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Comparative analysis of the lower leg multiapical deformity correction by various methods of orthopedic hexapods usage

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Abstract

Introduction The technique of multiapical deformity correction with orthopaedic hexapods can be accepted as "standard." This requires several software calculations a and lengths changes in the 12–18 struts. The "spring" technique was designed to address these disadvantages.

Purpose To analyze the treatment results of patients with lower leg multiapical deformities corrected by "standard" and "spring" techniques

Methods The data of patient group 1 (standard technique, $n = 17$) and patient group 2 (spring technique, $n = 17$), were used. Correction accuracy, duration of correction, and fixation periods were compared. In patients requiring lengthening, fixation and osteosynthesis indices were additionally analyzed. Quality of life and segment function were assessed using the LEFS questionnaire.

Results There was no statistically significant difference between the groups when comparing each of the parameters studied. When comparing LEFS parameters before external fixation (EF) and 2–3 months after frame removal, a statistically significant difference was observed in patients within each of the first and second groups.

Discussion The correction accuracy in each group was 94.4 %, which, along with the absence of a significant difference in the duration of treatment and data from the LEFS questionnaire, indicates equal clinical effectiveness of both methods. It was noted that treatment with various modifications of circular external fixators is equally uncomfortable for patients. At the same time, the need for only one calculation in a hexapod software instead of 2–3, the ability to change the length of 6 struts instead of 12–18, as well as simpler assembly and less cumbersome construct if there is small (less than 10–12 cm) distance between the rings are advantages of a "spring" technique.

Conclusion Based on the analysis of the criteria used for evaluation, it can be concluded that the “spring” technique for correcting lower leg multiapical deformities is as effective as the “standard” technique. The advantages of the "spring" technique are associated with the greater convenience of its use: both for the orthopedic surgeon and the patient.

Keywords: multiapical deformities, multi-planar deformities, multi-level deformities, lower leg deformities, deformity correction, gradual correction, orthopaedic hexapod, Ortho-SUV frame, «spring» technique, correction accuracy, functional results

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INTRODUCTION

In recent decades, orthopaedic hexapods have been actively used to correct deformities, including multi-apical deformities. Their main advantage is one-stage correction of all deformity components [1–5]. The method of correction of multi-apical deformities, which can be accepted as standard, is the simultaneous elimination of the deformity at the levels of all apexes using several orthopaedic hexapods, i.e. their number is equal to the number of deformity apexes [2, 6–12] (Fig. 1 a). It is quite difficult to plan the correction, especially if the intermediate fragment is nonlinear, or the second rule of osteotomies must be used at one of the levels. In such a case, the use of the anatomical axis of the intermediate fragment is unacceptable and the so-called assigned axis is necessary for successful implementation of the correction. Moreover, the orthopaedic surgeon must perform several (according to the number of hexapods) independent calculations with computer software, and during correction, change the lengths of 12 (in the presence of two apexes) or 18 (three-apex deformities) strata. The use of several orthopaedic hexapods increases the weight of the frame and worsens patient's comfort during treatment [13].

In order to eliminate these shortcomings, a "spring" technique has been developed and clinically tested [4]. Its implementation requires only one orthopaedic hexapod, which is more convenient for both the surgeon and the patient (Fig. 1 b).

