relevant [17, 18].

Thus, three strategies of osteosynthesis surgeries can be distinguished, namely, emergency surgeries upon hospital admission, delayed surgeries in elective operating rooms during daytime, and a combination of these two strategies.

Performing urgent surgeries of osteosynthesis of fractures has benefits and drawbacks. Analysis of the results of the I.I. Dzhanelidze Research Institute of Emergency Medicine showed that the practice of emergency osteosynthesis of isolated fractures leads to a significant decrease in hospital stay. Contrary to literature data, we have not registered an increase in the number of early osteosynthesis complications associated with emergency surgery. Nevertheless, it appears theoretically more adequate to perform surgeries

during working hours when all the most experienced surgeons are in the clinic, and in case of intraoperative complications or unforeseen situations, they can be fully involved, and all clinic resources are available. This is a global problem and consists in the lack of operating rooms. The desire of surgeons to operate should not be disregarded, as it can be fully actualized during duty hours. This is true for young surgeons.

Some fractures are quite difficult for osteosynthesis, which is impossible to perform or can be performed with inadequate quality by the team of on-duty traumatologists. To avoid such situations, we have defined a list of osteosynthesis surgeries that can be performed on an urgent basis. According to this list, internal osteosynthesis is indicated in isolated and combined cases with a favorable prognosis for the surgical treatment of fractures and dislocations of the clavicle according to Yu.N. Tsibin – A.N. Keyer, as well as two-part fractures of the surgical neck of the humerus, fractures of the olecranon, diaphyseal fractures of the forearm bones, extra-articular fractures of the distal radius, medial fractures of the femoral neck (in case of indications for osteosynthesis), transtrochanteric, subtrochanteric, and diaphyseal fractures of the femoral bone, low-energy fractures of the tibial shaft, fractures of the ankles (in the absence of pronounced soft tissue edema), fractures of the patella, bones of the hand and foot, fractures and dislocations of the talus bone. Primary immobilization of the fracture with an external fixation apparatus is indicated in all cases with unstable hemodynamics (systolic blood pressure <90 mm Hg), unfavorable prognosis of surgical treatment according to Yu.N. Tsibin – A.N. Keyer for fractures of the knee and ankle joints, diaphyseal part of the lower leg due to high-energy trauma, with open fractures G2–G3 (according to the Gustillo–Andersen classification), fractures of the long bones of the lower extremities with polytrauma (ISS > 17) when internal fixation is impossible, and unstable damage to the pelvic ring (if it is impossible to perform primary internal osteosynthesis of the pelvic bones and stabilize the fracture).

The material presented herein is only the beginning of a large work on the analysis of the results and duration of inpatient treatment of patients, depending on the timing of osteosynthesis surgeries. The data obtained indicate that emergency osteosynthesis surgeries with certain injuries are safe in terms of the quality of their performance and infectious complications and deserve to be used. On the contrary, the optimization of the hospital operation during daytime can decrease the need for emergency osteosynthesis surgeries and reduce the load on the bed capacity, making the problem of emergency osteosynthesis less urgent.

Regarding urgent osteosynthesis surgeries, it is necessary to define clearly the groups of patients depending on the nature and location of the fracture, that is, who should undergo such surgeries, with the creation of adequate algorithms for choosing a treatment method and strict adherence to them. In addition, the introduction of performing urgent osteosynthesis requires serious organizational measures. Not all trauma centers, even if they wish, can presently shift to such a practice of providing assistance due to the peculiarities of the staffing and organizational structure. Thus, conducting an economic justification for the expediency of the approach outlined is extremely important.

## CONCLUSIONS

Nowadays, the trauma community lacks the unanimity of views on the optimal strategy for osteosynthesis surgeries. The lack of consensus is due to the multifactorial nature of the problem, which affects the organization of the provision of specialized trauma care, financing, staffing of the hospital, and professional training of the personnel.

The conclusions about which strategy of osteosynthesis surgery is optimal can be made after an extensive discussion of this problem and a deeper analysis of it.

## 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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Editorial
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# Fracture fixation strategy: experience and recommendations

## Editorial Comment on the Article by Belenkiy I.G. et al. “Strategies of Osteosynthesis: Problems and Perspectives”

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The commentary critically analyzes the strategy proposed by the authors of the article for performing osteosynthesis and describes the system of care for patients with fractures in Moscow. Operating rooms are divided into planned and emergency. And they, in turn, are divided into conventional and hybrid, in which it is simultaneously possible to perform endoscopic, endovascular, and open surgery. Surgeries are performed in order of priority. Highest priority: extra-focal fixation of limb bones and/or pelvis with ex-fix devices; surgery on extremities with impaired blood supply in the distal parts; decompressive fasciotomies with simultaneous external fixation of fragments in ex-fix devices with suspected formation of compartment syndrome; surgeries performed in patients with severe combined or multiple trauma. High priority: open fractures of type 3A and 3B according to the Gustillo classification, requiring primary surgical treatment of wounds and external fixation; closed unstable fractures.

**Keywords:** osteosynthesis, emergency trauma care, healthcare organization.

Редакционная статья
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# Стратегия выполнения остеосинтеза: опыт и рекомендации

## Редакционный комментарий к статье И.Г. Беленького с соавторами «Стратегия выполнения остеосинтеза: проблемы и перспективы»

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В комментарии критически анализируется предложенная авторами статьи стратегия выполнения операций остеосинтеза и описывается система оказания помощи пациентам с переломами в г. Москве. Операционные делятся на плановые и экстренные. А они, в свою очередь, подразделяются на обычные и гибридные, в которых одновременно возможно выполнять и эндоскопические, и эндоваскулярные, и открытые вмешательства. Операции выполняются в порядке приоритета. Высочайший приоритет: внеочаговая фиксация костей конечностей и/или таза стержневыми аппаратами; операции на конечностях при нарушении кровоснабжения в дистальных отделах; декомпрессивные фасциотомии с одновременной внешней фиксацией отломков в стержневых аппаратах при подозрении на формирование компартмент-синдрома; операции, выполняемые пациентам с тяжелой сочетанной или множественной травмой. Высокий приоритет: открытые переломы типа 3А и 3В по классификации Gustillo, требующие проведения первичной хирургической обработки ран и внешней фиксации; закрытые нестабильные переломы.

**Ключевые слова:** остеосинтез, неотложная травматологическая помощь, организация здравоохранения.

After reviewing the manuscript of the article by I.G. Belenkiy et al. “Strategy of Osteosynthesis: Problems and Perspectives,” I could not resist polemics.

Certainly, we (and only jointly!) must create a system for providing care to patients with fractures, but I suppose that the different level of equipment of medical organizations and their provision of personnel in the regions is unlikely to enable this system to become equally effective in the near future. Nevertheless, it is possible to analyze the work of trauma hospitals in megacities, isolate a rational kernel, and evaluate the method of transfer of the knowledge and experience gained to various levels of care. Moreover, in cities such as Moscow, any hospital in terms of its equipment represents practically a

first-level trauma center. However, even in the capital, it is impossible to provide equal assistance in all these hospitals due to the discrepancy between the number of surgical and anesthetic teams. Therefore, a patient routing system was created in accordance with the capabilities of a medical organization. For example, only six and four hospitals have been subspecialized for the treatment of patients with severe pelvic trauma and patients with isolated injuries of the hand and upper limb, respectively. Thus, even in the capital, uniform rules cannot be formulated for everyone, especially since many attempts at organizational and staff changes are limited by the order of the Ministry of Health of the Russian Federation of November 12, 2012 No. 901n "On approval of the Procedure for providing medical care to the population in the trauma and orthopedics specializations." Therefore, it has not yet been possible to provide medical organizations in Moscow with full-fledged traumatology and anesthesiology teams on duty to ensure surgical care in accordance with the number of non-specialized hospital beds, but with the number, for example, of operating rooms.

In addition, the concepts differ. For example, medical organizations in Moscow lack units such as an anti-shock operating room. We subdivide operating rooms into elective and emergency ones, which, in turn, are subdivided into conventional and hybrid ones, where endoscopic, endovascular, and open interventions can be performed simultaneously. In some hospitals, there is no division at all into emergency and elective operating rooms due to the possibility of full-fledged processing of the premises between interventions. Indeed, surgeries such as external fixation, hemostasis, and emergency tracheostomy are (and should be) performed in an intensive care unit that is not an operating room but allows various procedures to be performed simultaneously for several patients without violating sanitary and epidemiological rules.

Therefore, I do not understand the desire to perform urgent surgical interventions in rooms that are not adapted for this. It is unclear why it is impossible to place a full-fledged orthopedic table together with an electron-optical image intensifier in an emergency operating room, and it is unclear why an orthopedic table is needed when conducting anti-shock measures.

In Moscow, an approach has been adopted, somewhat different when compared with the I.I. Dzhanelidze Research Institute of Emergency Medicine, to the distribution of the emergency of osteosynthesis.

## Surgeries of the highest priority

1. Osteosynthesis surgeries performed in the resuscitation room of the intensive care unit as a resuscitation aid without bringing the patient to the operating room. These include only extrafocal fixation of the bones of the extremities and/or pelvis with the use of rod devices (Table 1).

2. Surgeries on extremities in the case of impaired blood supply in the distal sections are not only surgeries of simultaneous revascularization and osteosynthesis of bone fragments in fractures with impaired main blood flow but also surgeries of osteosynthesis in the replantation of disconnected segments or the imposition of rod devices in severe soft tissue injuries.

3. Decompressive fasciotomy with simultaneous external fixation of fragments in rod-type apparatus in the case of suspected formation of a compartment syndrome.

4. Surgeries performed on patients with severe concomitant or multiple traumas simultaneously (or sequentially) with surgical or neurosurgical interventions.

## High priority surgeries

1. Open fractures of type 3A and 3B according to the Gustillo classification that require primary debridement and external fixation.

2. Closed unstable fractures (most often of the ankles and distal metaepiphyzes of the forearm

*Table 1*

**Number of extrafocal fixations using external fixation device, performed upon admission**

| Localization | Year | | | | |
|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2020 | 2021 |
| Upper limb | 378 | 365 | 363 | 335 | 494 |
| Lower limb | 865 | 1028 | 1170 | 1158 | 1527 |
| Pelvis | 332 | 325 | 392 | 268 | 346 |

bones), especially in the case of a threat to the viability or integrity of the skin. In this case, either stable internal osteosynthesis is performed at any time of the day or (with a shortage of personnel, mass admissions, etc.) external fixation of the segment is performed using rod devices, followed by conversion of the fragment fixation method. Despite a significant annual increase in cases of surgical treatment of fractures of the distal metaepiphysis of the radial bone, there was a clear tendency to perform this type of treatment in the first 48 h after injury, but not on an emergency basis (Table 2).

Thus, it is necessary to emphasize that diaphyseal fractures and some epimetaphyseal fractures of the lower extremities in Moscow in cases where emergency surgery is not possible upon admission are an indication not for skeletal traction but for external fixation with rod devices, including bridge-like ones. In cases where the surgery on the lower limb is planned to be performed only a few hours after admission, immobilization at this time is implemented using external fixation devices, vacuum splints or mattresses, or in extreme cases, plaster casts or plastic adaptive splints, but not with skeletal traction. It is of fundamental importance that the duration of osteosynthesis surgery of fragments of diaphyseal fractures is determined in accordance with the concepts of Early Total Care, Damage Control Orthopedics, or Early Appropriate Care, depending on objective indicators of the severity of the patient's condition. Therefore, for us, it is incomprehensible and surprising that the proportion of the use of external fixation devices in the I.I. Dzhanelidze Research Institute of Emergency Medicine is extremely low in comparison with internal osteosynthesis.

3. On the day of admission, we strive to perform surgeries for fractures of the proximal femur in elderly patients. As shown in Tables 3 and 4, there is an annual increase in the amount of surgeries performed in the first 48 h from the moment of admission.

If the patient's condition is satisfactory, especially if osteosynthesis is possible, we strive to perform the surgery within the next few hours from the moment of admission. Moreover, there is not a single medical organization in Moscow that could not use an electron-optical image intensifier and an orthopedic table 24 h straight.

4. We also include interventions for injuries of the extensor apparatus of the knee and elbow joints, metacarpal bones, and phalanges of the fingers to urgent surgeries within the first hours from the moment of admission, since progressing edema worsens inevitably the results of late interventions, with number also increasing every year (Table 5).

