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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- 33-A2 and A3		 10 (32.3%) 21 (67.7%)	 14 (42.4%) 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 3 years 4 years		 12 (38.7%) 15 (48.3%) 4 (12.9%)	 15 (45.4%) 15 (45.4%) 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.

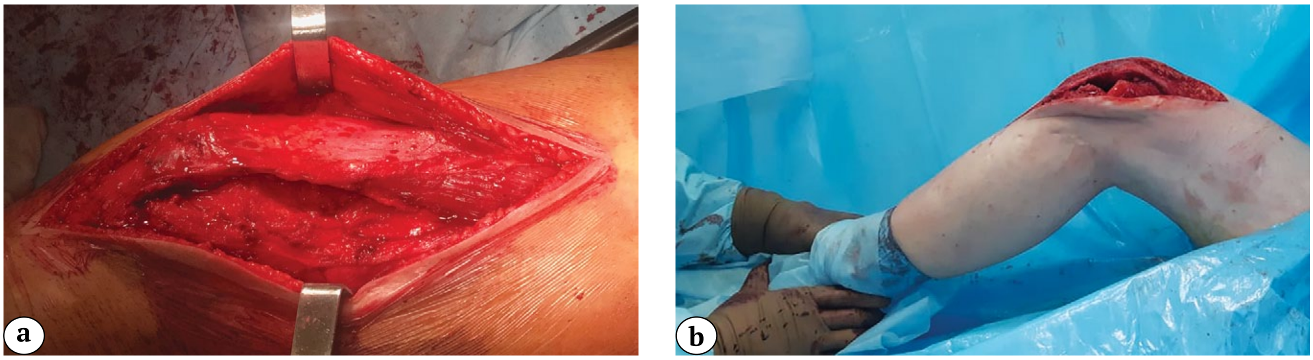

Fig. 1. Soft tissue procedure: a — after soft tissue release; b — maximal flexion 65°

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.