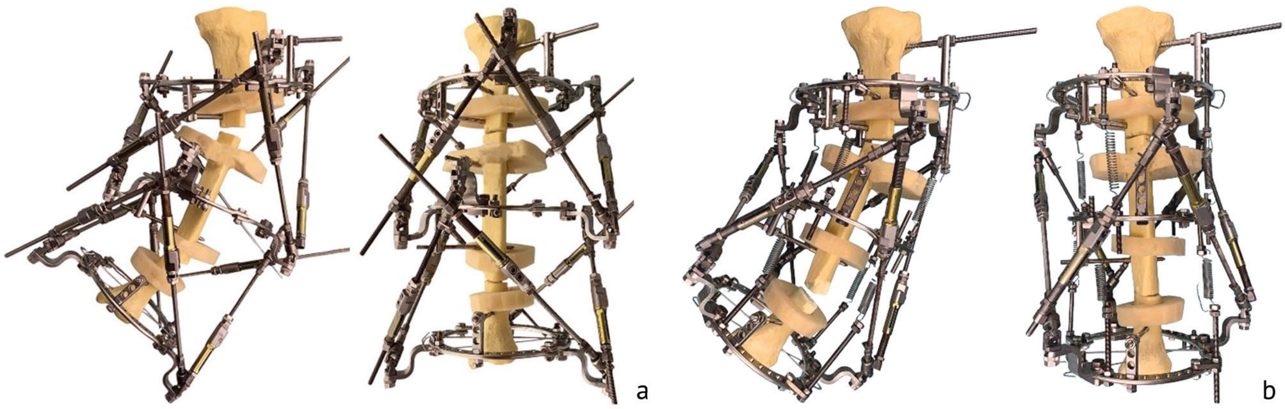


Fig. 1 Diagrams of gradual correction (before and after) of multi-apex deformities of the tibia with orthopaedic hexapods: (a) standard technique; (b) spring technique

However, it is still not known whether the spring technique is as clinically effective as the standard technique.

Purpose To compare treatment results of patients with lower leg multiapical deformities corrected by standard and spring techniques

MATERIAL AND METHODS

The study included patients who were treated at the Vreden National Medical Research Center of Traumatology and Orthopedics from 2012 to 2024. A total of 36 corrections of multi-apical deformity of the lower legs were performed. All patients gave informed consent to participate in the study and subsequent publication of its results.

The control group (Group 1) included 17 patients (18 segments) who were treated with the standard technique (4 retrospective cases, 14 prospective cases). The study group (Group 2) included 17 patients (18 segments), whose deformity correction was performed using the "spring" technique (18 prospective cases). Both groups were comparable in the studied parameters ($p > 0.05$) (Table 1).