*Table 2*

**Number of emergency and elective osteosynthesis surgeries of the distal radius, performed in Moscow**

| Surgery time | Year | | | | |
|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2020 | 2021 |
| Emergency osteosynthesis | 228 | 287 | 215 | 184 | 189 |
| Elective osteosynthesis | 1237 | 1374 | 2755 | 1349 | 1835 |

*Table 3*

**Distribution of surgeries for proximal femur fractures by time intervals from the moment of admission**

| Year | Osteosynthesis | | | | | Endoprosthetics | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | up to 6 h | 6–12 h | 12–24 h | 24–48 h | > 48 h | up to 6 h | 6–12 h | 12–24 h | 24–48 h | > 48 h |
| 2019 | 224 | 705 | 1310 | 1282 | 960 | 13 | 56 | 321 | 938 | 1446 |
| 2020 | 281 | 530 | 835 | 826 | 569 | 5 | 24 | 250 | 940 | 1310 |
| 2021 | 409 | 588 | 997 | 1093 | 539 | 19 | 89 | 436 | 1097 | 1467 |

*Table 4*

**Proportion of surgeries for proximal femur fractures depending on the timing of surgical treatment, %**

| Year | Osteosynthesis | | Endoprosthetics | |
|---|---|---|---|---|
| | up to 48 h | > 48 h | up to 48 h | > 48 h |
| 2019 | 79.0 | 21.0 | 47.9 | 52.1 |
| 2020 | 81.3 | 18.7 | 48.2 | 51.8 |
| 2021 | 85.2 | 14.8 | 52.8 | 47.2 |

*Table 5*

**Number of emergency surgeries performed for extensor apparatus of the knee, elbow joints, and hand injuries**

| Surgery type | Year | | | |
|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 |
| Olecranon osteosynthesis | 603 | 549 | 513 | 661 |
| Surgeries for injuries of the extensor apparatus of the knee joint: | | | | |
| –Injury of the quadriceps | 59 | 87 | 58 | 73 |
| –Fracture of the patella | 374 | 398 | 333 | 440 |
| –Patella ligament rupture | 62 | 64 | 46 | 53 |
| Surgeries for injuries of the hand tendons | 386 | 668 | 845 | 1860 |
| Osteosynthesis of hand bones | 916 | 1270 | 1257 | 2397 |

Injuries in which internal osteosynthesis surgeries are not recommended for emergency indications (but only external fixation of the segment is allowed) include peri-implant fractures of any location, transacetabular fractures, calcaneal bone fractures, and intra-articular fractures of the elbow joint.

Surgeries, such as osteosynthesis of fragments of the clavicle, ankles, foot bones, distal metaepiphysis of the radial bone, and proximal metaepiphysis of the humerus, are performed according to emergency indications only if there are free operating rooms, teams of anesthesiologists and orthopedic traumatologists, and only at a time sufficiently comfortable for surgeons and anesthesiologists. Indeed, performing these surgeries on an emergency basis reduces significantly the duration of the patient's hospital stay, but the desire to comply with the economic interests of the healthcare system does not always lead to an increase in the quality of care provided at night by a tired surgeon, not to mention the possibility of free choice and selection of hardware in this time of the day. In these cases, we try to prioritize the order of surgeries to elderly patients first. For example, with the simultaneous admission of an elderly patient with a fracture type 32 A, B, and C according to AO-Müller/Orthopaedic Trauma Association classification and a young patient with a multi-fragmentary fracture of the patella, assistance will be provided first to that elderly patient. However, if a young patient with an open fracture of the ankles of type 44-B3 is admitted along with such an elderly patient, priority is given to the patient with a fracture in the ankle joint.

It took decades to create this system, since from our point of view; it is not the number of surgeries that should be evaluated, but their long-term results.

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Editorial
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# Is early fixation of the fracture promising?

## Editorial Comment on the Article by Belenkiy I.G. et al. “Strategies of Osteosynthesis: Problems and Perspectives”

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The commentary discusses the advantages and disadvantages of the model proposed by the authors of the article for performing osteosynthesis for urgent indications within 24 hours after the patient’s admission to the hospital, and also focuses on the need for comprehensive assessment of treatment outcomes and financial costs of the healthcare system. The determination of indications for emergency osteosynthesis and the identification of patients groups depending on the pattern and localization of the fracture are also important issues in justifying the shortening of the time before surgery. It is necessary to justify the priority localization of fractures for urgent fixation based on the analysis of the authors’ own experience and literature data. Changes in the system of emergency trauma care will require a revision of the standards of staffing and financing in the system of compulsory medical insurance. Therefore, the commentary emphasizes the expediency of a preliminary assessment of the new model effectiveness in some medical institutions by comparing it with the traditional system.

**Keywords:** osteosynthesis, urgent trauma care, healthcare organization.

Редакционная статья
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# К вопросу о перспективности экстренного выполнения остеосинтеза

## Редакционный комментарий к статье И.Г. Беленького с соавторами «Стратегия выполнения остеосинтеза: проблемы и перспективы»

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В комментарии обсуждаются преимущества и недостатки предложенной авторами статьи модели выполнения остеосинтеза по неотложным показаниям в течение 24 ч. после поступления пациента в стационар, а также акцентируется внимание на необходимости комплексной оценки исходов лечения и финансовых затрат системы здравоохранения. Определение показаний к неотложному остеосинтезу и выделение групп пациентов в зависимости от характера и локализации перелома также являются важными вопросами при обосновании сокращения сроков операции. Необходимо обосновать приоритетные локализации переломов для неотложной фиксации на основании анализа собственного опыта авторов статьи и данных литературы. Изменение системы оказания экстренной травматологической помощи потребует пересмотра нормативов кадрового обеспечения и финансирования в системе обязательного медицинского страхования. В комментарии подчеркивается целесообразность предварительной оценки эффективности новой модели в некоторых лечебных учреждениях путем сравнения с традиционной действующей системой.

**Ключевые слова:** остеосинтез, неотложная травматологическая помощь, организация здравоохранения.

Improving the organization of medical care for patients with bone fractures is an essential task of our specialty, and the health and working capacity of individuals with injuries depend on this solution. The economic component of the problem and the increase in the incidence of multiple and multisystem injuries, open fractures, and soft tissue injuries determined the need to search for ways to shorten the preoperative period. Improving the methods of assessing the condition of the patients, osteosynthesis technologies, and postoperative rehabilitation determines the

possibility of solving this problem at the modern level without negative consequences on the quality of interventions and treatment results.

The work under discussion focused on determining the advantages and disadvantages of osteosynthesis for urgent indications within 24 h after admission to the hospital. The authors describe the structure of the patient population according to the location of fractures in a medical institution, which is a first-level trauma center, and evaluate the duration of inpatient treatment depending on the timing of osteosynthesis.

The large-scale task set to determine the advantages and disadvantages of existing strategies for performing osteosynthesis is solved only partially and mainly by the analysis of international publications. The absence of re-osteosynthesis cases and early infectious complications during hospitalization of patients who underwent osteosynthesis in the first 24 h characterizes positively the chosen approach of emergency osteosynthesis, but does not take into account the treatment results, frequency of unsatisfactory outcomes, and complications. Determining the advantages and disadvantages of the strategies under consideration implies conducting a comprehensive assessment of treatment outcomes and the financial costs of the healthcare system. The apparent reduction in the hospitalization stay of patients with osteosynthesis upon admission is not necessarily accompanied by a decrease in financial costs, as it requires expenses associated with the involvement of qualified personnel at night, postponing elective surgeries scheduled for the next day, or use of additional equipment in the operating room. The measures necessary for the organization of emergency osteosynthesis require an economic justification. In addition, it may not be possible to allocate an additional operating room for emergency osteosynthesis in hospitals designed more than 30 years ago, which complicates the extrapolation of successful international experience under conditions in Russia.

The determination of indications for emergency osteosynthesis and the selection of patients depending on the nature and location of the fracture are important issues in justifying the reduction of surgery time. A more detailed analysis of our experience and literature on the study of complications and outcomes of osteosynthesis of various segments of the musculoskeletal system, performed at different times after injury, would justify the choice of priority fracture locations for emergency fixation. Moreover, it is necessary to determine the degree of subspecialization and education requirements of surgeons providing emergency and urgent trauma care, including those at night, and to evaluate the feasibility of the centralization of emergency trauma care and in-depth specialization of employees involved.

Since the organization of the emergency trauma care system will require a revision of the staffing and financing standards in the compulsory medical insurance system, it is advisable to evaluate first its efficiency, including the economic one, on the model of a medical institution by comparison with the traditional current system.

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Case Report
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# Reccurence of Heterotopic Ossification as the Result of Total Hip Endoprosthesis Dislocation: A Case Report

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***Background.*** Heterotopic ossification (HO) is the formation of mature bone in soft tissues. HO in the hip area can be a consequence of both injury to the nervous system and local trauma. After total hip arthroplasty HO develops in 30% of cases.

***The aim of the study*** is to demonstrate a rare clinical case of a recurrence of HO in patient after a primary total hip arthroplasty, accompanied by ankylosing.

***Case presentation.*** A 32-year-old patient was admitted to the clinic for revision hip arthroplasty with a diagnosis «long-standing dislocation of the right hip joint endoprosthesis head, heterotopic ossification» 3 years after dislocation. During the surgery, there were difficulties with the sciatic nerve dissection, as well as the structures of the endoprosthesis. We removed all the ossifications that obstructed the dislocation of the endoprosthesis. The patient had sciatic nerve neuropathy on the right lower limb with lesions of the fibular and tibial nerves on the background of edema. The patient was discharged on the 21st day. The presented clinical case is interesting because the patient's relapse could be caused by a combination of various risk factors. Taking into account the fact that the injury was received as a result of an accident and the patient had a fracture of the bones of the contralateral shin, it could be the effect of a local hip injury that aggravated the process.

***Conclusions.*** This clinical observation highlights the importance of preventing possible complications after surgery and maintaining feedback with patients, especially those belonging to the high-risk group. It is likely that with adequate prevention of the HO formation and timely reduction of dislocation, the problems described in the article after primary total hip arthroplasty could have been avoided.

**Keywords:** heterotopic ossification, hip arthroplasty, endoprosthesis dislocation.

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# Рецидив гетеротопической оссификации в результате вывиха эндопротеза тазобедренного сустава: клинический случай

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***Актуальность.*** Гетеротопическая оссификация (ГО) — это формирование зрелой кости в мягких тканях. ГО в области тазобедренного сустава может быть следствием как повреждения нервной системы, так и локальной травмы. После тотального эндопротезирования тазобедренного сустава ГО развивается в 30% наблюдений.

***Целью*** публикации является демонстрация редкого клинического наблюдения пациента с рецидивом ГО после сложного первичного эндопротезирования тазобедренного сустава, сопровождающимся анкилозированием.

***Описание случая.*** Пациент 32 лет поступил в клинику для ревизионного эндопротезирования тазобедренного сустава с диагнозом «застарелый вывих головки эндопротеза правого тазобедренного сустава, гетеротопическая оссификация» спустя 3 года после вывиха. Во время операции были сложности с выделением седалищного нерва, а также структур эндопротеза. Нами были удалены все оссификаты, которые препятствовали вывиху эндопротеза. У пациента наблюдалась невропатия седалищного нерва справа с поражением малоберцового и большеберцового нервов на фоне отека. Пациент был выписан на 21-й день. Представленный клинический случай интересен тем, что у пациента рецидив ГО мог быть обусловлен комбинацией различных факторов риска. С учетом того, что травма была получена в результате ДТП и у пациента имелся перелом костей контралатеральной голени, нельзя исключить эффект местной травмы тазобедренного сустава, усугубившей процесс.

***Заключение.*** Данное клиническое наблюдение подчеркивает важность профилактики вероятных осложнений после операции и поддержания обратной связи с пациентами, особенно относящимися к группе высокого риска. Вполне вероятно, что при адекватной профилактике формирования ГО и своевременном вправлении вывиха описанных в статье проблем после первичного эндопротезирования удалось бы избежать.

**Ключевые слова:** гетеротопическая оссификация, эндопротезирование, вывих эндопротеза.

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## BACKGROUND

Heterotopic ossification (HO) is defined as the formation of mature lamellar bone in soft tissues, usually between the muscles and the joint capsule [1]. Neurogenic HO occurs following trauma to the brain and/or spinal cord. Specifically, after a craniocerebral injury, the appearance of foci of ectopic bone formation in areas around large joints is recorded in 10–23% of cases and in 40–50% of cases after spinal cord injury. This pathological condition is detected in men 2.5 times more often than in women [2]. HO in the area of the hip joint can result from damage to the nervous system and local trauma [3, 4].

From 1980 to 1990, the incidence of HO reached 80%. Studies have reported the need for prophylactic treatment in the postoperative period with nonsteroidal anti-inflammatory drugs (NSAIDs) [5, 6].

The anatomical and morphological classification of HO, proposed by Brooker et al. [7], is the most popular in the world:

Class 1 implies islets of bone in the soft tissues around the thigh.

Class 2 implies bone spurs originating from the pelvis or proximal femur, with at least 1 cm between opposite surfaces of the bones.

Class 3 implies bone spurs originating from the pelvis or proximal femur, reducing the distance between opposite surfaces of the bone to less than 1 cm.

