

Original article

<https://doi.org/10.18019/1028-4427-2026-32-2-149-161>



Comparative evaluation of the results of using the Ilizarov apparatus and an orthopedic hexapod in the treatment of patients with flexion knee joint contractures

L.N. Solomin¹, S.A. Rokhovev²✉

¹ Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russian Federation

² Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, St. Petersburg, Russian Federation

Corresponding author: Saigidula A. Rokhovev, 09saga@mail.ru

Abstract

Relevance When soft tissue release is ineffective in the treatment of persistent flexion contractures of the knee joint, external fixation devices are used. Orthopedic hexapods can be used as an alternative to the traditional Ilizarov frame with a uniaxial hinge.

Purpose To conduct a comparative analysis of the effectiveness of the clinical use of an orthopedic hexapod and the Ilizarov fixator with a uniaxial hinge in the treatment of patients with flexion contractures of the knee joint.

Materials and methods A total of 67 cases of flexion contracture of the knee joint due to spastic paresis were analyzed. All patients underwent posterior release surgery followed by the application of an external fixation device (EFD). Patients were divided into two groups: the study group ($n = 35$) treated using the "Orto-SUV" orthopedic hexapod, and the comparison group ($n = 32$) treated using the Ilizarov fixator with a uniaxial hinge. Patients were also subdivided based on the presence or absence of a preoperatively diagnosed posterior tibial subluxation. The duration of treatment stages, range of motion in the knee joint and functional outcomes (assessed with KSS, Lysholm, and LEFS systems) were evaluated at 2 days, 6 months, and 12 months after frame removal.

Results The use of the orthopedic hexapod significantly reduced the duration of the extension stage compared to the Ilizarov fixator. However, the overall duration of external fixation in both groups did not differ significantly. No statistically significant differences were found between the groups at any follow-up time-point for the main functional indicators: range of motion (flexion and extension) and overall lower extremity function (LEFS score). However, according to specialized knee joint assessment scales (KSS and Lysholm), patients in the study group demonstrated significantly better results at 12 months. The complication rate in both groups was comparable.

Discussion Factors affecting functional outcomes in both groups included preoperative tibial subluxation and patient compliance with postoperative recommendations. A specific factor affecting functional outcomes for a uniaxial external fixator is the precise positioning of the hinge on the flexion-extension axis to avoid iatrogenic knee instability. The total duration of external fixation and overall lower extremity function (LEFS) in the compared groups did not differ statistically, indicating no significant advantage of using one type of device over the other.

Conclusion With the orthopedic hexapod, the extension stage was significantly shorter than with the Ilizarov fixator; however, the total duration of external fixation in both groups did not differ significantly. No statistically significant differences were found between the groups at any follow-up point in terms of the main functional indicators, range of motion (flexion and extension), and LEFS. Based on the KSS and Lysholm scales, patients in the study group demonstrated significantly better results at 12 months. Complication rates were comparable in both groups.

Keywords: contracture, knee joint, flexion contracture, external fixation, Ilizarov apparatus, orthopedic hexapods

For citation: Solomin LN, Rokhovev SA. Comparative evaluation of the results of using the Ilizarov apparatus and an orthopedic hexapod in the treatment of patients with flexion knee joint contractures. *Genij Ortopedii*. 2026;32(2):149-161. doi: 10.18019/1028-4427-2026-32-2-149-161.

© Solomin L.N., Rokhovev S.A., 2026
© Translator Tatyana A. Malkova, 2026

INTRODUCTION

Flexion contractures of the knee joint mostly develop in diseases accompanied by spasticity syndrome and significantly impair the patients' quality of life, depriving them of the ability to move without additional supports [1–4]. In long duration of contracture, secondary changes in the soft tissues develop and conservative treatment fails [5, 6]. To eliminate persistent flexion contracture of the knee joint, a "posterior release" is performed, including neurolysis of the peroneal nerve, myolysis, tenolysis, lengthening and transfer of the tibia flexors, as well as posterior capsulotomy of the knee joint [7–11]. Regardless of the quality of the posterior release performed, the maximum possible one-stage elimination may be limited due to severe pathological retraction of the muscle-tendon complex and the neurovascular bundle. Therefore, to avoid their traction damage, the "soft tissue" operation may be supplemented by a "hinged" external fixation apparatus, most often it is the Ilizarov apparatus [12–15].

The available studies have shown that uniaxial hinge devices that are traditionally used for movement exercises do not correspond to the kinematics of the knee joint [16, 17]. To comply with this kinematics, an external fixation device (EFD) must provide movements based on a virtual hinge [18]. Orthopedic hexapods meet this requirement, the effectiveness of which has already been proven in the treatment of persistent extension contractures of the knee joint [19]. However, a comparison of the clinical effectiveness of an orthopedic hexapod and a uniaxial hinge external fixator in the treatment of persistent flexion contractures of the knee joint has not yet been conducted.

Purpose To conduct a comparative analysis of the clinical effectiveness of the orthopedic hexapod and the uniaxial hinge Ilizarov apparatus in the treatment of patients with flexion contractures of the knee joint.

MATERIAL AND METHODS

Study design This is a retrospective, non-randomized cohort study. It is based on S.A. Rokhovev's dissertation, "Substantiation of the Use of an Orthopedic Hexapod in the Treatment of Patients with Knee Joint Contractures" (St. Petersburg, 2022).

Patients

The study was conducted at the Vreden National Medical Research Center of Traumatology and Orthopedics. The study included patients treated between 2005 and 2021. Sixty-seven cases of combined (posterior release + external fixation device) treatment for knee flexion contractures resulting from spastic paresis were analyzed. The causes of spastic paresis included traumatic brain injury (TBI), sequelae of cerebral palsy (CP), and acute cerebrovascular accidents (CVA).

The study group, which used the Ortho-SUV orthopedic hexapod in addition to the posterior release, included 35 patients. Of these, 14 were analyzed prospectively and 21 were analyzed retrospectively.

The comparison group, which combined the posterior release and the Ilizarov frame with a uniaxial hinge, included 32 patients.

The gender, age, and etiological characteristics of patients in both groups are presented in Table 1. Both groups were comparable in etiology, gender, age, contracture duration, and concomitant posterior tibial subluxation ($p > 0.05$).

Both groups included patients with preoperatively diagnosed posterior tibial subluxation. Accordingly, those patients were divided into subgroups 1 and 2.