Table 1

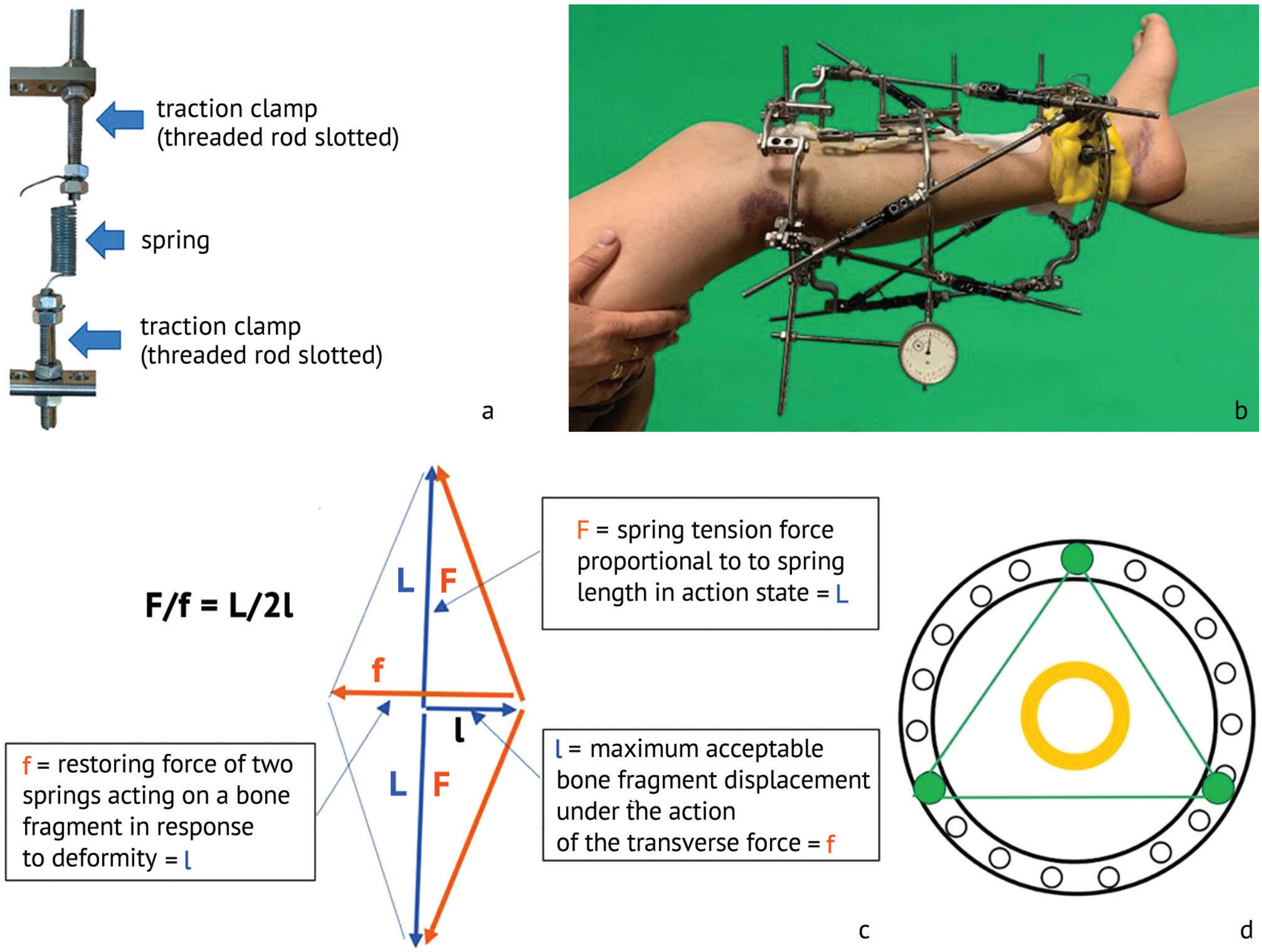
Patients' data

Parameter	Quantity, Me [Q25; Q75]			
	Group 1 (standard technique), *n* = 17		Group 2 (spring technique), *n* = 17	
	n	%	*n*	%
Total of segments	18	100	18	100
Males	9	50	8	44
Females	9	50	10	56
Congenital etiology	9	50	11	61
Acquired etiology	9	50	7	39
Coronal plane varus	5	28	11	61
Coronal plane valgus	12	67	7	39
Antecurvatum in the sagittal plane	12	67	13	72
Recurvatum in the sagittal plane	2	11	2	11
Lengthening	7	39	5	28
Tosion	7	39	10	56
Number of osteotomies = 2	18	100	17	94
Number of osteotomies = 3	0	0	1	6
Ages, years	39.5 [25;48.8]		36 [26;45.5]	
Angular deformity (coronal plane), °	25 [16.3;33.8]		20 [17.3;23.8]	
Angular deformity (sagittal plane), °	18.5 [1;29.8]		10 [4;12.8]	
Lengthening magnitude, mm	0 [0;25]		0 [0;10.5]	
Value of torsion, °	0 [0;10]		8.5 [0;14.3]	

In both groups, an external fixator (EF) based on three supports was used (35 segments) for two deformity apices or four supports in one patient with three apices. Osteotomies of the tibia and fibula were performed through minimally invasive approaches according to de Bastiani. On postoperative days 5 to 7, the distraction period was initiated at a rate of 1 mm per day in 4 steps. Distraction was performed using two-plane Ilizarov hinge posts and continued until interfragmentary diastases of 4–6 mm were achieved at each osteotomy level. If patients required segment lengthening (n_1 = 7; n_2 = 5), distraction continued until the required lengthening magnitude was achieved (Group 1: 12–28 mm; Group 2: 12–44 mm). Upon completion of distraction, the EF was readjusted with the installation of several orthopaedic hexapods (Group 1) or one orthopaedic hexapod and springs (Group 2).

For this purpose, when implementing the "spring" technique, the orthopaedic hexapod "Ortho-SUV" struts [1, 3, 11, 14] connected the proximal and distal EF supports. The intermediate supports were attached to the adjacent supports using a spring unit. It included a set of custom manufactured springs in the amount of six for two-apical deformations or nine for three-apical deformities. Each spring was attached to the supports using traction clamps (Fig. 2 a). The parameters required for manufacturing the springs were determined on day 1 or 2 after the operation. The first required parameter was the length of the spring in the working (stretched) state. For this purpose, the minimum distance between the intermediate EF support and one of the osteotomies was measured in the patient's postoperative radiograph. The value of 15 mm which is the thickness of the three nuts required to fix the spring to the traction clamp and the support was subtracted from the resulting measurement.