Class 4 implies obvious ankylosis of the hip bones.

The case described herein belongs to class 4 according to this classification.

*This study aimed* to demonstrate a rare clinical case of a patient with recurrent HO following complex primary hip arthroplasty, accompanied by ankylosis.

## Case report

A 32-year-old man (weight, 76 kg; height, 176 cm; BMI, 24) was admitted to the clinic in March 2021 for a scheduled surgical treatment and complaints of recurrent pain in the right hip joint, lameness, and severely limited joint range of motion.

The anamnesis revealed that in 2008, the patient sustained multiple injuries during a traffic accident, namely, an open fracture of both bones of the left lower leg and an open craniocerebral injury. At the primary healthcare facility, cranial trepanation, primary surgical treatment of the left leg wound, plaster casting of the fracture were performed. The patient was in a coma for 1 month. After regaining consciousness, the patient demonstrated limited mobility in the right hip joint and a general decrease in sensitivity according to the hemitype in the right half of the body. Within 10 years, the pain syndrome and limited range of motion in the right hip joint progressed. Figure 1a presents a radiograph of the right hip joint, performed in 2018, in a state of ankylosis in presence of HO.

In August 2018, the patient underwent total right hip arthroplasty (Zimmer Trilogy IT/CLS-Spotorno), with a sliding pairing of metal-crosslink polyethylene, head 36/–3 mm) (Fig. 1b).

The patient was discharged from the clinic without complications, but within 10 days after the intervention, when sitting down on a bench, he noted a painful displacement in the joint area, which led to the impaired support ability of the extremity. The patient did not seek medical help and continued to walk with elbow crutches. Later, in a scheduled follow-up, he visited a traumatologist-orthopedist at the primary healthcare facility where a long-standing dislocation of the endoprosthesis head was detected, and revision arthroplasty was recommended.

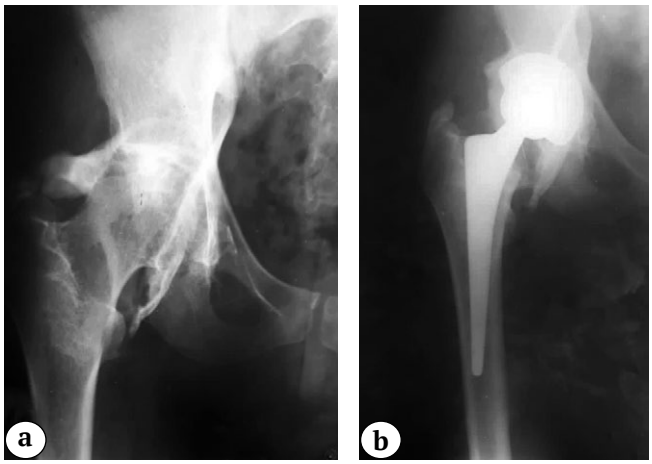


**Fig. 1.** X-rays of the right hip joint: a — before the first total hip arthroplasty; b — after surgery

In March 2021, the patient was admitted to the clinic of the Vreden Center of Traumatology and Orthopedics. Upon admission, the patient walked using a one-elbow crutch and had severe lameness on the right lower limb. Movements in the right hip joint were minimal (reciprocating) and painless; the right hip was in a fixed external rotation of approximately 35°. The relative shortening of the right lower limb was 2.5 cm, and the axial load was not painful. The right hip function scored 27 of 48 points according to the Oxford Hip Score (OHS). The patient also noted a gradual decrease in the sensitivity of the skin of the right lower limb in comparison with the opposite side during the last 6 months. Before the surgery, a neurologist in the hospital diagnosed the patient with post-traumatic encephalopathy, which was a consequence of a polytrauma from 2008, craniotomy without convulsive readiness, right-sided moderate hemiparesis, and more severe states of the lower limb. The patient's expectations from surgical treatment corresponded to 43 points according to the hip replacement expectation survey.

Additional clinical examination based on radiographs revealed dislocation of the endoprosthesis head with the formation of a bone bed of heterotopic ossificates at the anterosuperior edge of the acetabular component, and no signs of loosening of the components were noted (Fig. 2).

According to computed tomography (CT), the acetabular component orientation was 47° of the frontal inclination and 20° of anteversion, the femoral component anteversion was 54°, and the combined version of the components was 101°.

After ruling out the infectious process, the patient underwent re-endoprosthetics. During the access, the femoral abduction apparatus was moderately thinned, with signs of partial cicatricial degeneration of the musculus gluteus medius, but without significant defects. A combination of transgluteal and posterior approaches was used to resect the heterotopic ossificates. When performing a transgluteal approach, a bone bed was exposed around the endoprosthesis head located at the anterior–superior edge of the acetabulum. The bone bed was opened to mobilize the endoprosthesis head (Fig. 3 a,b). Then, through the posterior approach, the ossificates protruding above the posterior edge of the acetabulum and in the area of the sciatic nerve were visualized (Fig. 3c).

The sciatic nerve was also ossified. Resection of the ossificates around the nerve, extended release of the proximal femur, and resection of heterotopic ossificates capable of causing bone-to-bone or component-to-bone impingement were performed.

After the detection of the cavity edges, the anti-luxation visor of the liner was oriented posteriorly, despite the excessive combined anteversion of the components. The initial plan of the surgery included the implantation of a dual-mobility component in a well-fixed cup using bone cement; however, this approach was discarded due to the excessive tension on the soft tissues, which caused difficulties in repositioning the 36-mm provisional heads. After the implantation of a new Zimmer Continuum Longevity liner into the cup-locking mechanism with anti-luxation visor orientation anterosuperiorly and implantation of the Zimmer VerSys 36/+0 mm head (next size compared with the removed head), a sufficient joint range of


**Fig. 2.** X-ray of the pelvis at admission: dislocation of the endoprosthesis head the with the formation of a bone bed of heterotopic ossifications at the anterosuperior edge of the acetabulum component, no signs of loosening of the endoprosthesis components

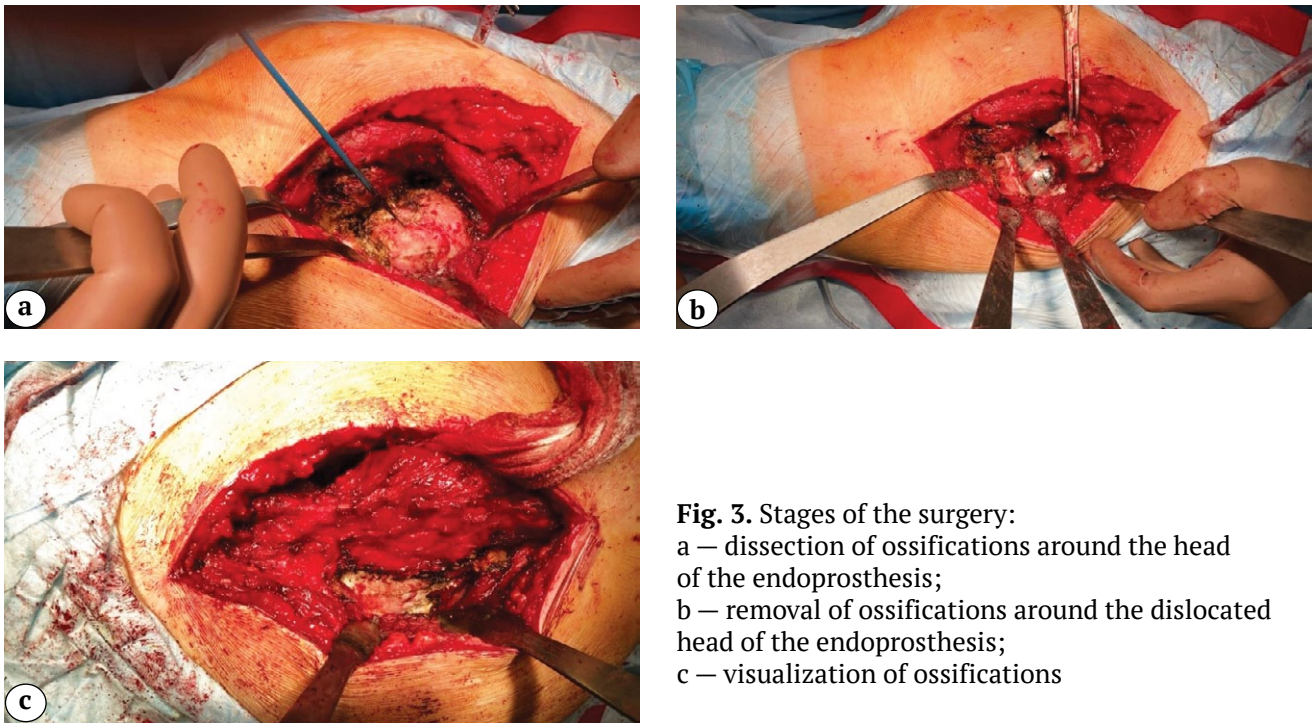

**Fig. 3.** Stages of the surgery:
a — dissection of ossifications around the head of the endoprosthesis;
b — removal of ossifications around the dislocated head of the endoprosthesis;
c — visualization of ossifications

motion was obtained before impingement. Hip joint flexion was achieved at 60°, and the patient retained the soft tissue component of the contracture. Dislocation of the endoprosthesis after reduction was not observed (Fig. 4). The intervention duration was 4 h and 5 min, and the intraoperative blood loss was 700 ml.

After the surgery, the patient noted the absence of the active dorsiflexion of the right foot and impaired sensation along the anterolateral surface of the thigh. According to the neurologist, there was neuropathy of the sciatic nerve on the right foot and damage to the peroneal nerve and tibial nerve associated with edema. The patient received drug therapy and physiotherapy (myorhythm stimulation and magnetotherapy). During the hospitalization, an improvement was achieved in the form of paresthesias in the right foot. The patient was verticalized on day 2 after surgery.

**Fig. 4.** X-ray of the pelvis after revision surgery

The postoperative wound healed by primary intention. The patient was discharged for outpatient treatment on day 21 with recommendations to measure the load on the operated limb and to use crutches for 6 weeks and then for up to 6 months with the help of a cane. Antibiotic prophylaxis and thromboprophylaxis were performed according to local protocols. As a medical prevention of HO, the patient received celecoxib 200 mg orally two times a day from the day of surgery for 4 weeks.

After 5 months, the patient was interviewed remotely. The OHS functional status of the joint was assessed as 39 of 48 points. Over the past period, the patient had an unexpressed improvement in the state of the sciatic nerve, and active dorsiflexion of the foot is possible to a limited extent. The patient is generally satisfied with the treatment; at the time of the survey, he walked without additional support and did not experience significant difficulties in walking and taking care of himself.

## DISCUSSION

In patients with a history of spinal cord injury, HO usually develops distal to the injury level, most commonly around the hip joint. HO in small joints is rare [8]. Patients with cognitive impairment, tracheostomy, pneumonia, and/or urinary tract infections are at higher risk of HO [9].

The clinical presentation of HO in the initial stages is nonspecific. Many HO cases are asymptomatic, and patients may complain of inflammation, including pain, edema, erythema, and fever, and limited joint range of motion, which appears at any time, for a period of 3–12 weeks, after the triggering event; and in the future, ankylosis of the joint may form [10, 11].

Radiation studies, mainly radiography and CT, are the gold standard for diagnosing HO [12]. However, their disadvantage is the inability to detect calcifications earlier than 6 weeks after a triggering injury [8]. Clinicians often perform standard radiography followed by a tree-phase bone scan to confirm the diagnosis of HO and establish the extent and metabolic activity of this ossifying lesion. A three-phase bone scintigraphy is the most sensitive method for detecting HO, and diagnostics is already possible 2.5 weeks after the injury [8, 13]. The method is also effective for monitoring the progression of HO and determining the appropriate time for surgical intervention. Bone activity during scanning usually reaches its maximum several months after the triggering event and returns to baseline after 12 months. Differential diagnostics of HO implies ruling out of conditions such as tumor calcification, osteosarcoma, or dystrophic calcification [10].

Two main approaches are recommended to the treatment of HO in the hip area: isolated resection of ossifications and resection in combination with arthroplasty. The choice of a method depends on the location and size of the ossifications and extent of joint damage. Most often, the treatment approach is determined intraoperatively. If possible, resection of ossificates is performed. If the main sources of blood supply to the femoral head are affected, total hip arthroplasty is performed [14].

When choosing resection, the technique differs from oncological one, as only ossificates that cause limitation of mobility and compression of blood vessels or nerves should be removed. Exhaustive resection may increase the risk of recurrence and injury rate of the surgery. Arthroplasty is highly effective; however, even for experienced surgeons, these patients require experience, knowledge of the pathology characteristics, possibilities of additional diagnostics and technical support for surgeries, and an individualized program of rehabilitation and relapse prevention.