Table 1

Distribution of patients in both subgroups by main characteristics, *n*/%, Me [Q1; Q3]

Group		Study group (orthopedic hexapod)		Comparison group (uni-axial apparatus)	
Number of patients		35		32	
Age		32 [27;43]		28 [26;37]	
Gender		<i>n</i>	%	<i>n</i>	%
Males		21	60	19	59.4
Females		14	40	13	40.6
Etiology	CP	17	48.5	18	56.2
	TBI	10	28.5	8	25.0
	CVA	8	22.8	6	18.7
Disease duration	3–5 years	14	40	9	28.1
	6–10 years	4	11.4	5	15.6
	↑10 years	17	48.5	18	56.2
Associated tibial subluxation		Subgroup 1		Subgroup 2	
		<i>n</i>	%	<i>n</i>	%
Number of patients		12	34.3	8	25

Surgical technique

All patients first underwent a posterior release through two approaches (medial and lateral) in the paraarticular region at the level of the lower third of the femur. The lateral approach was used for exploration and neurolysis of the common peroneal nerve (Fig. 1a) from the lower third of the femur to its entry into the intermuscular septum. Following this, depending on the degree of tension, either distal fractional lengthening of the biceps femoris ($n = 26$, 38 %) or Z-lengthening of its distal tendon ($n = 41$, 62 %) was performed. This approach was also used to visualize and protect the popliteal neurovascular bundle (PNVB).

The medial approach was used to isolate the sartorius, semitendinosus, semimembranosus, and gracilis muscles. The semimembranosus and sartorius muscles were fractionally lengthened if they were tense. The gracilis tendon was dissected distally at the junction of the muscularis and the tendinous portion, while the semitendinosus tendon was transected at its most distal portion (Fig. 1c). If tension was detected in the heads of the gastrocnemius muscles, they were bluntly dissected at their femoral attachment. Similarly, if tension was detected in the plantaris muscle, it was "slided." Finally, a posterior capsulotomy of the knee joint was performed (Fig. 1d); if tension was severe, fractional lengthening of the dorsal fascia was performed. The leg was then extended until tension was felt in the NVB. The proximal end of the semitendinosus and the distal end of the gracilis tendon were sutured in a side-to-side fashion while maintaining their moderate tone.

In all analyzed cases, full acute extension of the lower leg was impossible due to tension in the NVB and the surgery was supplemented by the placement of a femur-to-tibia external fixator (EF). To prevent traction neuropathy, the joint was fixed at +10° of flexion relative to the angle at which the NVB tension occurred.

Both groups had similar fixator configurations, including a basic support at the level of the lower third of the thigh and a mobile support at the level of the middle third or the junction of the middle and upper thirds of the tibia. In the study group, to avoid contact between the struts and the skin at placement of the mobile support at the level of the middle third of the tibia, a "free" sector-type support was added (Fig. 2 a). In the frontal plane, the supports were oriented perpendicular to the overall mechanical axis of the limb, and in the sagittal plane, each module was oriented perpendicular to the anatomical axes of the femur and tibia.

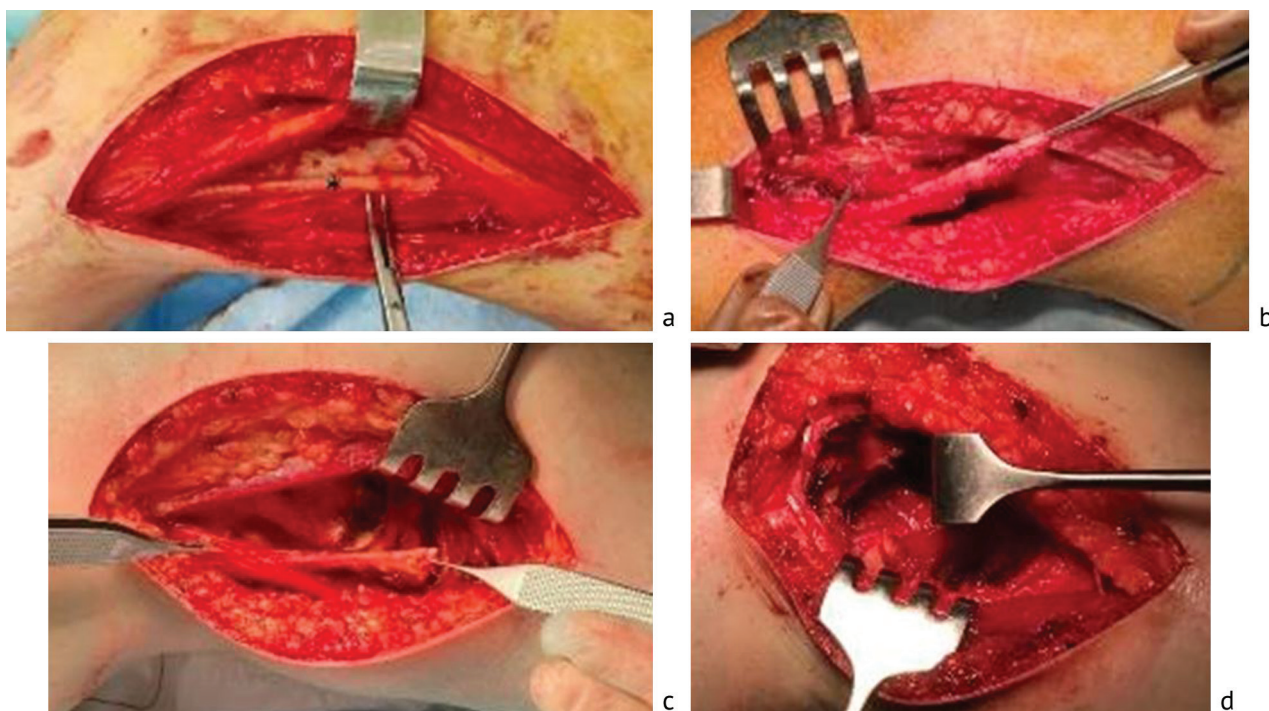


Fig. 1 Stages of posterior release: (a) neurolysis of the peroneal nerve; (b) lengthening of the distal biceps tendon; (c) fractional lengthening of the semimembranosus muscle, dissection of the gracilis muscle at the transition from the muscular to the tendinous part, and the semitendinosus muscle in its most distal part; (d) posterior capsulotomy

In the study group, the basic and mobile supports were connected by six struts of an orthopedic hexapod [20]. On the first day after surgery, X-ray control of the knee joint was performed in two projections. Checking radiographs were opened in the orthopedic hexapod software (SUV-Software v.7.2). For the calculation, a distraction rate of 5–7 mm was set at the initial stage. Then, using the multi-stage correction option, staged (every 10°) calculations of leg extension were performed. Considering the possibility of the “rebound” phenomenon (recurrence of contracture due to soft tissue retraction), “hyperextension” of the lower leg within 5–7° was added to the calculations in the software (Fig. 2b). The initial rate of extension was 2.5° per day in four steps. Distraction began on the second to fourth days after surgery; next, lower leg extension was initiated. The initial extension rate could be accelerated or slowed depending on pain severity. Upon completion of the extension period, the orthopedic hexapod struts were dismantled, and the base and mobile supports were connected with fixation hinges.