Next, the transverse restoring force was determined. With the segment in a horizontal position, a multi-turn indicator (Type MIG, GOST 9696-75) was attached to the rear surface, the end of the needle of which touched the intermediate support. Once the two-plane hinges had relaxed under the influence of gravity, the intermediate support shifted, which was recorded by the indicator (Fig. 2 b). Then, using a dynamometer, a pull was performed in the opposite direction until the indicator arrow was at "0". The dynamometer reading at this point corresponded to the transverse restoring force required to hold the intermediate fragment in a neutral position. The indicators were introduced into an Excel table, which was formed based on the similarity of the force triangle and the transverse displacement triangle (Fig. 2 c). In the calculations, a transverse displacement of the fragment of no more than 1 mm was allowed. Based on the introduced data, the longitudinal (tensile) force of the spring was determined, providing the required restoring force at a given transverse deformation. Based on the available force values, as well as the working length, using a calculator on the manufacturer's website (calculation based on GOST 13765-86), the optimal technical parameters of the springs were determined: diameter and number of spring turns, wire diameter



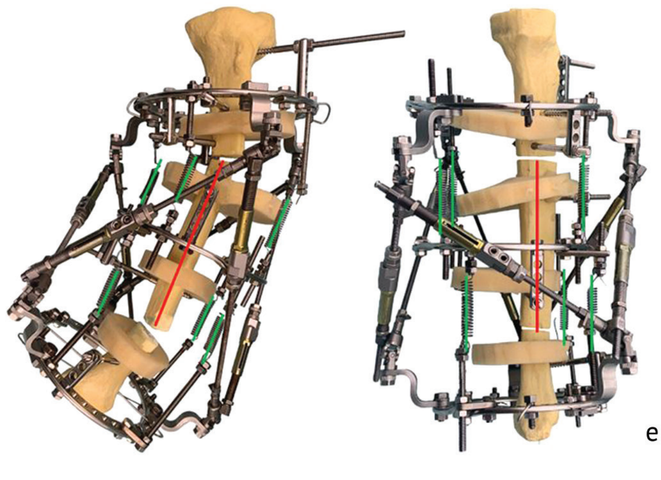


Fig. 2 Principles of determining the technical characteristics and installation of springs for the implementation of the "spring" technology: (a) spring unit components, springs complete with traction clamps; (b) multi-rotational indicator and dynamometer used to determine the transverse restoring force; (c) diagrams of triangles of forces and transverse displacements; (d) points of fixation of springs to the rings; (e) in both planes, the springs are positioned parallel to the intermediate fragment (the axes in accordance with which the springs are tensioned are in green color, the anatomical axis of the intermediate fragment is red)

Orders for the components of the "spring unit" were manufactured by NPP "Slantsevsky Spring Plant", which sells products according to customized designs. Manufacturing of the products took no more than 12 days, which did not affect the duration of the patient's treatment, since it corresponded to the duration of the latent period and the period of primary distraction. During installation, the springs were positioned at the maximum possible equal distance from each other, trying to form an equilateral triangle (Fig. 2 d). Three patients required elimination of the displacement that occurred during the distraction period. In such cases, four springs were used for each apex, positioned in the shape of a square. The springs were fixed to the supports using traction clamps. In this case, the springs were positioned so that they were parallel to the anatomical axis of the intermediate fragment in both planes (Fig. 2 e). The lengths of the springs and the positions of their axes were kept constant during the correction period, and adjustment was performed using traction clamps. Upon completion of correction, the springs and struts of the orthopaedic hexapod were dismantled, and the supports were fixed using two-plane Ilizarov set hinges.

In the comparative analysis, the duration of the correction periods (with and without distraction to achieve the initial diastasis), fixation, and the accuracy of the correction were assessed. In patients who did not undergo segment lengthening (n_1 = 11; n_2 = 13), the duration of the fixation period was calculated. If segment lengthening was necessary (n_1 = 7; n_2 = 5), the following indicators were additionally determined:

— fixation index (FI): the ratio of the number of days of fixation to the value of lengthening in cm;

— osteosynthesis index (fixator period): the ratio of the number of days in the EF to the value of lengthening in cm.

To assess the accuracy of the correction, the values of mechanical (mMPTA, mLDTA) and anatomical (aADTA, aPPTA) angles were assessed before and after the correction.

Complications were evaluated according to the classification of J. Caton [15–19].

The functional outcome and quality of life were assessed by analyzing the LEFS questionnaires completed by patients [17–19]. The questionnaire, consisting of 20 questions, was completed by patients before surgery, at the end of the correction period (before dismantling the struts), before EF removal, and 2.5–3 months after EF removal. A score of less than 19 points was rated as minimal function or no function; 20–39 points as significant limitation of function; 40–59 points as moderate restriction, 60–79 points as minor limitation. A score of 80 points was the maximum and implied full function.