The presented clinical case is interesting in that the HO recurrence could be due to a combination of various risk factors. Moreover, considering the injury was sustained following a road traffic incident and the patient had a fracture of the contralateral tibia, the effect of a local injury of the hip joint, which aggravated the process, cannot be excluded. Total hip arthroplasty performed on the patient in 2018 was also associated with a high risk of HO recurrence. The incidence of HO after hip arthroplasty according to the literature is 30% [3]. However, circumstances such as joint ankylosis and history of HO are considered high risk factors for the formation of ossificates [18]. In addition, in the early postoperative period, the patient had a dislocation of the endoprosthesis head, which in itself is a significant injury and is accompanied by hematoma formation. Finally, according to the patient, no HO prophylaxis was performed at that moment, despite the high risk of its formation. On the contrary, the formation of a supporting bone bed around the endoprosthesis head allowed the patient to walk with a load on the operated limb in the presence of dislocation. As for the development of the endoprosthesis head dislocation, the patient also belonged to the high risk group because of nervous system pathology.

Notably, primary arthroplasty was performed for the hip joint ankylosis that existed for 10 years. In this situation, the risk of joint instability increases due to inadequate tension of the soft tissues and dysfunction of the abductor apparatus of the thigh, which is the main soft tissue stabilizer [15].

To prevent dislocations during primary arthroplasty, two of the available options for mechanical stabilization were used, namely, a large-diameter sliding pair (36 mm) and an insert with an anti-luxation roller. However, the posterior orientation of the anti-luxation ridge, despite

the achieved excessive combined anteversion of the components (i.e., in the zone of potential impingement of the neck-liner), indicates technical difficulties in arthroplasty, specifically a disorientation of the acetabular component in presence of HO along the acetabulum perimeter. At the time of re-endoprosthetics, the priority tasks were the prevention of HO recurrence and relapse of instability. Initially, we did not aim to remove all ossificates; however, to achieve joint mobility, almost everything had to be excised.

For HO prevention, localized radiation therapy is generally used [11], as well as drug therapy using corticosteroids (prednisone and dexamethasone) and NSAIDs (aspirin, indomethacin, a specific COX-2 inhibitor, and celecoxib). Bisphosphonates are often the drug of choice in the later stages of HO, when dense bone formation has already started [16]. In this case, celecoxib was prescribed to the patient, as it has similar efficacy to indomethacin with less side effects during the long-term intake [17]. Further, in the hospital stage, joint punctures were repeatedly performed to evacuate the hematoma.

Regarding joint stability, re-arthroplasty for dislocations is associated with a high risk of recurrence if the components, particularly the acetabular component, are preserved [18]. In the presented case, an attempt to revise the acetabular or femoral component would be associated with a greater injury rate of the intervention, which would aggravate the risk of HO recurrence and introduce additional risks of loosening the newly installed components. The installation of a dual-mobility cup using the cement technique in a well-fixed acetabular component is described as an effective technique that not only prevents dislocation due to the diameter of the sliding pair but also changes partially the mutual arrangement of the components [19, 20]. However, in the present case, tissue tension after bringing the hip down did not allow the reduction of a large-diameter system, and additional releases would be associated with the risk of detachment of key structures and the formation of an even larger cavity filled with hematoma. On the contrary, the limitation of the joint range of motion due to the soft tissue component of the contracture prevented the patient from performing dangerous movements until the formation of a dense pseudocapsule, which could lead to dislocation.

## CONCLUSIONS

This clinical case emphasizes the importance of preventing possible complications of surgery and maintaining feedback with patients, especially those in the high risk group. Adequate prevention of HO formation and timely reduction of the dislocation could avoid the aforementioned problems after primary arthroplasty.

## 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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***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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Case Report
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# Successful Prosthetics for Traumatic Femoral Vascular Injury: A Case Report

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***Background.*** Injury to the main vessels is often accompanied by life-threatening bleeding, permanent disability or death. In the modern literature, only isolated cases of reconstructive surgery for major vein injury are described, their long-term results are insufficiently studied, there is little information about the introduction of telemedicine technologies into the practice of emergency angiosurgical care.
***The aim of the study*** is to demonstrate the immediate and long-term results of the joint work of trauma surgeons and angiosurgeons in helping a patient with injury to the main femoral vessels.
***Case presentation.*** The results of treatment of the patient with the diagnosis: laceration of the upper third of the right thigh with rupture of the common femoral vein and superficial femoral artery and the development of threatening ischemia of the right lower limb; severe blood loss; hemorrhagic shock IV; severity of injury: VPH SP 33; MESS 7. Treatment of the patient took place in several stages. At the first of them, hemostasis was performed, the hemorrhagic shock was resolved. Further, the patient was consulted by an angiosurgeon through telecommunication technologies, after which it was decided to include an angiosurgeon in the surgical team. The prosthetics of femoral vessels was performed: the main venous and arterial blood flow was restored in the affected limb. The patient was discharged in a satisfactory condition with no signs of thrombosis.
***Conclusions.*** Compliance with consistent actions in helping a patient with a vascular injury prevents the development of a «deadly triad» and a fatal outcome. The use of telemedicine consultations provides the angiosurgeon with the opportunity to remotely assess the clinical picture, the severity of the injury, discuss the sequence and volume of necessary medical care at the place of primary hospitalization. Performing reconstructive surgeries using various types of grafts allows you to restore the main blood flow through damaged vessels with good immediate and long-term results.

**Keywords:** vascular injury, artery and vein trauma, thigh laceration, specialized care, telemedicine consultation.

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# Успешное протезирование при травматическом повреждении бедренных сосудов: клинический случай

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***Актуальность.*** Повреждение магистральных сосудов нередко сопровождается жизнеугрожающим кровотечением, стойкой утратой трудоспособности или летальным исходом. В современной литературе описаны лишь единичные случаи реконструктивных вмешательств при травме магистральных вен, недостаточно изучены их отдаленные результаты, мало информации о внедрении телемедицинских технологий в практику неотложной ангиохирургической помощи.

***Описание случая.*** Представлены результаты оказания ангиохирургической помощи пострадавшему с диагнозом: рваная рана верхней трети правого бедра с разрывом общей бедренной вены и поверхностной бедренной артерии, развитие угрожающей ишемии правой нижней конечности; кровопотеря тяжелой степени; геморрагический шок IV степени. Тяжесть травмы: ВПХ СП 33; MESS 7. Оказание помощи пострадавшему проходило в несколько этапов. На первом этапе была выполнена остановка кровотечения, пациент выведен из геморрагического шока. Затем была проведена телемедицинская консультация, после чего было принято решение о включении в бригаду ангиохирурга. Была выполнена реконструктивная операция – протезирование бедренных сосудов. В пострадавшей конечности восстановлен магистральный венозный и артериальный кровоток. Пациент в удовлетворительном состоянии был выписан без признаков тромбоза.

***Заключение.*** Соблюдение последовательных действий при оказании помощи пациенту с травмой сосудов позволяет не допустить развитие «смертельной триады» и фатального исхода. Применение телемедицинских консультаций предоставляет ангиохирургу возможность дистанционно оценить клиническую картину, тяжесть повреждения, обсудить последовательность и объем необходимой медицинской помощи по месту первичной госпитализации. Выполнение реконструктивных операций с использованием различных видов трансплантатов позволяет восстановить магистральный кровоток по поврежденным сосудам с хорошими ближайшим и отдаленным результатами.

**Ключевые слова:** повреждение сосудов, травма магистральных сосудов, рваная рана бедра, специализированная помощь, телемедицинские консультации.

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## BACKGROUND

According to the literature, the incidence of open traumatic vascular injuries ranges from 2.0% to 25.5% [1, 2, 3, 4]. According to Quan et al., they are caused by injuries in 95% of cases [5]. Szaniewski et al. noted an increase in the incidence of damage to the main vessels due to the impact of firearms, sharp and piercing objects, and traffic accidents [4]. Injuries resulting from occupational accidents are considered important among the causes of injury. Annually, 340 million such accidents of varying severity are recorded worldwide, and the mortality rate is 2.3 million people per year [6].

Damage to two or more great vessels is accompanied by massive bleeding, often leading to the development of refractory hemorrhagic shock, lethal outcomes, and amputation due to the development of irreversible limb ischemia [5, 7, 8].

Until now, the question of the expediency of restoring the main venous blood flow, especially with massive severe injuries, remains unresolved. The lateral suture of the vessel is the main type of surgery for vein injuries in 90% of cases [8, 9]. Total damage to a vein requires a reconstructive intervention, and the absence of the necessary graft sometimes ends with ligation.

The modern literature describes isolated cases of reconstructive interventions for injuries of the major veins, their long-term results are insufficiently studied, and there is little information on the introduction of telemedicine technologies into the practice of emergency angiosurgical care.

Herein, we present a rare clinical case of the formation of an autovenous conduit for prosthetics of a damaged vein.

## CLINICAL CASE

A 56-year-old patient was transferred to the trauma department of the Central City Clinical Hospital No. 24 in Yekaterinburg by an ambulance team on 04/09/2020 in a terminal condition due to stage IV hemorrhagic shock according to the Advanced Trauma Life Support classification. Forty minutes before admission, during the installation of a metal constructional timber, the patient received a blow with the end of an iron beam (weighing 30 kg) on the upper third of the right thigh, followed by loss of consciousness. At the pre-hospital stage, a tight pressure aseptic bandage was applied to the patient in the wound area, anesthesia was performed with narcotic analgesics, and an infusion of crystalloids and colloids was started with the administration of direct-acting adrenomimetics (norepinephrine) at a rate of 1 μg/kg/min. The total volume of infusion therapy by the ambulance team was 1000 mL.

During the physical examination in the admission department of a trauma hospital, the level of consciousness on the Glasgow scale was estimated at 10 points (sopor). The skin was pale, breathing was spontaneous, and the respiratory rate was 28 per minute. Hemodynamic parameters were unstable, with a pulse of 90–120 beats/min and blood pressure of 40/0 mm Hg. In the upper third of the right thigh, in the projection of the neurovascular bundle, there was a lacerated wound sized 30×20 mm with signs of continuing bleeding, and the blood loss volume was 2500 mL (Fig. 1). The right lower limb was cyanotic and cooler than the left one. Pulsation was not detected distal to the wound, and there was no contracture in the ankle joint.

**Fig. 1.** Wound with ongoing venous bleeding

Indicators of the general blood test showed hemoglobin of 78 g/L, erythrocytes of 2.6×1012/L, and hematocrit of 19%. Given the severity of the condition due to continuing bleeding, the patient was transported immediately to the operating room. The trauma team performed a revision of the femoral vessels under endotracheal anesthesia and revealed a rupture of the vascular bundle of the right inguinal region. Bleeding was stopped by applying hemostatic clamps to the proximal and distal ends of the vessels (Fig. 2).

Intensive therapy was continued with 1500 mL of crystalloids, 705 mL of erythrocyte suspension, and 400 mL of fresh frozen plasma. The vascu-

lar surgeon on duty at the Territorial Center for Disaster Medicine consulted the patient via a secure videoconferencing channel with a further decision on the urgent inclusion of a vascular surgeon in the operating team. At the time of the arrival of the vascular surgeon (1.5 h from the moment of injury), the patient's condition was stabilized, blood pressure was 110–130/90 mm Hg with minimal doses of vasopressor support, the HR was 80–90 bpm, and anuria resolved. Ischemia of the right lower limb was assessed as threatening, the skin of the right lower limb remained pale, the foot and lower leg were hypothermic, and the saphenous veins were empty, but there was no contracture. Specialized care was started for the patient. After the excision and mobilization of the ends of the damaged vessels, diastasis was determined for 5 cm between the arterial ends and 4 cm between the venous ends.

To restore the main arterial blood flow and to arrest acute ischemia of the injured limb, replacement of the superficial femoral artery was performed first, followed by the replacement of the common femoral vein. During the revision of the great saphenous vein on the left thigh, its small diameter was revealed; therefore, a blood vessel prosthesis was used. The defect of the superficial femoral artery was replaced with a polytetrafluoroethylene explant with end-to-end anastomoses. The main pulsatile blood flow was restored at all levels of the injured limb. To form an autovenous conduit of the common femoral vein of a suitable diameter, two parts of the great saphenous vein of the contralateral limb were used, which were collected over a distance of 12 cm. Subsequently, both sections of the great saphenous vein were dissected longitudinally and then, without reversion, sutured together on a 5-mL syringe barrel (Fig. 3).

Then, the graft was hydraulically dilated, and end-to-end anastomoses were formed with the common femoral vein (Fig. 4).

By the end of the surgical treatment, the ischemia of the right lower limb regressed, without impairments in arterial and venous hemodynamics. The time of ischemia of the injured limb from the moment of injury to the complete restoration of blood flow was 3.5 h. During the surgery, the total volumes of transfusion of erythrocyte suspension, fresh frozen plasma, and crystalloids were 2081 mL, 1010 mL, and 1750 mL, respectively.