The above parameters were based on the works of Herzenberg et al., Balci et al., which noted the occurrence of the rebound phenomenon and provided recommendations for the prevention of this complication [14, 21]. In the work of Volkov and Oganessian, recommendations were given for the rate of lower leg extension in the EFD of 2–6° per day [22]. In our study, using a computer program for an orthopedic hexapod, we expected to complete a staged extension equal to 10° in four days. The formula was as follows: $10^\circ / 4 \text{ days} = 2.5^\circ \text{ per day}$, which is close to the minimum values recommended by the authors and, in our opinion, is optimal for the initial rate.

In the comparison group, the basic and mobile supports were connected by axial hinges positioned under image intensifier control in the projection of the knee joint flexion-extension axis [23]. Passive movements were performed using rotation hinges (Fig. 3). The initial distraction rate was 8 mm (an average of 2–2.5° per day) in four steps; it was also adjusted, as in the patients in the study group and depended on pain [22].

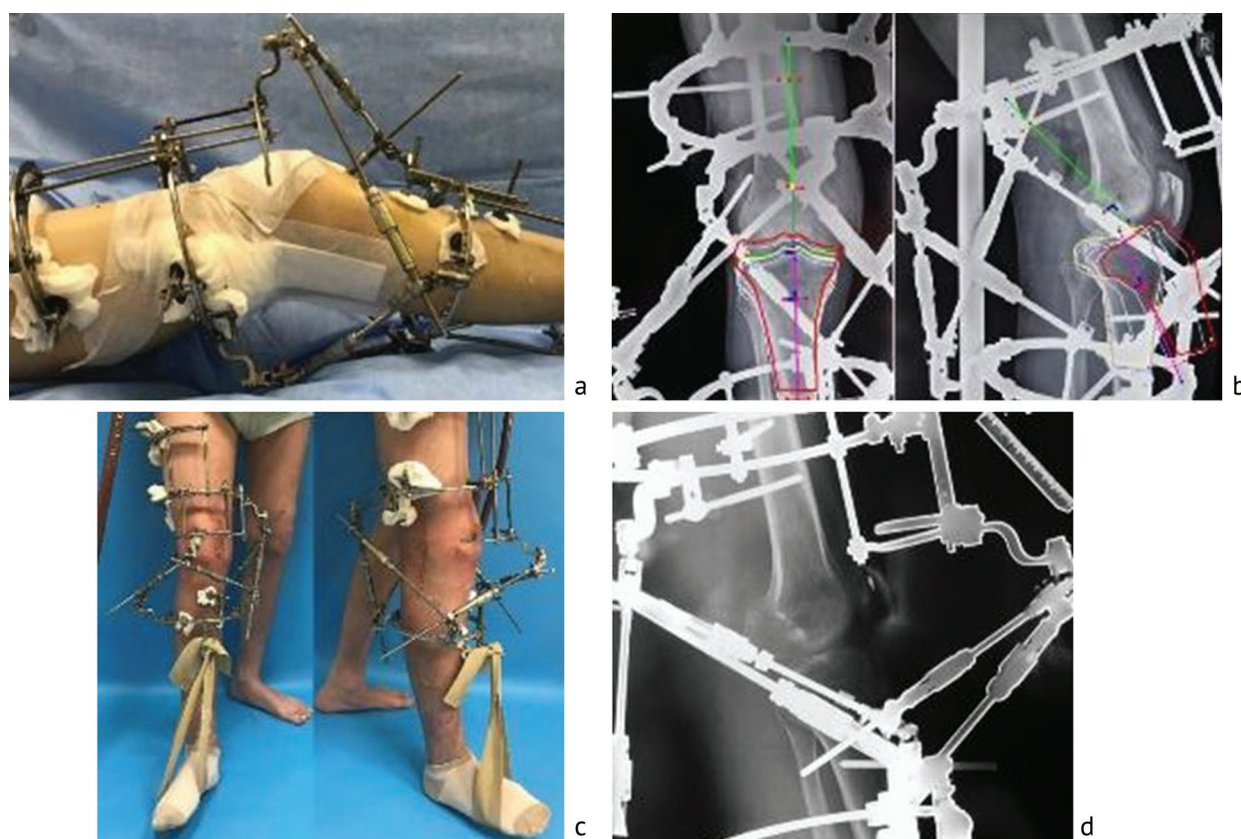


Fig. 2 Application of the orthopedic hexapod: (a) appearance after placement of the orthopedic hexapod; (b) calculation of lower leg extension in a computer program; (c, d) a photograph and a radiograph in lateral projection after completion of the lower leg extension stage