Comparison of frequency characteristics of nominal data (gender, etiology, deformed segment) was performed using the chi-square test (with Yates' correction for small cohorts) and Fisher's exact test. When comparing quantitative parameters (age, RLU values, magnitude of deformation components, duration of treatment and its constituent periods, magnitude of lengthening, IF, IO, etc.), the Mann-Whitney U-test, Student's t-test, and median chi-square were used. The dynamics of the parameters (LEFS questionnaire data) were assessed using the sign test and the Wilcoxon test. Quantitative data were rounded to tenths. Statistical processing was performed using the MO Excel 2016 and Jamovi 2.3.28 software.

RESULTS

Data on the duration of treatment periods for patients in both groups, as well as the values of fixation and osteosynthesis indices assessed in patients requiring segment lengthening, are presented in Tables 2 and 3. No statistically significant difference ($p < 0.05$) was found in any of the assessed indicators.

After correction in each group, the mechanical and anatomical angles were within the reference values in 88.9 % of cases (16 of 18 segments). Two patients (one in each group) had periprosthetic deformity. Since the correction of deformities in those cases had to consider the upcoming arthroplasty, the target angle values differed from the reference values and were achieved. Thus, the accuracy of correction in both Group1 and Group 2 was 94.4 %. The median values of mechanical angles (in the frontal plane) and anatomical angles (in the sagittal plane), as well as the quartile values, are given in Tables 4 and 5.

Table 2

Duration of separate periods of patients' treatment, Me [Q25;Q75]

Periods	Duration, days		*p*
	Group 1 (standard technique)	Group 2 (spring technique)	
Correction, considering distraction	30.5 [15.8;34.8]	21.5 [18.3;36.5]	> 0.05
Correction without considering distraction	16 [9.3;26.3]	14 [10.3;27.3]	> 0.05
Fixation (among patients who do not need lengthening)	251 [207;272]	239 [196.3;335.5]	> 0.05

Table 3

Additional outcome measures for patients undergoing segment lengthening, Me [Q25;Q75]

Indices	Index value, days/cm		*p*
	Group 1 (standard technique)	Group 2 (spring technique)	
Fixation	98.15 [84.5;128]	107 [91;109.3]	> 0.05
Osteosynthesis	126.55 [102.4;151.4]	119 [80.6;119.5]	> 0.05

Table 4

Accuracy of correction of multi-apical deformities in the frontal plane, Me [Q25;Q75]

Angular deformities	Accuracy of correction of multi-apical deformities, °							
	Group 1 (standard technique)				Group 2 (spring technique)			
	Before correction		After correction		Before correction		After correction	
	mMPTA	mLDTA	mMPTA	mLDTA	mMPTA	mLDTA	mMPTA	mLDTA
Varus	80 [67.3;83]	98 [96.5;99.5]	88 [86.3;89.8]	87.5 [86.3;91]	83 [81;84]	97 [94.5;100]	88 [87;88]	89 [87.5;89.5]
Valgus	95 [91;100]	77.5 [71;84.3]	88 [86;89]	88 [88;90]	95 [94.5;98.5]	76 [68.5;80.5]	88 [87;88]	89 [89;91.5]

Notes: mMPTA — mechanical medial proximal tibial angle; mLDTA mechanical lateral distal tibial angle

Table 5

Accuracy of correction of multi-apical deformities in the sagittal plane, Me [Q25;Q75]

Angular deformities	Accuracy of correction of multi-apical deformities, °							
	Group 1 (standard technique)				Group 2 (spring technique)			
	Before correction		After correction		Before correction		After correction	
	aPPTA	aADTA	aPPTA	aADTA	aPPTA	aADTA	aPPTA	aADTA
Antecurvatum	75 [65;80]	99 [90;103]	80 [79;83.3]	81 [79;82]	79 [76;80.5]	86.5 [84.5;92.5]	80 [78.8;81.3]	81 [80;81.3]
Recurvatum	88 [81;95]	79 [77.5;80.5]	82.5 [82.3;82.8]	80 [79.5;80.5]	80.5 [80.3;80.8]	70.5 [68.3;72.8]	82 [81.5;82.5]	80.5 [79.8;81.3]

Note: aPPTA — anatomical posterior proximal tibial angle; aADTA — anatomical anterior distal tibial angle

The comparison of the LEFS questionnaire data filled in by patients of both groups at different stages of treatment showed no statistically significant difference between the groups (Table 6). The assessment of the dynamics of the indicators before the start of treatment and upon its completion revealed significant difference was in both the control and study groups (Table 7).