In the postoperative period, in addition to infusion therapy, compression therapy was performed, therapeutic doses of anticoagulants were used, and antibacterial prophylaxis was also conducted.

On postoperative day 10, against the symptoms of infection of the postoperative wound of the left thigh, a phlegmon occurred accompanied by febrile hyperthermia, bright hyperemia of the wound edges of the left inguinal region with propagation to the womb area, and serous purulent discharge. In the general blood test, leukocytes reached the level of 15.0×109/L. The wound on the right thigh remained without signs of inflammation. The patient was transferred from the traumatological hospital to the department

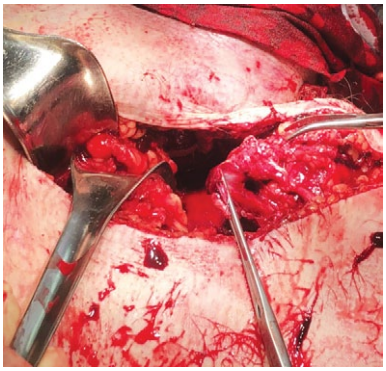

**Fig. 2.** Revision of the wound and stopping the bleeding

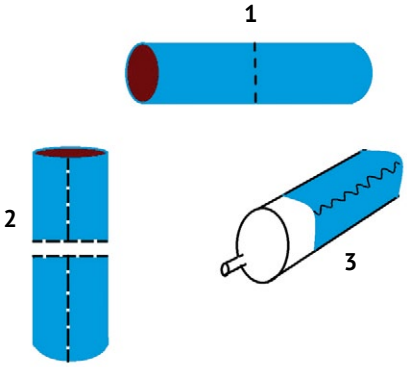


**Fig. 3.** Stages of an autovenous graft formation from a great saphenous vein:
1 — division of great saphenous vein into two fragments;
2 — dissection of two fragments of great saphenous vein along;
3 — formation of a venous conduit on a syringe cylinder

of purulent surgery. The left thigh wound was successfully drained, and a pus leak was opened in the womb region.

Bacteriological studies of the wound discharge revealed the growth of gram-negative flora with Klebsiella pneumoniae and Proteus mirabilis. Taking into account the sensitivity of microorganisms, antibiotic therapy with a broad-spectrum drug Amoxiclav 1200 mg given three times a day intravenously was continued.

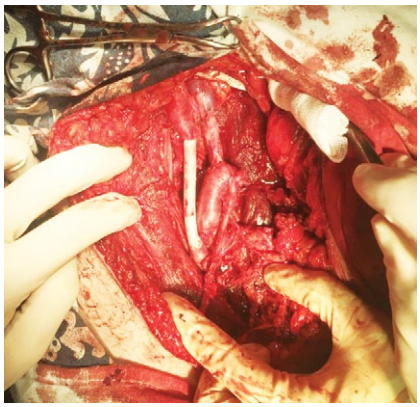

**Fig. 4.** Prosthetics of the common femoral vein with the formed autovenous conduit and the superficial femoral artery with an explant

After another 10 days, the patient was discharged in a satisfactory condition; the left thigh wound healed with secondary intention, without suturing. The right thigh wound remained without signs of infection; according to clinical and ultrasound data, the main arterial and venous blood flow was preserved. At the outpatient stage, a regimen of elastic limb compression and intake of therapeutic doses of direct anticoagulant rivaroxaban 20 mg once a day was recommended. The patient was examined by a vascular surgeon after 3, 6, and 12 months.

Three months after the discharge, the rivaroxaban dose was reduced to 10 mg/day, and after 6 months, the drug was discontinued; low doses of acetylsalicylic acid (50 mg/day) were prescribed. Data from repeated clinical examinations and control ultrasound studies demonstrated the preservation of the main blood flow through the damaged vessels (Fig. 5).

No recurrences of the infectious process were registered. The patient gained full recovery of the ability to work.

## DISCUSSION

The results of treatment of combined injuries of arteries and veins are not often discussed in modern literature. Thus, in PubMed, from 2016 to 2022, we found only eight publications on this subject. The keywords used for the search were *combined injury veins, arteries; injury veins and arteries extremities; autovenous graft, telemedicine* [8, 9, 10, 11, 12, 13, 14, 15].

The principles of care for patients with vein and artery injuries have been developed and improved over the centuries. Until the 1960s and 1970s, the main type of surgical intervention was ligation of the vessel, especially in the case of damage to the venous vessel. On this occasion,

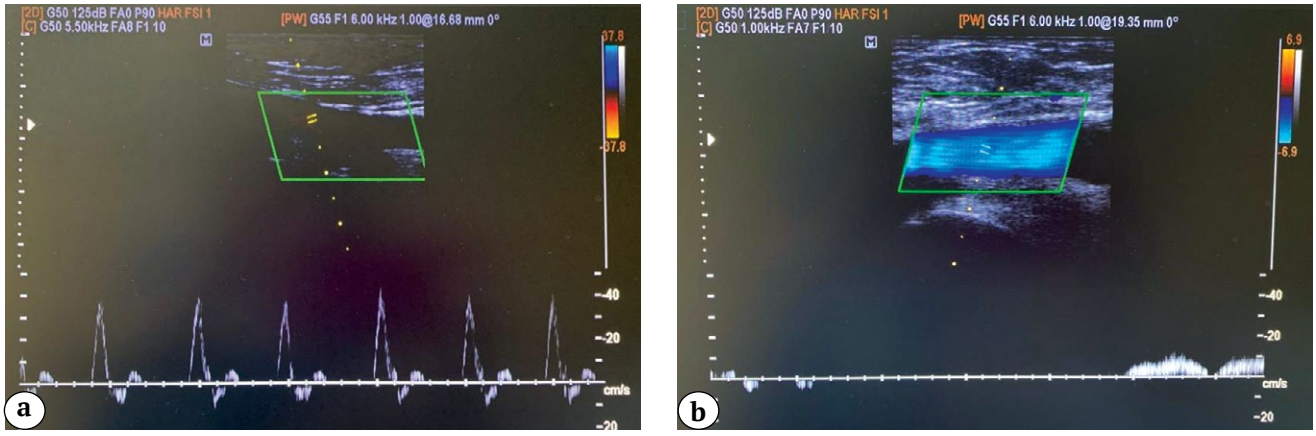


**Fig. 5.** Ultrasound duplex scanning (control study after 12 months):
a — superficial femoral artery; b — common femoral vein

N.I. Pirogov wrote during the Crimean War: "The wounded after ligation of major vessels mostly die." The famous surgeon himself had the greatest experience in such surgeries, performing more than 80 of them, while 46% of patients recovered [16].

For a long time, such an approach was considered appropriate in military field surgery. Thus, the frequency of ligature surgeries during World War II reached 97.5% of cases, and the proportion of amputations exceeded 40% [17, 18, 19]. Evidence also presents that not only ligation of arteries can lead to impaired limb viability, but also ligation of large main veins can cause the development of ischemic venous thrombosis [1]. Vein ligation still accounts for a high proportion of cases and reaches 57%, and the lateral suture prevails in the range of restorative surgeries [8].

To date, arterial prosthesis techniques have been developed and are widely used in practice. An autovein is the optimal plastic material for restoring the integrity of the main vessels, especially in the initial microbial contamination of the wound at a young age. The use of the great and small saphenous veins of the lower extremities, as well as the cephalic and main veins of the upper extremities as an autograft, has been described [1, 4, 7]. Vascular prostheses can be used in the case of damage to the aorta or the absence of an autovein of the required diameter in cases of injury to other vessels.

Severe trauma is not a simple clinical situation, and standard solutions are often not suitable for it. Many factors depend on the surgeon's experience. The variant of the main vein replacement with an autograft we presented was first described in 1952 by Hurwitt and Kantarowitz [20]. In 1979, Vedensky studied in detail the technical aspects of this and other techniques of reconstructive vein surgery. The author also noted several disadvantages, namely, the surgery duration and the need for the application a longitudinal suture, explaining the rare practical use of the described technique in injury [21].

Unfortunately, the desire to restore only the main arterial blood flow, without taking into account the role of the venous system in limb hemodynamics, does not always lead to the desired result. Thus, cases of the development of phlegmasia cerulea during ligation of the main veins were described. Al-Ganadi pointed out the important role of the restoration of major damaged venous trunks of the extremities in trauma. The author performed such interventions in 77% of cases with combined damage to veins and arteries, reaching a frequency of limb amputations of no more than 5% [1]. The time of limb ischemia is also significant in the restoration of the main arterial blood flow; a period of 6-8 h from the moment of injury is considered critical, while no data in the literature provide the acceptable period for the restoration of venous vessels [7, 8, 22, 23]. In our patient, the time from the moment of injury to the restoration of arterial and venous blood flow was 3.5 h. The absence of venous thromboembolic complications during the intake of therapeutic doses of anticoagulants helped avoid post-thrombotic disease in the future.

Continuing bleeding and unstable hemodynamics are indicative of damage to the main vessel and significant blood loss, which can lead to the deadly triad [7].

The current principles of injury surgery are formulated in the concept of "damage control," which is the control of bleeding, intensive therapy of life-threatening conditions, normalization and stabilization of the physiological parameters of the patient, and provision of specialized surgical intervention. In the case of vessel injury, this concept can be implemented, including using temporary prosthetics for the main vessels [7, 24, 25].

In the clinical case presented, a set of measures aimed at arresting the hemorrhage and quick resolving of hemorrhagic shock enabled the prevention of a lethal outcome. Soft vascular clamps were used during the surgical treatment of the wound. Temporary shunts were not used in this case because of the possibility of performing reconstructive surgery in a trauma hospital. Feliciano noted that with the correct provision of primary care, timely hospitalization of the patient in a specialized trauma hospital, and performing all the possibilities of contemporary surgery, anesthesiology, and intensive care, the number of amputations for vascular injury in peacetime does not exceed 7.8% [19].

Diagnostics of vascular injury is based on the patient's complaints, anamnesis data, physical examination, and various instrumental research methods. Computed angiography is recognized as the gold standard for examining an individual with wounds [7, 22, 23]. In the terminal state of the patient, every second counts, the level, lo-

cation, and nature of the damage should be assessed intraoperatively.

In the Sverdlovsk Region, vascular surgeons from the Territorial Center for Disaster Medicine are involved in assisting patients in trauma hospitals in the case of damage to the main vessels. In the period from 2015 to 2020, in cooperation with traumatologists, 240 surgical interventions were performed in patients with main vessel injuries. Since 2020, remote consultations using telemedicine technologies have been introduced into the practical activities of the angiosurgical service. The use of imaging techniques in emergencies enables the collection of the most complete amount of information, assessment of the real condition of the patient, discussion of the technical capabilities of the medical institution, and decision on the need and timing of high-tech intervention. The evolvement of videoconferencing allows for initial consultations, postoperative examinations, case follow-up, and advising of the operating team by highly specialized doctors. Telemedicine consultations are widely used in abdominal and endocrine surgery, traumatology, and urological practice [26]. However, the available literature provides no information on the use of telemedicine consultations in the treatment of patients with great vessel injuries.

Any purulent complication is naturally a cause for concern for doctors due to the risk of thrombosis, arrosive bleeding, and generalization of the infectious process. Mortality in the event of the development of such complications can reach 60% [25]. The developed suppuration of the postoperative wound of the left thigh after the autovenous graft sampling was diagnosed on day 10. The focus was drained, and the patient was treated with a broad-spectrum antibacterial drug, taking into account the microflora sensitivity.

The clinical case presented once again demonstrates that quality medical care for a patient with main vessel injury is important at every stage of treatment, namely, at the injury site, stage of transportation, and hospital stage. Adequate primary surgical treatment of the wound; activities of the competent anesthetic team; use of standard and nonstandard methods of prosthetics of the main vessels; prevention, timely diagnostics, and treatment of complications; and the patient's adherence to the treatment prescribed enable not only to save lives but also achieve good long-term results and restore working capacity after severe damage to the main vessels.

## CONCLUSIONS

Awareness of the clinical presentation in the case of damage to the main vessels and adequate assessment of the severity of the patient's condition allow for the selection of the most appropriate surgical approach within the contemporary scientific ideas about vascular injuries. Thanks to real-time telemedicine consultations, it is possible to obtain the most complete information about the patient, coordinate the management of the patient before the arrival of the vascular surgeon, and make a consensus decision on the required amount of surgical treatment at this stage. A multidisciplinary approach to providing care to patients with injuries of the great vessels contributes to the use of a wider range of reconstructive interventions. When the general condition of the patient is stabilized, the use of nonstandard methods for the formation of an autovenous conduit can be considered an alternative to ligature interventions.