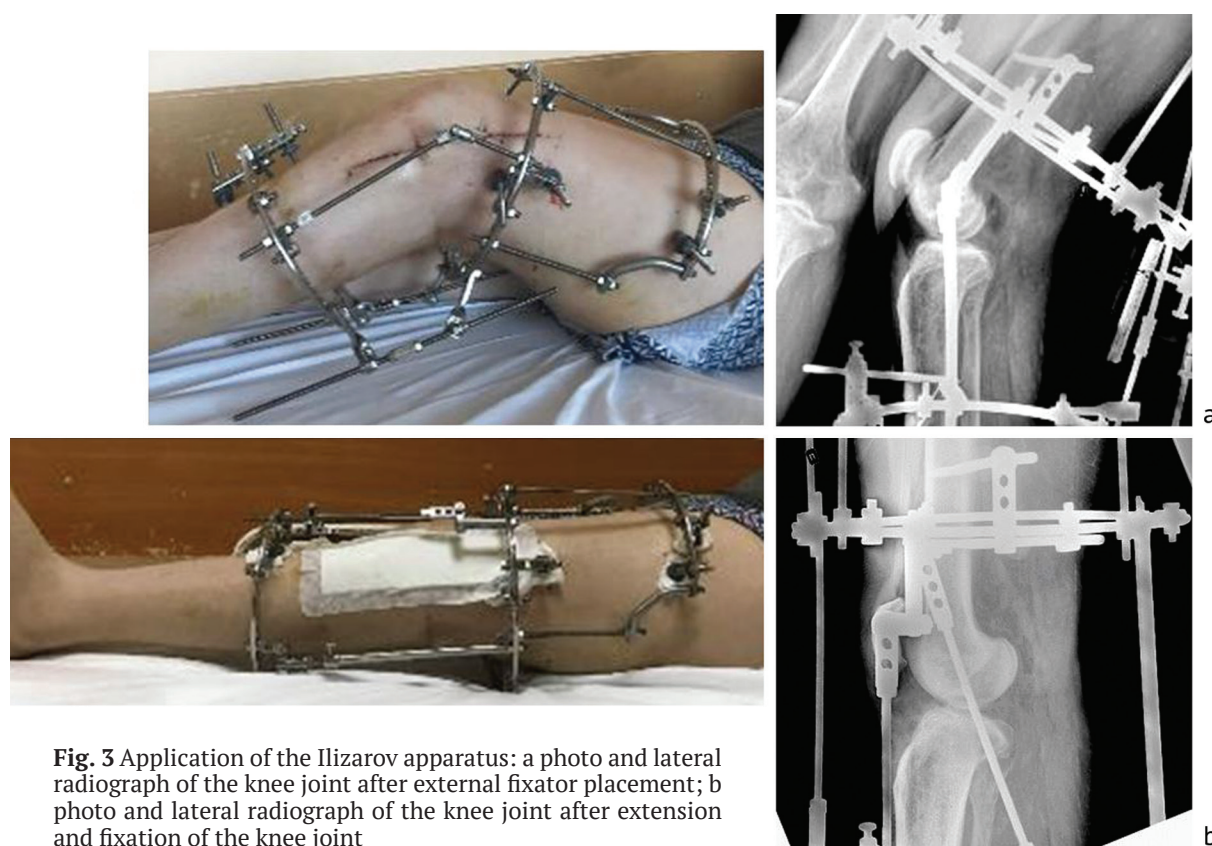


Fig. 3 Application of the Ilizarov apparatus: a photo and lateral radiograph of the knee joint after external fixator placement; b photo and lateral radiograph of the knee joint after extension and fixation of the knee joint

In both groups, after completion of the extension stage, the knee joint was immobilized in a hyperextension with the EF for six weeks. After that, the device was removed, and the knee joint was immobilized for another three weeks with a plaster cast or orthosis. The postoperative care and rehabilitation protocol for both groups was generally similar. In both groups, from the moment the EF was removed, patients were recommended to undergo rehabilitation courses, including physical therapy sessions with a physician, mechanotherapy, electrical muscle stimulation of the quadriceps, and therapeutic massage.

Some differences were observed in patients included in the subgroups with posterior tibial subluxation. In 12 patients (34 %) from subgroup 1, after calculating the extension magnitude, correction of subluxation was additionally calculated using the "multi-stage correction" software option. In eight patients (25 %) from subgroup 2, posterior tibial subluxation was corrected after joint extension by moving the mobile support anteriorly. The postoperative rehabilitation and care protocol after EF removal were generally the same as described above. However, given the concomitant preoperative subluxation, such patients in both subgroups were recommended to immobilize the knee joint in the EF for eight weeks rather than six.

Comparison of the results

For comparison, the duration of different treatment stages (Fig. 4), range of motion and, in particular, extension deficit after EF dismantling were analyzed according to the criteria of Herzenberg et al. [21]. According to the proposed criteria, an extension deficit of $< 5^\circ$ was considered excellent, of $6-15^\circ$ — good, $16-29^\circ$ — fair, and $> 30^\circ$ — poor. Complications of the treatment were assessed according to the classification of Caton [24]. The function of the knee joint and the lower limb as a whole was assessed using the Lysholm, KSS (Knee Society Score) and LEFS (Lower Extremity Functional Scale) questionnaires [25–27]. The listed parameters were assessed before surgery, on the second day after EF dismantling, six and 12 months after EF dismantling. In prospectively examined patients from the study group ($n = 14$), the parameters were additionally assessed at three and nine months after EF dismantling.

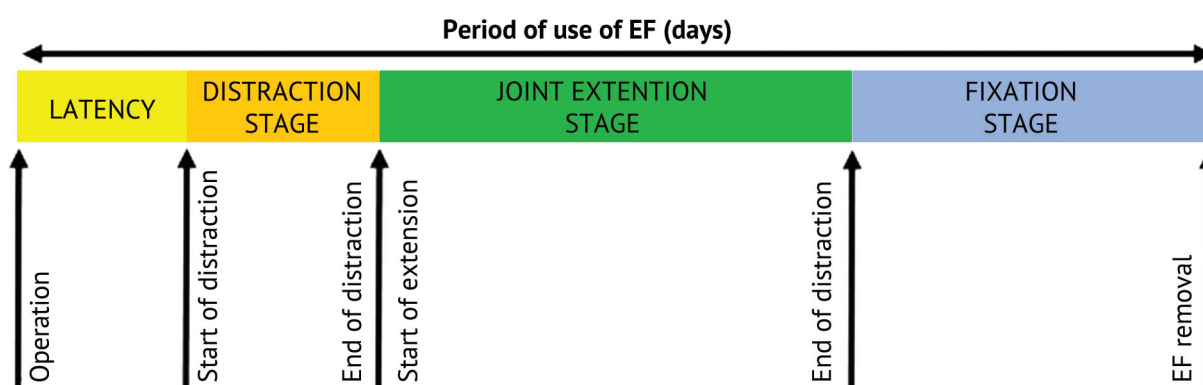


Fig. 4 Treatment stages in the patients with flexion knee joint contractures

Statistical analysis

The data were recorded in Microsoft Excel spreadsheets. Statistical analysis was performed using Statistica v.10 and jamovi 2.6.17. Normality of distribution was determined using the Shapiro – Wilk test. Due to the abnormal distribution of most analyzed numerical variables, nonparametric statistical methods were used. Quantitative parameters in two independent groups were assessed using the Mann – Whitney U test. Given the use of nonparametric methods, quantitative data were presented as medians (Med) and lower and upper quartiles (Q1:Q3). Statistical processing

and analysis of nominal data were performed using the Chi-square test (with Yates' correction for small groups) and Fisher's exact test. For the analysis of dependent samples in the same group and the study of dynamic parameters after surgery, the Wilcoxon and Friedman tests were used.

Patients signed informed consent for examination, treatment, collection, storage and analysis of medical records for scientific and educational purposes, as well as their publication.

RESULTS

Since the posterior release operation, full extension (from 35° to hyperextension of 5°) in the knee joint in the study group was achieved in an average of 22 [18;27] days, and in the comparison group (from 30° to hyperextension of 5°) in 24.5 [21;31] days (Table 2; Table 3).

In a comparative analysis, a significantly shorter extension period was observed in the study group ($p < 0.05$). Comparison of the average duration of the fixation period found similar indicators ($p > 0.05$): 46 days in the study group and 45 days in the comparison group (Table 2). The total duration of EF in both groups also did not have significant differences ($p < 0.05$): 78 days in the study group and 76.5 days in the comparison group (Table 2).

Table 2

Comparative characteristics of treatment stages

Stage	Stage duration, days Med [Q1; Q3]		
	Study group	Comparison group	<i>p</i> -value
Latent stage	3.0 [2;4]	3.0 [2;5]	> 0.05
Distraction stage	3.0 [2;3]	3.0 [2;3]	> 0.05
Extension stage	22.0 [18;27]	24.5 [21;31]	< 0.05
Fixation stage	46.0 [43;54]	45.0 [43;50]	> 0.05
Total time with the EF on	78.0 [68;86]	76.5 [71;89]	> 0.05

Assessment of the range of motion (maximum flexion and extension) of the knee joint after dismantling the EFD found comparable ($p < 0.05$) rates of reduction in the magnitude of maximum flexion in both groups: on average from 130° to 30° in the study group and from 122° to 33° in the comparison group, while the achieved full extension was maintained (Table 3).