All complications that arose during treatment belonged to categories I and II according to Caton (Table 8).

Table 6

Comparison of the indices of subjective assessment of quality of life and segment function according to the LEFS questionnaire at different stages of treatment, Me [Q25;Q75]

Evaluation period	Evaluation score, points		*p*
	Group 1 (standard technique)	Group 2 (spring technique)	
Before surgery	56.5 [43.5;62.5]	55.5 [44.3;65]	> 0.05
Upon correction completion	25.5 [23;29.8]	26.5 [23;31.5]	> 0.05
Before EF removal	38.5 [32;42]	43 [36;45]	> 0.05
2–3 months after EF removal	64 [52;72.3]	65 [56.8;76]	> 0.05

Table 7

Evaluation of the dynamics of the indicators of subjective assessment of the quality of life and segment function according to the LEFS questionnaire before the start of treatment and at its completion, Me [Q25;Q75]

Evaluation period	Evaluation points		*p*
	Group 1 (standard technique)	Group 2 (spring technique)	
Before surgery	56.5 [43.5;62.5]	55.5 [44.3;65]	< 0.05
2–3 after EF removal	64 [52;72.3]	65 [56.8;76]	< 0.05

Table 8

Complications according to J. Caton (1991)

Category J. Caton	Complication	Number of complications			
		Group 1 (standard technique)		Group 2 (spring technique)	
		No	%	No	%
I	Soft-tissue pin-tract infection	8	44.4	7	38.9
	Hypotrophic regenerate	1	5.6	2	11.1
	Neuropathy	1	5.6	1	5.6
	Ankle contracture	1	5.6	1	5.6
	Total	11	61.1	11	61.1
II	Hypotrophic regenerate	2	11.1	3	16.7
	Premature consolidation	1	5.6	0	0
	Transoseous element instability	2	11.1	3	16.7
	Regenerate fracture	2	11.1	0	0
	Total	7	38.9	6	33.3

DISCUSSION

The study revealed that the accuracy of correction in both groups was 94.4 %. The correction period for Group 1 was 16 days (30.5 days with distraction), for Group 2 it was 14 days (21.5 days with distraction). The duration of the fixation period in patients who did not need lengthening was 251 and 239 days, respectively. The difference in all cases was insignificant.

The indicators of quality of life and segment function require separate consideration. This is especially important, since one of the objectives of the "spring" technique development was to ensure greater comfort for the patient during the correction period [4, 13]. However, the analysis of the data of the questionnaire on quality of life and segment function showed no significant difference in the indicators at the end of correction, i.e. before dismantling the strata. Formally, one could conclude that both methods are assessed by patients as equally uncomfortable and equally restricting the function of the segment. However, it should be noted that there was not a single patient in the samples whose treatment was performed in stages using each of the techniques and who could compare the discomfort from both methods from his/her own experience. Therefore, the conclusion can rather be made that the treatment with application of EF modifications (circular ones) is uncomfortable for patients.

Thus, formally, the "spring" technique for correction of multi-apical deformities of the tibia does not have significant advantages over the standard one. However, this statement is based only on the criteria that were considered by the study design. However, it is necessary to indicate other important details. It is known that if the distance between the rings is less than 10–12 cm, the fixator frame is more cumbersome due to the need to use Z-plates and/or "idele" rings, an alternative is to use minimized struts which also has its limitations [20]. The use of the "spring" technique allows us to completely avoid this problem.

Figure 3 shows a case report of a patient with a three-apical deformity. Due to pronounced antecurvatum (75°), the distance between the rings along the posterior surface of the segment was from 68 to 72 mm. The installation of three orthopaedic hexapods would have been technically possible, but it was a difficult task for the orthopaedic surgeon, both in terms of assembling the construct and in the “triple” computer calculation. Such a fixator would have been extremely inconvenient for the patient due to its weight, bulkiness and the need to change the lengths of 18 struts. Therefore, the correction was successfully implemented using the “spring” technique.

The search in the world literature [13] revealed eight studies that discuss the issues of gradual correction of multi-apical deformities of the lower leg using orthopaedic hexapods [2, 4, 6, 8–10, 21, 22]. However, only two of them have the content that allows for a limited comparison of the parameters studied in this work.