## DISCLAIMERS

### *Author contribution*

*Chernyadyev S.A.* — research concept, interpretation of data, editing of the text.
*Leshchinskaya A.Yu.* — research concept, interpretation of data, editing of the text.
Bochegov V.S. — collecting, analyzing data, writing the text of the article.

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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Review Article
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# Skin Closure After Subtotal Aponeurectomy in Severe Dupuytren's Contracture: Review

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One of the significant problems of surgical treatment of Dupuytren's contracture is skin deficiency after subtotal aponeurectomy. There are many options for skin grafting after subtotal aponeurectomy. However, there is no consensus on surgical approach to an altered palmar aponeurosis and on the choice of method for replacing soft tissue defects, taking into account the severity of the disease and the number of rays involved in the pathological process. The aim of the study was a comparative analysis of skin plasty methods after subtotal aponeurectomy in patients with Dupuytren's contracture stages III-IV. The review analyzes various treatment tactics, including preliminary distraction elimination of contracture in the external fixation devices followed by aponeurectomy, as well as various methods of skin plasty methods formed after excision of altered areas of palmar aponeurosis and elimination of contracture. In the early stages of the disease, Z- and V-Y plasty are sufficient. In patients with severe degree of the disease, more complex techniques have to be used due to large skin defects that cannot be covered with local tissues. Each of the proposed methods of surgical treatment has its advantages and disadvantages. An analysis of the literature has shown that the most common method of soft tissue plasty after aponeurectomy is Z-plasty. However, as the severity of the disease increases, its effectiveness decreases. To date, there is no consensus regarding surgical approach to an altered palmar aponeurosis and the choice of technique for soft tissue plasty in the Dupuytren's contracture stages III–IV.

**Keywords:** palmar fibromatosis, Dupuytren's contracture, Dupuytren's disease, skin plasty, subtotal aponeurectomy.

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# Восполнение дефицита кожного покрова после субтотальной апоневрэктомии при контрактуре Дюпюитрена тяжелой степени: обзор литературы

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Одной из существенных проблем хирургического лечения контрактуры Дюпюитрена является дефицит кожного покрова при ушивании раны после субтотальной апоневрэктомии. Существует множество вариантов пластики кожи, однако нет единого мнения о доступе к измененному ладонному апоневрозу и о выборе способа замещения дефектов мягких тканей с учетом тяжести заболевания и количества лучей, вовлеченных в патологический процесс. Целью обзора является сравнительный анализ методов пластического восполнения дефицита кожи после субтотальной апоневрэктомии у пациентов с III-IV степенью заболевания. В обзоре анализируются различные тактики лечения, включая предварительное дистракционное устранение контрактуры в аппарате внешней фиксации с последующей апоневрэктомией, а также различные способы пластического замещения дефектов кожи, образующихся после иссечения измененных участков ладонного апоневроза и устранения контрактуры. На ранних стадиях заболевания достаточно Z- и V-Y-пластики. У пациентов с тяжелой степенью заболевания приходится использовать более сложные методики из-за больших дефектов кожи, которые невозможно укрыть местными тканями. Каждый из предлагаемых способов хирургического лечения имеет свои преимущества и недостатки. Анализ литературы показал, что самой распространенной методикой восполнения дефицита мягких тканей после апоневрэктомии является Z-пластика. Однако по мере увеличения степени тяжести заболевания ее эффективность снижается.

**Ключевые слова:** ладонный фиброматоз, контрактура Дюпюитрена, болезнь Дюпюитрена, пластика кожи, субтотальная апоневрэктомия.

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## BACKGROUND

The treatment of Dupuytren's contracture stages III-IV is a difficult task for specialists, since after aponeurectomy and elimination of the contracture of the joints of the fingers, significant skin defects are formed that require plastic replacement [1]. There are many options for skin plastic surgery after subtotal aponeurectomy. However, there is no consensus on the access to the altered palmar aponeurosis and the choice of a method for replacing soft tissue defects, taking into account the disease severity and the number of rays involved in the pathological process [2].

According to international and Russian experts, subtotal aponeurectomy is the gold standard for the treatment of Dupuytren's contracture [3, 4]. Despite this, in recent decades, more and more articles have focused on minimally invasive treatment methods (needle aponeurotomy and enzymatic aponeurotomy) [5, 6]. First of all, this is due to a large number of early and late postoperative complications that range from 3.6% to 46.0% and the complexity of the plastic stage of the surgery for large skin defects [7, 8, 9]. Despite the low number (1-2%) of complications of minimally invasive methods of treatment, the recurrence rate with their use is 80-90% during the first 3 years after manipulation, while the recurrence rate with subtotal aponeurectomy reaches 34% [5, 6, 7, 8, 9].

Taking into account the contracture duration with a pronounced disease stage, which can reach 10-15 years from the appearance of the first signs until the patient seeks help, the skin on the palmar surface of the hand shrinks inevitably, which determines the need to compensate for its deficiency after the contracture is eliminated. When planning the surgical intervention, the surgeon must consider the solution of several questions, namely, 1) which access to choose, 2) how to avoid skin necrosis during its detachment, and 3) how to replace the skin defect formed?

To date, there is no consensus among specialists on the method of replacing defects in the skin of the hand after aponeurectomy in stages III–IV of the disease. This review aimed to conduct a comparative analysis of various methods of plastic replacement of skin deficiency after subtotal aponeurectomy in patients with stages III-IV of the disease.

## EPIDEMIOLOGY AND SOCIAL SIGNIFICANCE

To date, the prevalence of Dupuytren's disease varies greatly. Its incidence data varied in different countries [10]. According to the UK hand surgery centers, the prevalence of Dupuytren's contracture is 32.5 per 100.000 populations per year [11], it is 20% of all hand diseases in Germany, 11.8% in Russia, 8.8% in France, and only 2-3% in the USA [12]. The highest prevalence of this pathology is registered in Scandinavia, where it reaches 46% in people aged >60 years [13], and the lowest incidence was revealed among people of African and Asian origins [13, 14, 15, 16, 17]. Such a wide range of values depends mainly on the ethnicity, sex, and age of the patients. In the vast majority of cases (92-96%), middle- and old-age men are affected by palmar fibromatosis [18, 19].

In 67% of patients engaged in manual labor, the rapid progressive course of this disease leads to severe impairment of professional activity and, in 3% of cases, to a sustained disability, which is not only a medical but also a socioeconomic problem [20, 21].

In addition to the most common form of Dupuytren's contracture, many experts distinguish a special type of this pathology, known as fibrous diathesis, or Dupuytren's diathesis. This disease is characterized by a more aggressive course, manifests itself at a young age, affects several fingers and the radial side of the hand, and occurs bilaterally. It is characterized by the presence of nodules on the dorsal surface of the interphalangeal joints (often proximal interphalangeal joints, PIP), the so-called Garrod pads; positive family history (the presence of this disease in close relatives, such as the father, mother, etc.); combination with Peyronie's and Ledderhose's diseases; and tendency to recurrence and progression [22, 23].

## CLASSIFICATIONS

The main criteria for the classification of palmar fibromatosis are the localization of the pathological process on the hand and the severity of flexion contracture of the metacarpophalangeal and interphalangeal joints of the fingers involved in the pathological process [24].

In 1993, Volkova proposed her classification of Dupuytren's contracture according to the following parameters:

1. By prevalence

– finger shape, which is characterized by flexion contracture of the PIP and extensor contracture in the distal interphalangeal joint (DIP);

– palmar form, which is characterized by flexion contracture of the metacarpophalangeal joint (MCP);

– a mixed form (palmar-finger), when changes are registered on both the palm and fingers.

2. According to the flexion contracture stage, where stage I corresponds to 0-70°; stage II, 71-139°; and stage III, ≥140°.

3. According to the clinical course (primary form, secondary (relapse) form, mixed (relapse and progression) form) [25].

However, the classification proposed by Tubiana is more often used as the most acceptable and convenient [26]. In this classification, five disease stages are distinguished:

– Stage 0: presence of clinical signs of the disease in the form of nodules in the palm without contracture of the fingers.

– Stage I: total flexion contracture of the fingers of 0–45°.

– Stage II: total flexion contracture of the fingers of 45-90°.

– Stage III: total flexion contracture of the fingers of 90-135°.

– Stage IV: total flexion contracture of fingers of >135° [26, 27].

Both classifications are similar and take into account only the total contracture of the joints of the fingers, whereas neither of them takes into account the number of rays involved, which also determines the disease severity.

Zhigalo et al. proposed a classification of Dupuytren's contracture, which takes into account all the aspects of this disease, i.e., stage, shape, and number of affected rays [28]. The authors divided the classification into the following parameters:

1) According to the localization of the pathological process: right hand, left hand, and both hands.

2) By damage to the rays of the palmar aponeurosis: rays 1, 2, 3, 4, and ray 5.

3) According to the finger joints involved in the contracture: MCP as palmar form (palma); PIP or DIP as dactylar form (digitus); MCP+PIP or DIP as palmar-dactylar form (PD); MCP+PIP+ DIP as total form (total).

4) According to the contracture severity, where 0 corresponds to nodules/strands on the palm; 0I, restriction of overextension; stage I, 0-45°; stage II, 45-90°; stage III, 90-135°; and stage IV, 135-180°.

To explain this classification, the authors cited a clinical example with a standard formulation of the diagnosis and coding according to the proposed option, namely, stage III Dupuytren's contracture of the left hand with a predominant lesion of ray 5 and palmar-dactylar form of stage III Dupuytren's contracture of the left hand (L5C-PD-III). According to the authors, the use of the proposed coding for the diagnosis of Dupuytren's contracture saves time when filling out medical documentation and makes the diagnosis understandable in any language, which simplifies the communication between specialists from different countries [28]. However, this classification has not yet been widely used.

## TREATMENT OF DUPUYTREN'S CONTRACTURE

The treatment of extremely severe Dupuytren's contracture is a difficult task. Various approaches for the treatment of this category have been proposed. In general, all treatment options for Dupuytren's contracture can be divided into surgical (open) interventions, minimally invasive (closed) techniques, and conservative methods. However, since our review focused on methods of replacing skin defects after aponeurectomy, we analyzed only surgical techniques. In the range of the surgical methods for the treatment of Dupuytren's contracture, there are radical (total), segmental, and subtotal (partial) aponeurectomy [7, 29].

*Radical aponeurectomy* is the only method that has only historical significance. This method was used in the 1950s–1960s. The essence of the method consisted of the complete removal of the entire palmar aponeurosis (normal and altered) on the hand and fingers to prevent disease recurrence and progression. However, this surgery has not become widely used because of its complications, such as postoperative hematoma, prolonged wound healing, complex regional pain syndrome, which prolonged the rehabilitation.

With *segmental aponeurectomy*, a small fragment (up to 1 cm) of the altered tissue is excised through a C-shaped or linear skin incision along the pathological strand. This enables the formation of a defect between the strand ends, which excludes the possibility of their fusion and subsequent contraction. This technique is indicated for stage I-II Dupuytren's contracture with a predominant lesion of the MCP, which eliminates the need for skin plastic surgery after aponeurectomy. Moreover, contracture can be eliminated with minimal postoperative risks with a short recovery period [30].

*Subtotal aponeurectomy* is currently the most common surgical treatment for Dupuytren's contracture. Access to the altered areas of the aponeurosis is performed through skin incisions of various shapes and lengths [3, 4, 6]. In most cases, specialists strive to suture the wounds primarily, but in the presence of skin deficiency, some authors leave separate areas of wounds open for secondary healing [31, 32, 33], particularly when performing aponeurectomy using McCash's method proposed in 1964 [34]. The authors who prefer this approach note decreased complications associated with postoperative hematoma and wound infection. However, these patients require long-term follow-up and frequent dressings; in addition, the rehabilitation process is prolonged due to the long-lasting healing of wounds on the hand [35].

The incidence of complications after subtotal aponeurectomy ranges from 6% to 46% (damage to nerves, arteries, infectious complications, postoperative hematoma, complex regional pain syndrome, etc.) [36]. One of the causes of the complications, in addition to age and comorbidities, is seeking medical help by patients at a late disease stage, when there is a significant limitation of hand function [37]. In their study, Bulstrode et al. showed a direct correlation between the number of complications and disease stage, with the largest number of them in patients with stages III-IV [38].

Given all of the above, specialists should solve the following problems:

1) Skin deficiency that occurs after the elimination of severe contracture.

2) Correction of PIP contracture caused by secondary changes in para-articular tissues.

3) Prevention of postoperative complications.

Taking into account the problems that arise during subtotal aponeurectomy with a pronounced stage of the disease, two options for solving these problems are described:

1) Distraction method for eliminating contracture followed by aponeurectomy.

2) Simultaneous elimination of the contracture of the joints of the fingers, followed by the replacement of the skin defects of the hand.