Table 3

Goniometric knee joint examination data

Study time point	Goniometric indicators, degrees, Med [Q1; Q3]			
	Study group		Comparison group	
	Maximum flexion	Extension deficit	Maximum flexion	Extension deficit
Preoperatively	130 [130;135]	65 [55;70]	122 [120;135]	67 [55;72]
After release	130 [130;135]	35 [30;45]	122 [120;135]	30 [20;40]
Day 2 after frame removal	30 [25;35]	0 [0;0]	33 [24;35]	0 [0;0]
Follow-up, 6 months	80 [65;85]	0 [0;0]	79 [58;84]	0 [0;0]
Follow-up, 12 months	110 [97;120]	0 [0;0]	104 [95;108]	0 [0;0]

Evaluation of the average flexion in the knee joint showed a comparable ($p < 0.05$) increase from 30° to 80° in the study group and from 33° to 79° in the comparison group six months after EF dismantling, and an increase from 80° to 110° in the study group and from 79° to 104° in the comparison group after 12 months.

At six months from the moment of EF dismantling, one case of extension deficit of 7° was detected in the study group, which increased during the follow-up at 12 months from the moment of EF removal. In the comparison group, at six months from the moment of EF cessation, the extension

deficit was found in three patients: 7° in two (6.25 %) and 5° in one (3.1 %). After 12 months, the extension deficit was also equal to 7° in two (6.25 %) patients, and in the third, the extension deficit increased by 3° (to 8°). Moreover, the average extension deficit noted at six and 12 months from the moment of EF removal was 0° in both groups ($p < 0.05$). According to the extension deficit assessment criteria of Herzenberg et. al. [23], 12 months after the EF dismantling in the study group, excellent results were noted in 34 cases (97.14 %), and one was good (2.86 %). In the comparison group, excellent results were recorded in 29 cases (82.85 %) and good in three cases (9.37 %).

The joint and limb function assessment data using the specialized KSS, Lysholm, and LEFS scales are presented in Table 4. In both groups of this study, an improvement in mean scores compared to preoperative functional indices was noted on all three scales.

One year after EF removal, all patients in the study group (100 %) had excellent joint function scores according to the KSS scale. In the comparison group, excellent joint function results according to the KSS scale were recorded in 27 patients (77.14 %), and good ones in five patients (15.6 %).

One year after EF removal, 32 patients (91.42 %) in the study group had excellent joint function according to the Lysholm scale, and three (8.58 %) had good function. In the comparison group, 23 patients (71.87 %) achieved excellent joint function according to the Lysholm scale, while the remaining nine patients (28.12 %) had good results.

At 12 months after EF removal, the LEFS score showed a slight limitation of lower limb function in all patients (100 %) in both study groups.

A comparative analysis of the KSS and Lysholm scores recorded after EF removal at six and 12 months revealed significantly better knee function in the study group ($p < 0.05$). Assessment of the lower limb function using the LEFS scale showed that the mean scores obtained were comparable ($p < 0.05$) at all follow-ups.

Table 4

Results of joint functional assessment at different stages of the study

Study time point	Functional assessment of the joint with scales (points), Med [Q1; Q3]					
	KSS		Lysholm		LEFS	
	Orto-SUV	Ilizarov	Orto-SUV	Ilizarov	Orto-SUV	Ilizarov
Before surger	43.0 [41;45]	43.0 [43;45]	57.0 [55;60]	55.0 [53;60]	15.0 [11;19]	16.0 [14;18]
	$p > 0.05$		$p > 0.05$		$p > 0.05$	
Day 2 after frame removal	55.0 [53;55]	53.0 [51;55]	59.0 [55;61]	55.0 [51;59]	23.0 [22;25]	24.5 [23;26]
	$p < 0.05$		$p < 0.05$		$p > 0.05$	
Follow-up, 6 months	80.0 [75;81]	77.0 [69;81]	85.0 [83;85]	81.0 [71;83]	64.0 [60;67]	62.5 [59;66]
	$p < 0.05$		$p < 0.05$		$p > 0.05$	
Follow-up, 12 months	102.0 [94;103]	100.0 [92;101]	99.0 [93;100]	95.0 [88;99]	74.0 [72;76]	73.5 [70;76]
	$p < 0.05$		$p < 0.05$		$p > 0.05$	

The dynamics of changes in maximum flexion, extension deficit, and mean scores on the functional scales in prospective patients of the study group are shown in Table 5. After EF removal, a fourfold decrease in the maximum flexion angle was recorded compared to preoperative measurements. Moreover, from the moment of EF removal, a gradual improvement was noted: the knee flexion angle increased, reaching good values by nine months and excellent values by 12 months. Excellent functional results according to the KSS scale were recorded at the ninth month after EF removal; however according to the Lysholm scale, this was revealed only at the 12th month. According to the LEFS scale, at six months after EF removal, patients demonstrated only minor limitation of lower limb function.

Table 5

Dynamics of changes in functional indicators according to goniometric study and assessment scales

Time point	Functional indicators of goniometric study and assessment scales, Med [Q1; Q3]				
	Maximum flexion, °	Extension deficit, °	KSS, points	Lysholm, points	LEFS, points
Before operation	130 [130;135]	62.5 [55;65]	41 [39;44]	58.5 [57;60]	15.5 [11;19]
After release	130 [130;135]	30 [25;35]	–	–	–
After EF removal	30 [25;35]	0 [0;0]	55 [52;58]	59 [55;61]	25 [23;27]
3-months follow-up	55 [50;65]	0 [0;0]	65 [61;67]	74 [71;76]	49 [47;53]
6 month follow-up	85 [70;85]	0 [0;0]	81 [75;81]	85 [83;85]	66 [62;67]
9-month follow-up	101 [85;110]	0 [0;0]	100.5 [87;103]	94 [90;99]	72 [71;74]
12 months follow-up	115 [100;120]	0 [0;0]	103 [94;103]	99 [93;100]	74 [72;76]

A comparative analysis revealed that patients with preoperative posterior subluxation of the tibia had a significantly increased duration of EF application ($p < 0.05$) due to both the duration of extension and fixation (Table 6). Patients with preoperatively diagnosed posterior subluxation of the tibia showed a statistically significant ($p < 0.05$) deterioration in the values of maximum flexion as well as in the functional status on all three scales at 12 months after EF removal, compared to those patients in whom the dislocation was not diagnosed (Table 6).