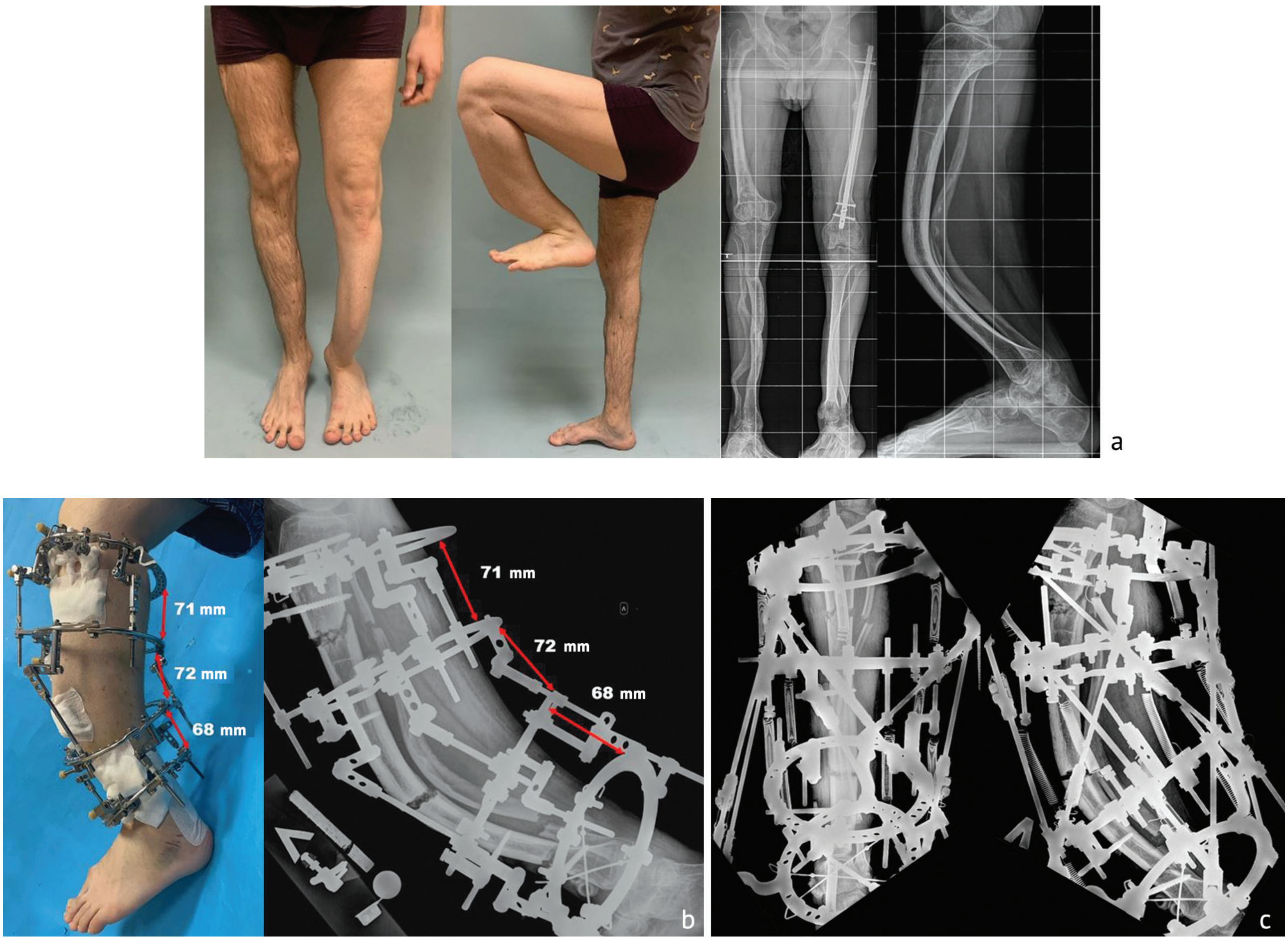


Fig. 3 Clinical case of applying the "spring" technique for tri-apical deformity of the tibia: (a) patient's appearance and radiographs before surgery; (b) at the end of distraction, the distance between the supports along the posterior surface is significantly smaller than the optimal distance for mounting the struts; (c) one orthopaedic hexapod and springs were been successfully mounted and correction began