### *Staged treatment of severe Dupuytren's contracture (stages III–IV)*

The two-stage technique is based on the elimination of the contracture of the finger joints by the distraction method in the external fixation apparatus. Gradual distraction reduces the stage of contracture by stretching the skin and para-articular structures. The next stage is an aponeurectomy. Numerous options for external fixation apparatus have been proposed; this approach helps avoid the need for plastic replacement and avoid joint arthrolysis [39, 40].

This technique has some advantages, such as the gradual lengthening of the skin and para-articular tissues, which facilitates the performance of subtotal aponeurectomy, but does not eliminate the need for plastic repair. Despite this, prolonged distraction in the external fixation apparatus is associated with the risk of complications, such as infectious (wire and rod osteomyelitis), limitation of mobility in the PIP, and skin ruptures. In addition, treatment takes a long time, which increases the costs and reduces patient satisfaction. At present, this technique has not yet been widely used.

## *One-stage treatment of Dupuytren's contracture*

Methods for replacing hand skin defects after aponeurectomy can be divided into several types, namely, the use of a free full-thickness skin graft, local skin grafting, and regional grafts [41, 42, 43, 44, 45].

### *Plastic repair with a full-thickness skin graft*

In the case of recurrence of contracture or Dupuytren's diathesis in young patients, some experts prefer to use a full-thickness skin graft (FTSG) to compensate for skin deficiency after the contracture of the finger joint has been eliminated. Several international studies have shown

that the skin from another part of the body, free of myofibroblasts, involved in the formation of pathological changes in the aponeurosis, prevents disease progression, creating a kind of barrier, known as a "firebreak" [46, 47, 48].

Ullah et al. conducted a prospective randomized study to evaluate the number of relapses of PIP contracture after dermofasciectomy and skin defect replacement with FTSG. The study included 79 patients. PIP contracture averaged 59° and MCP contracture averaged 21°. The patients were distributed into two groups: Group 1 included 39 patients who underwent Z-plasty after aponeurectomy and Group 2 included 40 patients who received FTSG after dermofasciectomy. Subjective and objective assessment of hand function was performed at months 3, 6, 12, 24, and 36. Wound healing and functional recovery in both groups were approximately the same. However, in one patient with Z-plasty, marginal necrosis of the graft was detected, and in four patients with FTSG, an insignificant separation of the wound edges was revealed. None of the cases required re-intervention. The mean movement amplitude in the PIP joints improved to 65° (from 2° to 98°) over 3 years in both groups of patients. At 36 months after surgery, no significant difference was found in the number of disease recurrences in the groups analyzed (11 cases in total with 5 patients in Group 1 and 6 patients in Group 2). The technique described is not free from shortcomings, such as the risk of graft rejection and the need for an additional incision to harvest the graft [46].

### *Plastic surgery with local tissues*

Uemura et al. conducted a retrospective analysis of the postoperative results of treatment of 23 patients with stage I-III Dupuytren's contracture (25 hands and 29 fingers), who underwent subtotal aponeurectomy, and Y-V- and Z-plasty were used to compensate for skin deficiency. The postoperative follow-up period ranged from 6 to 32 (average, 12) months. Clinical results were assessed by improving the extension in each joint in accordance with the Tubiana classification [27]. The authors reported that the wounds were sutured primarily in all cases. There were no postoperative complications, except for one patient who developed complex regional pain syndrome. His symptoms were arrested using oral steroids, which eventually led to a good outcome. Contracture was reduced on average from 46.5° preoperatively to 4.2° postoperatively for MCP and from 43.9° to 22.4° for PIP, with a mean percentage improvement of 92% for MCP and 56% for PIP. In 83% of cases, it was possible to achieve positive results and reduce the number of early and late postoperative complications [49]. Considering that the study included patients only with disease stages I-III, the method proposed by the authors does not cover completely the defect in the severe disease stage, which is one of the most difficult issues for specialists, because the complexity of the plastic stage of the surgery increases.

The advantages of Z-plasty were also demonstrated by Magomedov et al. in a study on the replacement of hand skin defects after subtotal aponeurectomy in the treatment of 86 patients. A zigzag incision and cutting out opposing triangular grafts provide good visualization of pathologically altered segments of aponeurosis and neurovascular bundles and eliminate flexion contracture of the fingers. In all cases, it was possible to close the wounds primarily, which reduced significantly the proportion of early postoperative complications to 0.9-1.0% [50]. However, the study lacks data on the magnitude of MCP and PIP contracture before surgery, and there is no information on the nature of complications or data on the stage of contracture correction.

Le Gall and Dautel proposed an original technique for filling the skin deficiency of the proximal phalanx in severe Dupuytren's contracture with localization mainly on the fifth finger. This method was initially tested on cadaveric material (12 upper limbs). The authors artificially formed a skin defect in the region of the proximal phalanx of the fifth finger, corresponding to the skin deficiency after the elimination of contracture in stages III-IV of the disease. This technique included variants of local grafts, namely, the Houston, Coulson, and wide-based grafts (the methods are known and described in the literature regarding the replacement of hand skin defects). The clinical study included 10 patients with stage II-IV Dupuytren's contracture and predominant lesion of PIP. In all cases, after aponeurectomy and elimination of the vicious position of the fingers, the skin defect was replaced according to the proposed method. In all pa-

tients, the wounds healed by primary intention, and there were no cases of skin necrosis of the grafts, separation of the wound edges, infectious complications, or other complications associated with the healing process. In the postoperative period, it was possible to achieve the correction of MCP contracture up to 4.2° on average and up to 22.4° for the PIP joint. The average follow-up period was 9.5 months. In 83% of cases, successful results were achieved. The authors believe that the use of the proposed technique helps obtain a larger tissue volume than did Y-V- and Z-plasty and thus achieve fewer complications associated with wound healing and more satisfactory aesthetic and functional results in the long-term [2]. Although the authors achieved optimal results, a study on a larger group of patients is required to obtain significant statistical data.

### *Regional grafts*

An alternative option for filling skin defects in the region of the main phalanx is cross-skin grafting (cross-plasty) from the adjacent finger or using an islet graft on the dorsal metacarpal artery. Spindler et al. presented a clinical case of the use of cross-plasty to fill the deficiency of the skin of the proximal phalanx after aponeurectomy on the fifth finger in a recurrent form of the disease. Before surgery, the MCP contracture was 15° and that of PIP was 100°. After excision of the altered aponeurosis, the lack of skin of the main phalanx was 3.5 × 2.5 cm. To eliminate it, a fasciocutaneous cross graft was cut from the adjacent finger according to the defect size, and a FTSG taken from the inner surface of the shoulder was used to close the donor area. According to the authors, after 4 months, excellent functional and aesthetic results have been achieved [37].

Large skin defects of the proximal phalanx can also be replaced with an islet graft on the dorsal metacarpal artery. Ekerot operated on 15 patients with a recurrent disease, who underwent replacement of the skin defect using this method after the removal of pathological strands. All patients in this group previously underwent the surgery repeatedly (the number of surgeries in history was 1.6 on average). Before surgery, the total contracture averaged 77°. Some patients required PIP joint release and additional transarticular wire fixation to maintain the joint extension. The rehabilitation period ranged from 3 to 5 months. According to the author, there was not a single case of complete loss of the graft; however, in four cases, marginal necrosis of the distal part of the graft was noted, which did not require additional intervention. One patient had subtotal graft necrosis due to venous insufficiency, which was the reason for repeated surgery. A graft on the dorsal metacarpal artery was also used to replace the defect. In 15 patients, it was possible to achieve correction of PIP contracture by an average of 15° [51].

The problem of replacing soft tissue defects during surgery for contracture recurrence, when the skin in the intervention site is scarred, is of greatest interest. According to Spindler et al., to obtain good esthetic and functional results in skin defects of the proximal phalanx, it is more expedient to use blood-supplying tissue complexes, particularly a wide-based graft from the adjacent finger (cross-plasty) [37]. The disadvantage of this method consists in damage to the adjacent finger and the need to collect FTSG to replace the donor defect. In this case, a more preferred option is an islet graft on the dorsal metacarpal artery, since in this case, an additional graft is not needed, and the donor wound is sutured in line. This method enables obtaining excellent aesthetic and functional results, as demonstrated by Ekerot [51].

In Dupuytren's contracture, the fourth–fifth fingers are more often affected. Methods for plastic replacement of defects on these fingers were presented above. Areas of the palmar aponeurosis are affected less commonly along rays 1–3. The literature describes a limited number of cases of replacement of skin defects of the palmar surface of the hand and the first, second, and third fingers after aponeurectomy. With this disease localization, careful preoperative planning is required to determine the expected skin defect size and choose the method of its replacement after the contracture has been eliminated. Interestingly, Seyhan focused on filling the deficit of soft tissues in the palm with an islet reversible perforant thenar graft after aponeurectomy in seven patients. The blood flow to this graft is supplied by the perforating vessel of the superficial palmar arch or the radial branch of the superficial palmar arch. Using this graft, a defect of 2.5×6.5 cm can be replaced with primary suturing of the donor wound without any consequences,

for example, adduction contracture of the first finger or the formation of a rough scar. The average follow-up period for patients was 12.6 months. In one case, due to venous stasis, marginal necrosis of the graft developed, which did not affect the final result. The author managed to obtain excellent cosmetic and functional results in all patients who underwent surgery. According to the author, the indication for the use of this graft is a defect located on the palm, the palmar surface of the main phalanx of the first, second, or third finger, in the area of the first interdigital space [52].

## CONCLUSIONS

The literature analysis showed that despite the achievements of modern medicine, the treatment of patients with stage III-IV Dupuytren's contracture remains an urgent problem. The elimination of the malposition of the fingers in a severe disease stage is always accompanied by the formation of a skin defect with the size determined by the stage of contracture. Currently, one of the demands that patients make is to reduce the duration of the disability. An important condition for fulfilling this requirement is the primary healing of hand wounds, which can be achieved only by plastic replacement of defects that have formed after the elimination of the contracture of fingers. Since all formed defects are deep, i.e., with exposure of the flexors and neurovascular bundles, the only possible way to replace them is plastic surgery with a blood-supplying complex of tissues, the choice of which is determined by the defect size. Nevertheless, Z-plasty remains the most common technique for filling soft tissue deficiency after aponeurectomy. However, its efficiency decreases with the increase in the disease severity. To date, there is no consensus on access to the altered area of the aponeurosis and the choice of methods for filling the tissue deficiency in stages III-IV of the disease.

## 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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# ЛИННИК СТАНИСЛАВ АНТОНОВИЧ
## К 70-летию со дня рождения

7 мая 2022 г. отметил 70-летний юбилей доктор медицинских наук, профессор, заслуженный врач РФ Станислав Антонович Линник.

Станислав Антонович родился в 1952 г. в многодетной семье в селе Недошевичи Барановичской области. В 1968 г. С.А. Линник окончил среднюю школу. В том же году он поступил в Ленинградский санитарно-гигиенический медицинский институт. Во время учебы Станислав Антонович принимал активное участие в работе студенческого научного кружка на кафедре, неоднократно выступал с докладами на студенческих научных конференциях. В течение 10 лет он был председателем совета Всесоюзного общества изобретателей и рационализаторов в ЛСГМИ, ежегодно признавался лучшим изобретателем института.

В 1975 г. С.А. Линник окончил институт и остался работать на кафедре и в клинике травматологии и ортопедии, где и трудится до настоящего времени. В 1979 г. он стал ассистентом, в 1987 г. — доцентом, а в 1991 г. — профессором кафедры травматологии, ортопедии и военно-полевой хирургии. В 1980 г. С.А. Линник защитил кандидатскую диссертацию «Лечение повреждений ахиллова сухожилия», а в 1988 г. — докторскую диссертацию «Послеоперационный остеомиелит, его профилактика, диагностика и лечение», в которой показал, что это тяжелое осложнение в 90% случаев носит ятрогенный характер и возникает вследствие ошибок, допущенных врачами при хирургическом лечении травм и ортопедических заболеваний.

В 2006 г. профессору С.А. Линнику было доверено возглавить кафедру травматологии, ортопедии и военно-полевой хирургии с курсом стоматологии, которой он руководил до 2012 г. Основным направлением научной работы кафедры и клиники уже более 30 лет является проблема диагностики, лечения и реабилитации больных с хроническими формами остеомиелита. В последние годы с применением микрососудистой техники в клинике успешно излечиваются не только обширные язвенные дефекты голени и стопы, но и глубокие пролежни при остеомиелите области крестца и большого вертела у спинальных больных.

С 2012 г. Станислав Антонович работает профессором кафедры травматологии, ортопедии и военно-полевой хирургии Северо-Западного медицинского университета им. И.И. Мечникова, успешно сочетая клиническую, научную и педагогическую работу. Он является членом Ассоциации травматологов-ортопедов России, членом правления Ассоциации травматологов-ортопедов Санкт-Петербурга и Ленинградской области, членом объединенного диссертационного совета при НМИЦ ТО им. Р.Р. Вредена и ВМедА им. С.М. Кирова, заместителем председателя аттестационной комиссии по травматологии и ортопедии Санкт-Петербурга.