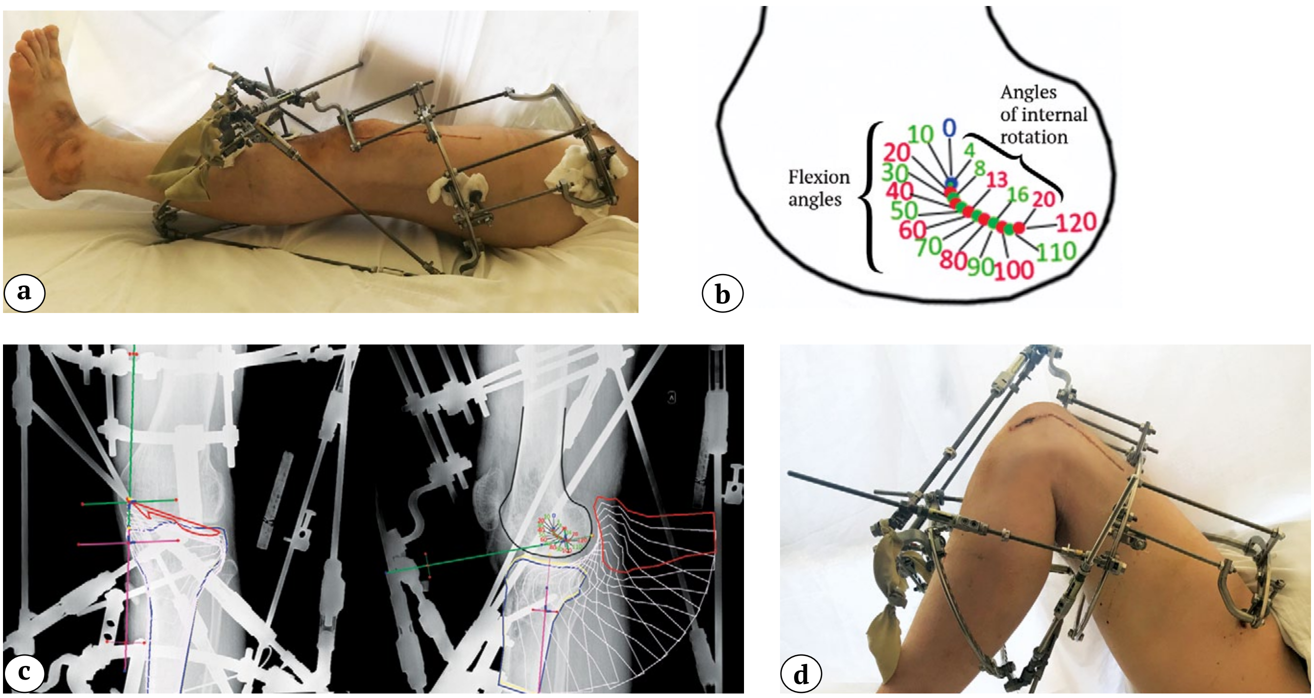

Fig. 2. Usage of Ortho-SUV Frame (OSF) hexapod:

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

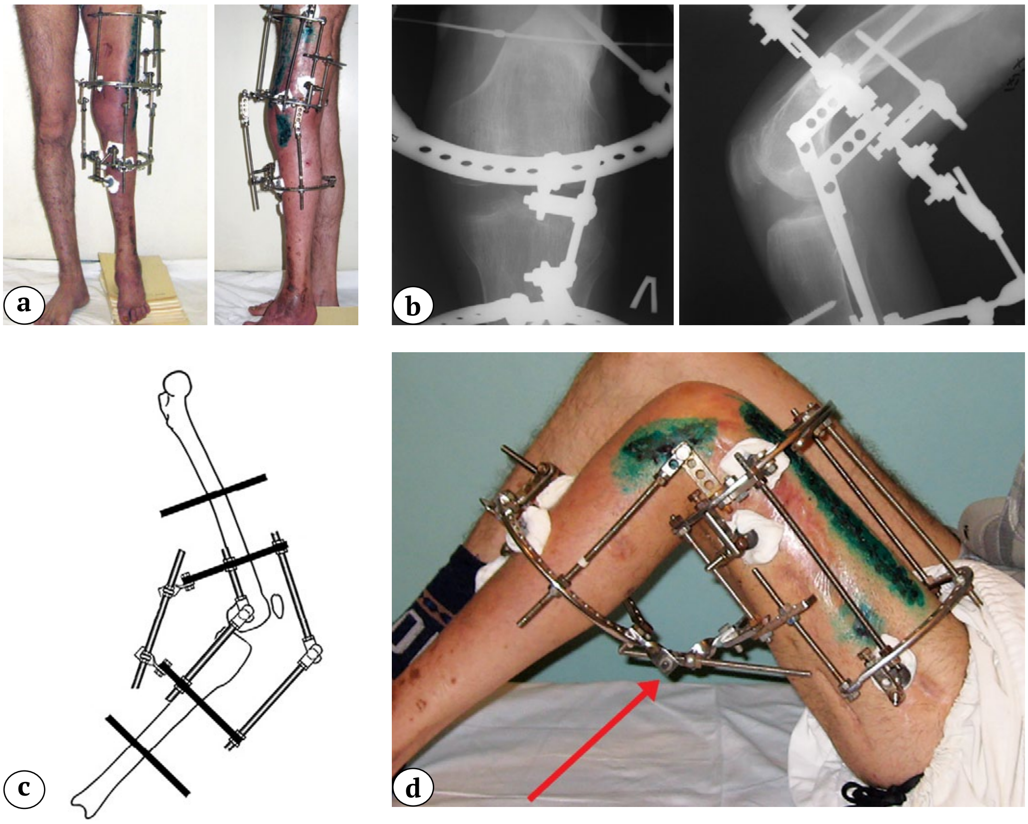

Fig. 3. Usage of Ilizarov apparatus:
a — after frame applying; b — X–ray during treatment;
c — axial and swivel hinges; d — ring-to-ring collision

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 χ^2 test (with the Yates correction for small cohorts) and Fisher's test. The assessment of the dependent 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≤0.05). 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 contractures. 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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