Table 6

Comparison of the evaluation results of various indicators

Indicator	Evaluation, Med [Q1;Q3]			
	Study group		Comparison group	
	No subluxation ($n = 23$)	Subluxation ($n = 12$)	No subluxation ($n = 23$)	Subluxation ($n = 8$)
Extension duration, days	19 [16;25]	25 [22;28]	22 [20;25]	32.5 [31;36]
Fixation duration, days	44 [42;43]	55 [53;55]	44 [42;46]	54.5 [54;55]
Total time with the AEF on, days	44 [42;46]	86 [83;89]	92 [89;97]	74 [70;78]
Range of motion (maximum flexion, °)				
Immediately after AEF removal	35 [32;37]	22 [20;25]	34 [30;35]	21 [20;22]
At 6 months follow-up	85 [81;87]	61 [55;65]	80 [78;85]	56 [55;57]
At 12 months follow-up	115 [110;120]	95 [93;100]	105 [90;95]	94 [100;112]
Range of motion (extension deficit, °)				
Immediately after AEF removal	0	0	0	0
At 6 months follow-up	0	0	0	0 [0;5]
At 12 months follow-up	0	0	0	0 [0;7]
Evaluation score after 12 months, points				
KSS	103 [102;103]	93 [92;94]	100 [94;102]	90 [90;92]
LYS	99 [99;100]	93 [92;95]	95 [94;99]	85 [85;87]
LEFS	75 [74;76]	71 [69;72]	74 [73;76]	69 [67;70]

The complication rate in the study group was 34.28 % (12 cases), including nine episodes (25.7 %) of superficial soft tissue inflammation around the transosseous elements (category 1) without loss of stability. The inflammatory process was stopped with chloramphenicol ointment and oral antibacterial therapy. In one case (2.85 %), a fracture of the lower third of the femur was diagnosed, due to which the extension procedure was temporarily suspended for EF readjustment and fracture stabilization (category 2). Instability of the proximal support was detected in one case (2.85 %), which required the insertion of additional transosseous elements for its stabilization (category 2), after which the extension procedure was resumed. Infection of the hematoma at the surgical site was reported in one patient (2.85 %), leading to temporary suspension of extension for exploration, debridement, and drainage of the infectious focus, followed by bacteriological examination of the hematoma contents and selection of specific antibiotic therapy. After the purulent-inflammatory process was resolved, extension was resumed (category 2).

In the comparison group, complications were observed in 31.42 % of patients (11 cases): 18.75 % (six cases) of soft tissue inflammation around the transosseous elements (category 1), managed conservatively; 15.63 % (five cases) of minor posterior subluxation of the tibia during the extension stage (category 2), corrected by moving the mobile support after completion of the extension stage. No statistically significant differences in complication rates were found between the groups ($p > 0.05$).

DISCUSSION

The analysis of the duration of the EF treatment stages (Table 3) revealed a statistically significant reduction in the extension stage by 2.5 days (9.8 %) in the study group ($p < 0.05$). This difference is likely due to the fact that in the study group, subluxation correction ($n = 12$) was performed synchronously with extension, in contrast to the comparison group ($n = 8$), where correction was performed in stages: first extension, then subluxation correction by changing the position of the mobile support according to the Ilizarov method. This is also confirmed by the fact that in the orthopedic hexapod subgroup, the extension period in patients with subluxation was, on average, seven days shorter than in similar patients in the comparison subgroup (Table 6).

Another possible factor may be a faster rate of extension due to less pain in patients who underwent joint extension using an orthopedic hexapod. Unfortunately, we cannot confirm this fact definitively, as we did not conduct a visual analog scale assessment in this study. However, even though the extension period in the study group was 2.5 days shorter, the total duration of EF use in the compared groups did not differ significantly. This indicates that there is no significant advantage to using one type of device over the other in terms of treatment duration.

Following EF removal, a decrease in maximum flexion of 76 % in the study group and 72 % in the control group, compared with baseline values, was recorded. This may be due to the fact that prolonged fixation aimed at maintaining full extension of the knee joint contributes to the development of immobilization extension contracture. According to Krupko IL, movement restriction for up to 10 weeks is classified as the unstable contracture phase [28]. This explains successful conservative treatment, as evidenced by dynamic observation data demonstrating a gradual improvement in joint function during rehabilitation measures (Tables 2, 4, 5).

The analysis of maximum flexion parameters revealed no significant differences between the groups at any stage of the study. However, in regard to concomitant preoperative tibia subluxation, all patients with this condition demonstrated lower functional parameters. This is likely due to the longer duration of knee fixation in these patients, which directly impacted joint function.

The analysis of the extension deficit revealed no significant differences between the groups. The obtained data indicate comparable joint extension efficacy using both the orthopedic hexapod and the Ilizarov apparatus. However, recurrence was observed in one patient in the study group (up to 10°) and three patients in the comparison group (two 7° and one 8°). The contracture in those patients was accompanied by posterior subluxation of the tibia. Based on the anamnesis data, it is known that none of those three patients with concomitant preoperative subluxation properly complied with the prescribed three-week period of plaster immobilization after EF removal. It can be assumed that neglected immobilization in the early stage after EF removal contributed to the development of the "rebound" phenomenon. However, a precise determination of the cause is difficult due to the retrospective assessment of minor contracture recurrence in those patients six months after EF removal.

The analysis revealed significantly higher mean scores on the KSS and Lysholm scales at six and 12 months after EF removal in the study group. Knee joint stability is one of the evaluation criteria in the KSS and Lysholm questionnaires. A comparative analysis of the KSS questionnaires (completed by patients and the physician) revealed that the decrease in total scores in the control group was primarily due to symptoms of knee instability. Five patients in the "joint stability" column of the Lysholm questionnaire indicated difficulty with intense physical activity due to joint instability.

After analyzing the clinical history and imaging data, we concluded that instability was caused by overstretching of the capulo-ligamentous structures due to inaccurate positioning of the axial hinge relative to the flexion-extension axis. In these five patients from the comparison group, we observed slight subluxation of the tibia after completing the extension phase. Although the tibia subluxation in these patients was corrected during their hospital stay, instability symptoms due to incorrect positioning of the axial hinges still persisted. Furthermore, overall lower limb function, assessed using the LEFS scale, showed no significant differences between the groups at any follow-up point.

The data of a systematic review devoted to the use of external fixation devices for knee joint contractures demonstrate that the most frequently used device is the Ilizarov device with a single-axis hinge [18]. The overwhelming majority of studies (seven out of eight) mention the use of external fixation devices specifically for flexion contractures of the knee joint [18]. It should also be noted that not all patients underwent a soft tissue release before EF placement. According to the study by Herzenberg et al., with an initial flexion contracture of approximately 60°, posterior release was performed in only eight of 14 patients [21]. The authors did not provide details of the release technique or the extension values achieved after its implementation. The average duration of EF application was 3.5 months (range 1.25–8.5 months), which is longer than in our groups and may be due to the lack of release. Among the eight patients who underwent release, the results were distributed as follows: excellent (extension deficit < 5°) — two cases, good (6–15°) — two cases, fair (16–29°) — two cases, and poor (> 30°) — two cases. The mean residual extension deficit (16°) exceeded the extension deficit observed in both groups of this study. Among the complications mentioned by the authors, there were cases of soft tissue inflammation around the transosseous elements (category 1), without specifying the number of cases.