Профессор С.А. Линник внес существенный вклад в разработку способов лечения хронического остеомиелита, хронических и нейротрофических язв, а также способов аллотендопластики при повреждениях и заболеваниях опорно-двигательной системы. В результате научных исследований им был обобщен многолетний опыт диагностики и лечения перипротезной инфекции крупных суставов, включая разработку антимикробных композиций пролонгированного действия и спейсеров тазобедренного и коленного суставов. В 1983 г. он впервые в России для замещения костного дефекта при хроническом остеомиелите использовал деминерализованные костные трансплантаты. В настоящее время изучаются возможности применения биокомпозитных материалов и стеклокристаллического остеозамещающего материала в клинике.

В последние годы его научные исследования посвящены лечению тяжелых форм заболеваний крупных суставов, комплексному лечению ослож-

ненных форм хронического остеомиелита с применением иммуномодуляторов, разработке эндопротезов и способов их применения, в том числе при онкологических заболеваниях. Разрабатывается и используется метод чрескостного остеосинтеза аппаратами внешней фиксации при лечении несросшихся переломов, ложных суставов, осложненных остеомиелитом. В эксперименте обоснованы, разработаны и защищены патентами доступы и способы мышечной пластики плечевой кости и ключицы.

С.А. Линник — автор более 500 научных работ, включая 13 монографий и руководств, 14 методических рекомендаций, 76 патентов и авторских свидетельств, 12 учебно-методических пособий для студентов и 148 рацпредложений. Наиболее значимыми монографиями являются «Аллотендопластика при лечении повреждений мышц, сухожилий и связок» (1994) и «Хронический остеомиелит» (1990), «Хирургическое лечение остеомиелита» (2000), «Пластическая хирургия хронических и нейротрофических язв» (2001), «Остеомиелит таза, остеоартрит тазобедренного сустава и их ортопедические последствия. Хирургическое лечение» (2007). Профессор С.А. Линник — автор четырех глав многотомного национального руководства «Травматология и ортопедия» (2004–2006). Под его руководством защищены 32 кандидатские и 3 докторские диссертации, в настоящее время выполняются еще одна докторская и 4 кандидатские диссертации. Он подготовил большое количество высококвалифицированных травматологов-ортопедов, работающих в России и за рубежом.

С.А. Линника отличает дисциплинированность, исполнительность, высокая работоспособность. За многолетний вклад в развитие медицины С.А. Линник награжден медалью «В память 300-летия Санкт-Петербурга», а в 2009 г. был удостоен почетного звания «Заслуженный врач РФ».

*Коллектив СЗГМУ им И.И. Мечникова и редакция журнала поздравляют Станислава Антоновича с юбилеем и желают ему крепкого здоровья, долгих лет плодотворной деятельности, благополучия.*

## Сообщение о ретракции: «Современный метод биомеханической оценки рациональности изготовления приемных гильз протезов нижних конечностей», журнал «Травматология и ортопедия России». 2007, № 3, С. 36-43.

Статья «Современный метод биомеханической оценки рациональности изготовления приемных гильз протезов нижних конечностей», опубликованная в журнале «Травматология и ортопедия России» (2007, № 3), авторами которой являются М.Г. Гусев, А.С. Малыхин, К.К. Щербина, представляет собой дубликат статьи «Современный метод биомеханической оценки рациональности изготовления приемных гильз протезов нижних конечностей» тех же авторов, опубликованной в журнале «Вестник Санкт-Петербургской государственной медицинской академии им. И.И. Мечникова». 2007, № 3, С. 186–189. В связи с этим указанная статья отозвана с публикации.

Выявлено 20/04/22 редколлегией журнала.

**Ключевые слова:** протезирование нижних конечностей, биомеханическая оценка.

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## Retraction notice: “Modern method of biomechanical estimation of the rational lower extremities prosthetic sockets production”. Traumatology and Orthopedics of Russia. 2007;(3):36-43.

The article “Modern method of biomechanical estimation of the rational lower extremities prosthetic sockets production” published in “Traumatology and Orthopedics of Russia” (2007, N 3) by M.G. Gusev, A.S. Malykhin, K.K. Shcherbina is a duplicate of the article “Modern method of biomechanical estimation of the rational lower extremities prosthetic sockets production” published in the “Bulletin of Mechnikov Saint Petersburg State Medical Academy”. 2007;(3):186–189. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** lower extremity prosthetics, biomechanical estimation.

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## Сообщение о ретракции: «Оценка результатов хирургического лечения повреждений седалищного нерва», журнал «Травматология и ортопедия России». 2009, № 1, С. 96–98

Статья «Оценка результатов хирургического лечения повреждений седалищного нерва», опубликованная в журнале «Травматология и ортопедия России» (2009, № 1), авторами которой являются Р.И. Хамзаев, В.П. Берснев, Ю.И. Борода, представляет собой дубликат статьи тех же авторов «Результаты эпиневрального шва седалищного нерва», опубликованной в журнале «Вестник хирургии им. И.И. Грекова». 2009, № 1, С. 61–63. В связи с этим указанная статья отозвана с публикации.

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**Ключевые слова:** седалищный нерв, травма.

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## Retraction Notice: “Assessment Results of Surgical Treatment of Sciatic Nerve Injuries”. Traumatology and Orthopedics of Russia. 2009;(1):96-98

The article “Assessment results of surgical treatment of sciatic nerve injuries” published in “Traumatology and Orthopedics of Russia” (2009, No 1) by R.A. Khamzaev, V.P. Bersnev, Y.I. Boroda is a duplicate of the article “Results of the epineural suture of the sciatic nerve” by the same authors published in the “Grekov’s Bulletin of Surgery”. 2009;(1):61-63. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** sciatic nerve, injury.

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## Сообщение о ретракции: «Иммунологические критерии прогнозирования замедленной консолидации костной ткани», журнал «Травматология и ортопедия России». 2009, № 2, С. 59–66

Статья «Иммунологические критерии прогнозирования замедленной консолидации костной ткани», опубликованная в журнале «Травматология и ортопедия России» (2009, № 2), авторами которой являются О.В. Бердюгина, К.А. Бердюгин, представляет собой дубликат статьи О.В. Бердюгиной «Иммунологический мониторинг замедленного остеогенеза», опубликованной в журнале «Медицинская иммунология». 2008, Т. 10, № 4-5, С. 371-378. В связи с этим указанная статья отозвана с публикации.

Выявлено 20/04/22 редколлегией журнала.

**Ключевые слова:** нарушения остеогенеза, иммунологические исследования.

DOI: 10.17816/2311-2905-1794

## Retraction Notice: “Immunologic Criteria of Prediction of Bone Delayed Union”. Traumatology and Orthopedics of Russia. 2009;(2):59-66

The article “Immunologic criteria of prediction of bone delayed union” published in “Traumatology and Orthopedics of Russia” (2009, N 2) by O.V. Berdyugina, K.A. Berdyugin is a duplicate of the article “Immunological monitoring of slow down ostheogenesis” published in “Medical Immunology”. 2009;(3-4):371-378. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** delayed union, immunologic researches.

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## Сообщение о ретракции: «Синдром Хаглунда: историческая справка и систематический обзор», журнал «Травматология и ортопедия России». 2014, № 1, С. 122-132

Статья «Синдром Хаглунда: историческая справка и систематический обзор», опубликованная в журнале «Травматология и ортопедия России» (2014, № 1), авторами которой являются А.П. Середа, Г.М. Кавалерский, представляет собой дубликат статьи тех же авторов «Деформация Хаглунда. Историческая справка и систематический обзор литературы», опубликованной в журнале «Сеченовский вестник». 2014, № 1, С. 30–39. В связи с этим указанная статья отозвана с публикации.

Выявлено 20/02/20 Редакционной коллегией.

**Ключевые слова:** синдром Хаглунда, деформация Хаглунда, тенопатия ахиллова сухожилия, консервативное и хирургическое лечение.

DOI: 10.17816/2311-2905-1793

## Retraction Notice: “Haglund Syndrome: Historical and Systematic Review”. Traumatology and Orthopedics of Russia. 2014;(1):122-132

The article “Haglund syndrome: Historical and systematic review” published in “Traumatology and Orthopedics of Russia” (2014, No 1) by A.P. Sereda, G.M Kavalersky, is a duplicate of the article “Haglund syndrome: Historical and systematic review” published by the same authors in “The Sechenov Medical Journal”. 2014;(1):30-39. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** Haglund syndrome, Haglund’’s deformity, achilles tendon tenopathy, conservative treatment, surgical correction.

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## Сообщение о ретракции: «Эндопротезирование суставной поверхности надколенника при тотальной артропластике коленного сустава: аналитический обзор литературы», журнал «Травматология и ортопедия России» 2014, № 3, С. 128-141. DOI: 10.21823/2311-2905-2014-0-3-128-141

Статья «Эндопротезирование суставной поверхности надколенника при тотальной артропластике коленного сустава: аналитический обзор литературы», опубликованная в журнале «Травматология и ортопедия России» (2014, № 3) авторами котрой являются Г.М. Кавалерский, А.П. Середа, А.В. Лычагин, С.М. Сметанин, представляет собой дубликат статьи «Эндопротезирование суставной поверхности надколенника при тотальной артропластике коленного сустава» авторов А.П. Середы, А.С. Саградяна, А.В. Лычагина, опубликованной в журнале «Кафедра травматологии и ортопедии». 2012, № 3, С. 18–28. В связи с этим указанная статья отозвана с публикации.

Выявлено 20/02/20 Редакционной коллегией.

**Ключевые слова:** эндопротезирование коленного сустава, замещение суставной поверхности надколенника.

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## Retraction Notice: “Patellar Resurfacing of Total Knee Arthroplasty: Analytical Review”. Traumatology and Orthopedics of Russia. 2014;(3):128-141 DOI: 10.21823/2311-2905-2014-0-3-128-141

The article “Patellar resurfacing of total knee arthroplasty: Analytical review” published in “Traumatology and Orthopedics of Russia” (2014, N 3) by G.M. Kavalersky, A.P. Sereda, A.V. Lychagin, S.M. Smetanin is a duplicate of the article “Patellar resurfacing of total knee arthroplasty” by A.P. Sereda, A.S. Sagradyan, A.V. Lychagin published in “The Department of Traumatology and Orthopedics”. 2014;(3):18–28. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** knee replacement, patellar resurfacing.

DOI: 10.17816/2311-2905-1796

## Сообщение о ретракции: «Функция коленного сустава во время ходьбы у больных с разрывом передней крестообразной связки коленного сустава до и после оперативного лечения», журнал «Травматология и ортопедия России». 2016, Т. 22, № 2, С. 15-24. DOI: 10.21823/2311-2905-2016-0-2-15-24

Статья «Функция коленного сустава во время ходьбы у больных с разрывом передней крестообразной связки коленного сустава до и после оперативного лечения», опубликованная в журнале «Травматология и ортопедия России» (2016, Т. 22, № 2), авторами которой являются А.А. Ахпашев, Н.В. Загородний, А.С. Канаев, С.Н. Кауркин, Д.В. Скворцов, представляет собой дубликат статьи «Функция ходьбы у больных с разрывом передней крестообразной связки коленного сустава до и после оперативного лечения» авторов А.А. Ахпашева, Н.В. Загороднего, С.Н. Кауркина, Д.В. Скворцова, опубликованной в журнале «Клиническая практика». 2015, № 3-4, С. 30–38. В связи с этим указанная статья отозвана с публикации.

Выявлено 20/04/22 редколлегией журнала.

**Ключевые слова:** коленный сустав, разрыв передней крестообразной связки, биомеханика ходьбы.

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## Retraction Notice: “Knee Joint Gait Function in Patients with ACL Rupture Before and After the Surgery”. Traumatology and Orthopedics of Russia. 2016;22(2):15-24. DOI: 10.21823/2311-2905-2016-0-2-15-24

The article “Knee joint gait function in patients with ACL rupture before and after the surgery” published in “Traumatology and Orthopedics of Russia” (2016, Vol. 22, N 1) by A.A. Akhpashev, N.V. Zagorodniy, A.S. Kanaev, S.N. Kaurkin, D.V. Skvortsov is a duplicate of the article by A.A. Akhpashev, N.V. Zagorodniy, S.N. Kaurkin, D.V. Skvortsov “Knee joint gait function in patients with ACL rupture before and after the surgery” published in “Clinical Practice”. 2009;(3-4):30-38. That was the reason for retraction.

Revealed April 20, 2022 by the Editorial Board.

**Keywords:** knee joint, anterior cruciate ligament, gait biomechanics.

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