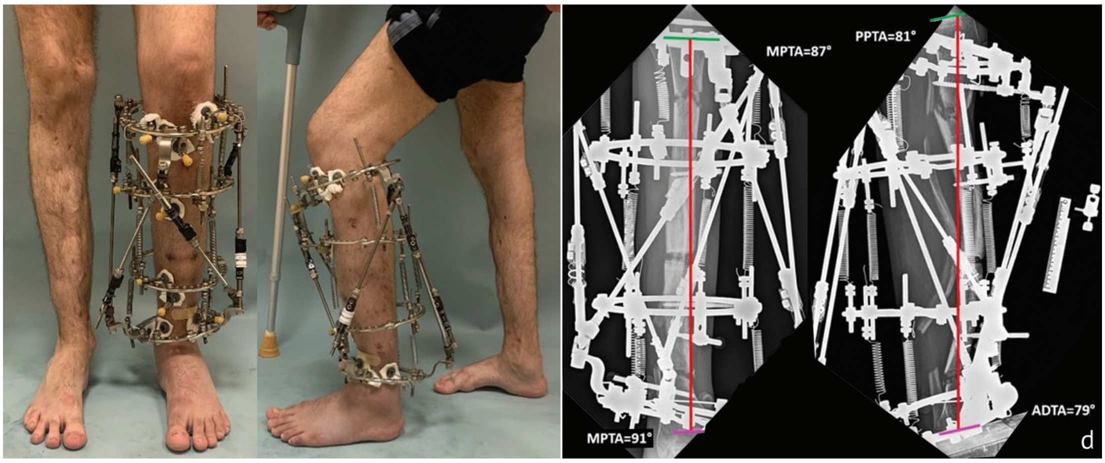


Fig. 3 (continued) Clinical case of applying the "spring" technique for tri-apical deformity of the tibia: (d) photo of the patient and his radiographs at the end of the correction

Among nine patients (13 segments) in the sample of Ray et al. [10], only two patients (three segments) had reached the age of 18 years at the time of treatment and therefore could be considered. To assess the correction accuracy, the authors used the mechanical axis deviation (MAD) which does not allow comparison with the results of our work, since we analyzed the values of mechanical and anatomical angles. The authors of the study assessed consolidation using the angular healing index (AHI). This parameter was the quotient of the number of fixation days divided by distraction regenerate length (cm) in the area where the distance between the bone fragments was the greatest. In adult patients, the average AHI value was 89 days/cm (64–128.3). It can be noted that in comparison with Group 1 of the present study, those data demonstrate better union rates by 9.15 days/cm. However, there is a significant difference in the average age of patients in the samples: 19.7 years (18–21) in Ray et al' s study [10] and 38.8 years (21–65) in our study.

To date, there is only one published paper containing data on the results of clinical application of the "spring" technique. A 2017 article by one of the authors of the present study [4] analyzed four cases of treatment of patients with multi-apical deformities of the lower leg bones. The average value of angular deformity was 34° (11–82). One of the patients also underwent segment lengthening by 30 mm. On average, the correction period was 7 weeks (5–9 weeks), and fixation was 49.5 weeks (41–54). When converted into days (for ease of comparison): 49 days (35–63) for the correction period and 346.5 days (287–441) for the fixation period. The comparison with Group 2 of the present study demonstrates significantly longer correction and fixation periods. However, the average value of angular deformity in the patients of the study was greater, which may partially explain the duration of treatment. It is also necessary to indicate in analyzing the results that the early version of the "spring" technique was used to treat those patients. It differs from the variant described in this paper in the following: the springs were fixed directly to the supports, without traction clamps and positioning the springs parallel to the axis of the intermediate fragment(s). The technical characteristics of the springs also differed: length in the neutral position — 100 mm, wire diameter — 1 mm, coil diameter — 10 mm, number of coils — 42. These factors created conditions for lower rigidity of fixation of the intermediate support. Therefore, it can be assumed that the action of the compression forces of the springs was uneven and multidirectional. The above fact increased the risk of undesired displacement of the intermediate fragment, which, in turn, affected the duration of treatment.

CONCLUSION

Based on the analysis of the criteria used for evaluation, it was found that the "spring" technique for multi-apical deformity correction of the lower-leg bones is as effective as the standard one. The advantages of the "spring" technique are related to its greater convenience of its use for the doctor and more comfort for the patient.

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