Balci et al. described the results of combined treatment of flexion contractures of the knee joint using the Ilizarov apparatus and posterior release (6/6 cases) [14]. The release technique included Z-shaped lengthening of the tendons of the medial flexor group, lengthening of the biceps femoris tendon (without specifying the technique), release of the heads of the gastrocnemius muscles and the joint capsule (without details). The authors did not indicate the magnitude of the achieved extension immediately after the release. The average follow-up period was eight years (5.5–10), and the duration of EF application was 4.4 months (2.5–10), which is longer than our results. The initial extension deficit averaged 45° (30–75°), and after eight years of follow-up it was 10° (5–15°), which is also higher than in our study. Complications included one case (16.6 %) of soft tissue inflammation around the transosseous elements (category 1), and one case (16.6 %) of postoperative subluxation of the tibia (category 2). The complication rates could not be conducted with our data due to a small sample size ($n = 6$) in that study.

Among the analyzed foreign publications, only the study by Vulcano et al. described the use of an orthopedic hexapod (Taylor Spatial Frame), but the authors did not provide any photographic documentation of the use of the structure or data on working with the computer program [29]. According to the study data, posterior release was performed in 19 of 21 patients (90.5 %) before EF placement, but the technical details of the procedure were not described. The follow-up period averaged 13 months (10–18 months). The initial extension deficit averaged 44° (range 10–120°), and at the final examination it was 10° (0–50°), which exceeds similar indicators in both of our groups. The average period of EF application reached three months. Among the reported complications, the authors noted inflammation at the site of the transosseous elements in 15 patients (71 %) (category 1), a hip fracture in one patient (4.8 %), and a complete recurrence of contracture in two patients (9.5 %) (40° in one and 45° in the other one) due to the lack of pharmacological control of spasticity. A significantly lower complication rate was observed in both groups of our study.

In the study of Damsin et al. posterior release was performed in only three of 13 patients, and Huang performed releases in two of 10 patients. We considered only complications that arose during extension in the EF device [30, 31]. Thus, Damsin et al. recorded: one case (7.6 %) of peroneal nerve

neuropathy, three cases (23 %) of impression fracture, three cases (23 %) of tibial subluxation. Huang reported two cases (20 %) of tibial subluxation, one case (10 %) of knee joint instability. In our study, minor tibial subluxation was observed in five patients (15.6 %) in the group with the Ilizarov apparatus what is a lower percentage than in the works of Damsin et al and Huang. However, due to differences in group size, we believe that a comparative analysis of complication rates cannot be completely reliable.

The study by Zhai et al. lacked data on either soft tissue release or possible complications during extension in the EF device, and therefore we did not conduct a comparison with this study [32].

Compared with the results of the above studies, the total duration of Ef application in both our groups was significantly shorter (1.4 times, an average of 28 days). As for functional outcomes, foreign authors also observed lower results. This difference can be attributed to the use of a more effective posterior release technique in our study. During the soft tissue stage, we achieved maximum possible knee extension, limited only by the tension of the neuro-vascular bundle. Thus, in the study group, after the soft tissue stage, the average achieved knee extension was 45 % (41–50 %) of the baseline value, while in the comparison group, after the posterior release, this figure was 53 % (38–60 %). Regarding the complications observed in patients in both subgroups of our study, their incidence generally does not exceed the rates described in the literature and is even significantly lower as compared with some studies.

We followed Caton's classification of complications in our study which fundamental goal is to assess the impact of the complication on the final outcome [24]. Using this classification, it was important for us to indicate not the severity of the complication, but its category, in order to determine whether the complication affected the final outcome. We did not find any significant differences in the impact on the final outcome in this study.

Based on the obtained results of our study, both EF types are undoubtedly an effective adjunct to posterior release surgery in the treatment of persistent flexion contractures of the knee joint. For extension contractures of the knee joint, the use of an orthopedic hexapod has been shown to achieve higher functional indicators in a shorter duration of external fixation [20]. In the case of flexion contractures, with proper surgical technique and correct positioning of the hinge along the flexion-extension axis, the use of an orthopedic hexapod does not offer any evident advantages over the Ilizarov apparatus.

CONCLUSION

The comparison of knee joint range of motion in both groups at all follow-up points showed comparable results. Knee function, assessed using specialized scales, was better in the study group, while overall lower limb function in both groups did not differ at all follow-ups. The orthopedic hexapod allows for faster joint extension; however, a comparative analysis of the overall period of EF application (from placement to removal) demonstrated no advantages for one external fixation type over the other. The results suggest that both EF types are effective in treating patients with knee flexion contractures. For knee flexion contractures associated with tibia subluxation, the orthopedic hexapod is preferable due to its ability to simultaneously achieve extension and resolve tibia subluxation, resulting in a shorter extension stage.

Conflict of interests Solomin LN is Orto-SUV ltd director, where the Orto-SUV hexapod was developed.

Source of funding The study was conducted without sponsorship.

Informed consent The authors obtained informed consent for the examination, treatment, collection, storage, and analysis of medical records for scientific and educational purposes, as well as for their publication. The authors confirm that the article does not contain any data that is not suitable for publication.

REFERENCES

1. Richards C, Higginson JS. Knee contact force in subjects with symmetrical OA grades: differences between OA severities. *J Biomech.* 2010;43(13):2595–2600. doi: 10.1016/j.jbiomech.2010.05.006.

2. Attias M, Chevalley O, Bonnefoy-Mazure A, et al. Effects of contracture on gait kinematics: A systematic review. *Clin Biomech (Bristol)*. 2016;33:103-110. doi: 10.1016/j.clinbiomech.2016.02.017.
3. Sendroy-Terrill M, Whiteneck GG, Brooks CA. Aging with traumatic brain injury: cross-sectional follow-up of people receiving inpatient rehabilitation over more than 3 decades. *Arch Phys Med Rehabil*. 2010;91(3):489-497. doi: 10.1016/j.apmr.2009.11.011.
4. Wissel J, Verrier M, Simpson DM, et al. Post-stroke spasticity: predictors of early development and considerations for therapeutic intervention. *PM R*. 2015;7(1):60-67. doi: 10.1016/j.pmrj.2014.08.946.
5. Ogorodova II, Zagorodneva VI, Ogorodov IA, Belaya NN. Morphological changes of the children's muscular apparatus with spastic forms of cerebral palsy during different approaches to the treatment. *Child and adolescent rehabilitation*. 2014;(1):24-30. (In Russ.)
6. Zinovyeva OE, Golovacheva VA. Questions of pathogenesis and treatment of post-stroke spasticity. *Medical Council*. 2016;(8):63-67. (In Russ.) doi: 10.21518/2079-701X-2016-8-63-67.
7. Vahedi H, Khlopas A, Szymczuk VL, et al. Treatment with posterior capsular release, botulinum toxin injection, hamstring tenotomy, and peroneal nerve decompression improves flexion contracture after total knee arthroplasty: minimum 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(8):2706-2714. doi: 10.1007/s00167-020-05939-0.
8. Chung CY, Kwon SS, Park MS, et al. Surgical outcomes after single event multilevel surgery in cerebral palsy patients with mid-stance knee hyperextension. *Gait Posture*. 2020;77:1-5. doi: 10.1016/j.gaitpost.2020.01.005.
9. Bozinovski Z, Popovski N. Operative treatment of the knee contractures in cerebral palsy patients. *Med Arch*. 2014;68(3):182-183. doi: 10.5455/medarh.2014.68.182-183.
10. Jones S, Al Hussainy HA, Ali F, et al. Davies AG. Distal hamstring lengthening in cerebral palsy: the influence of the proximal aponeurotic band of the semimembranosus. *J Pediatr Orthop B*. 2006;15(2):104-108. doi: 10.1097/01.bpb.0000179272.61726.a0.
11. Sung KH, Lee J, Chung CY, et al. Factors influencing outcomes after medial hamstring lengthening with semitendinosus transfer in patients with cerebral palsy. *J Neuroeng Rehabil*. 2017;14(1):83. doi: 10.1186/s12984-017-0296-0.
12. Karol LA, Chambers C, Popejoy D, Birch JG. Nerve palsy after hamstring lengthening in patients with cerebral palsy. *J Pediatr Orthop*. 2008;28(7):773-776. doi: 10.1097/BPO.0b013e318186bddd.
13. Gaurav K, Vilas J. A new approach to the management of fixed flexion deformity of the knee using Ilizarov's principle of distraction histogenesis: a preliminary communication. *Int J Low Extrem Wounds*. 2010;9(2):70-73. doi: 10.1177/1534734610371559.
14. Balci HI, Kocaoglu M, Eralp L, Bilen FE. Knee flexion contracture in haemophilia: treatment with circular external fixator. *Haemophilia*. 2014;20(6):879-883. doi: 10.1111/hae.12478.
15. Yaddikar S, Grover R, Kaur P, et al. Soft-tissue origin joint contractures treated with the Ilizarov fixation method. *Genij Ortopedii*. 2024;30(2):255-262. doi:10.18019/1028-4427-2024-30-2-255-262.
16. Sommers MB, Fitzpatrick DC, Kahn KM, et al. Hinged external fixation of the knee: intrinsic factors influencing passive joint motion. *J Orthop Trauma*. 2004;18(3):163-169. doi: 10.1097/00005131-200403000-00007.
17. Rokhovev SA, Solomin LN, Starchik DA. Template of instant centers of rotation developed for the knee joint (experimental study). *Genij Ortopedii*. 2022;28(4):554-558. doi: 10.18019/1028-4427-2022-28-4-554-558.
18. Rokhovev SA, Solomin LN. Usage of External Fixation in the Treatment of Adult Patients with Knee Joint Stiffness: Review. *Traumatology and Orthopedics of Russia*. 2021;27(1):185-197. (In Russ.) doi: 10.21823/2311-2905-2021-27-1-185-197.
19. Rokhovev S.A., Chugaev D.V., Solomin L.N. Treatment of Extension Knee Contractures with Ilizarov Apparatus Versus Orthopedic Hexapod Ortho-SUV Frame. *Traumatology and Orthopedics of Russia*. 2021;27(1):185-197. 2022;28(2):7-19. doi: 10.17816/2311-2905-1756.
20. Solomin LN, Schepkina EA, Vilensky VA, et al. Correction of femur deformities by ilizarov method and by apparatus "Ortho-Suv" based on computer navigation. *Traumatology and Orthopedics of Russia*. 2011;17(3):32-39. (In Russ.) doi: 10.21823/2311-2905-2011-0-3-32-39.
21. Herzenberg JE, Davis JR, Paley D, Bhav A. Mechanical distraction for treatment of severe knee flexion contractures. *Clin Orthop Relat Res*. 1994;(301):80-88.
22. Volkov MV, Oganessyan OV. *Reduction of the shape and function of joints and bones (by the authors' apparatus)*. Moscow.: Meditsina; 1986:256. (In Russ.)
23. Hollister AM, Jatana S, Singh AK, et al. The axes of rotation of the knee. *Clin Orthop Relat Res*. 1993;290:259-268.
24. Caton J. Treatment of leg length discrepancies and short stature in children and adolescents. *Rev Chir Orthop*. 1991;77 (Suppl. I):31-80. (In Franc.)
25. Kettelkamp DB, Chao EY. A method for quantitative analysis of medial and lateral compression forces at the knee during standing. *Clin Orthop Relat Res*. 1972;83:202-213. doi: 10.1097/00003086-197203000-00037.
26. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985;(198):43-49.
27. Dingemans SA, Kleipool SC, Mulders MAM, et al. Normative data for the lower extremity functional scale (LEFS). *Acta Orthop*. 2017;88(4):422-426. doi: 10.1080/17453674.2017.1309886.
28. Krupko IL. *Handbook of Traumatology and Orthopedics. Book 2. Orthopedics*. Leningrad: Medicine; 1975:270. (In Russ.)
29. Vulcano E, Markowitz JS, Fragomen AT, Rozbruch SR. Gradual correction of knee flexion contracture using external fixation. *J Limb Lengthen Reconstr*. 2016;2(2):102-107. doi: 10.4103/2455-3719.190712.
30. Damsin JP, Ghanem I. Treatment of severe flexion deformity of the knee in children and adolescents using the Ilizarov technique. *J Bone Joint Surg Br*. 1996;78(1):140-144.
31. Huang SC. Soft tissue contractures of the knee or ankle treated by the Ilizarov technique. High recurrence rate in 26 patients followed for 3-6 years. *Acta Orthop Scand*. 1996;67(5):443-449. doi: 10.3109/17453679608996665.
32. Zhai J, Weng X, Zhang B, et al. Management of knee flexion contracture in haemophilia with the Ilizarov technique. *Knee*. 2019;26(1):201-206. doi: 10.1016/j.knee.2018.08.006.

The article was submitted 16.09.2025; approved after reviewing 23.12.2025; accepted for publication 09.02.2026.

Information about the authors:

Leonid N. Solomin — Doctor of Medical Sciences, Professor, Leading Researcher, solomin.leonid@mail.ru, <https://orcid.org/0000-0003-3705-3280>;

Saigidula A. Rokhovev — orthopaedic surgeon, 09saga@mail.ru, <https://orcid.org/0000-0003-4369-9619>.