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TREATMENT OF CONGENITAL LONG-BONE DEFORMITIES IN CHILDREN USING THE CONSEQUTIVE APPLICATION OF GUIDED GROWTH AND EXTERNAL FIXATION: PRELIMINARY REPORT

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Aim. This study aimed to estimate the results of congenital long bone deformities using the consecutive application of guided growth and external fixation.

Materials and methods. We performed a retrospective analysis of the treatment results of 38 children with congenital deformities of long bones. Group 1 consisted of 17 children who underwent consecutive application of two methods: guided growth and external fixation. Group 2 (control group) consisted of 21 children who underwent isolated lengthening and deformity correction by external fixation.

Results. There were 14 complications in group 1 and 25 complications in group 2. Moreover, only seven cases in group 1 had complications requiring surgical treatment, whereas 17 cases in group 2 required operative treatment for complications. There was a relatively low level of refractures: zero cases in group 1 and three cases in group 2. The most common complication was a recurrence of deformity associated with the continuous growth of children: seven cases in group 1 and eight cases in group 2. However, no recurrence of the torsion component of deformity was observed in any group 1 cases, and repeated guided growth could be performed in the six cases of growing children.

Conclusion. The consecutive use of external fixation and guided growth to treat congenital deformities of the lower limbs is a promising direction for pediatric orthopedics because it reduces the incidence of complications. The repeated use of guided growth, because of its minimal invasiveness, is the most effective solution for the recurrence of deformity in a growing child.

Keywords: deformity correction; external fixation; guided growth; hemiepiphysiodesis.

ЛЕЧЕНИЕ ДЕТЕЙ С ВРОЖДЕННЫМИ ДЕФОРМАЦИЯМИ ДЛИННЫХ КОСТЕЙ НИЖНИХ КОНЕЧНОСТЕЙ ПУТЕМ ПОСЛЕДОВАТЕЛЬНОГО ИСПОЛЬЗОВАНИЯ УПРАВЛЯЕМОГО РОСТА И ЧРЕСКОСТНОГО ОСТЕОСИНТЕЗА (ПРЕДВАРИТЕЛЬНОЕ СООБЩЕНИЕ)

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Цель работы — оценить результаты лечения врожденных деформаций нижних конечностей путем последовательного использования управляемого роста и дистракционного остеосинтеза.

Материалы и методы. Выполнен ретроспективный анализ результатов лечения 38 детей с врожденными деформациями длинных костей. Группу 1 составили 17 детей, при лечении которых методики чрескостного остеосинтеза и управляемого роста применяли последовательно. Группу 2 (группа сравнения) составил 21 ребенок. Всем им выполняли удлинение и коррекцию деформации сегмента методом чрескостного остеосинтеза. Оценивали характер и частоту осложнений.

Результаты. В группе 1 количество осложнений составило 14, а в группе 2 — 25. При этом в группе 1 только в семи случаях осложнение потребовало оперативного лечения. В группе 2 оперативное лечение по поводу осложнения потребовалось в 17 случаях. Отмечался сравнительно низкий уровень рефрактур: в группе 1 —

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0 случаев, в группе 2 — 3 случая. Наиболее частым осложнением был рецидив деформации, ассоциированный с продолженным ростом ребенка: 7 случаев — в группе 1, 8 случаев — в группе 2. Однако в основной группе ни в одном из случаев не наблюдалось рецидива торсионного компонента деформации и во всех случаях у детей с сохраненным ростовым потенциалом (6 случаев) было возможно повторное применение управляемого роста.
Заключение. Последовательное использование методов чрескостного остеосинтеза и управляемого роста при лечении врожденных деформаций нижних конечностей является перспективным направлением детской ортопедии, так как снижает частоту осложнений. Повторное применение управляемого роста за счет своей малой травматичности позволяет максимально эффективно решать проблему рецидива деформации у растущего ребенка.

Ключевые слова: коррекция деформации; управляемый рост; гемиэпифизиодез; чрескостный остеосинтез; гексаподы.

Introduction

Deformities of long tubular bones in pediatric patients are commonly associated with the shortening of these bones. In most cases, the surgeon needs to eliminate the inequality of the lengths of the limbs and correct the deformity. Currently, transosseous osteosynthesis is the standard for treating deformities combined with shortening [1–3]. The use of the Ilizarov apparatus and its analogs makes it possible to achieve the ideal segment length and correct the deformity with any degree of complexity [3–5]. The widely used transosseous apparatus and repositioning units that are based on computer navigation, the so-called hexapods, provide the highest accuracy of correction [3, 6–8]. However, transosseous osteosynthesis is unable to solve several problems associated with congenital deformities of long bones in pediatric patients. Thus, transosseous osteosynthesis does not solve the problem of asymmetric work of the growth zone that is typical for various congenital defects (congenital shortening of the femur, fibular hemimelia). Therefore, even after an ideal elongation and correction of the deformity, with the child's growth, relapse associated with the asymmetric growth occurs.

In addition, there exists a problem that can conditionally be referred to as that of "joint deformities." This term refers to deformities with apex at the level of the joint or the region of the epiphysis. In such cases, the osteotomy at the apex of the deformity is not feasible because stable fixation of transosseous modules is necessary, and all transosseous elements must be placed outside the growth zone. When the mechanical axis of the segment is restored, removal of the osteotomy zone from the apex of the deformity displaces the bone fragments in width, the second Paley rule [9]. The greater the distance from the osteotomy to the apex of the deformity, the greater the width-wise displacement of the bone fragments after deformity correction (restoration of the correct passage of the segment mechanical axis). In such cases, the distraction graft acquires a "zigzag" shape that may affect its strength properties.

In recent years, with the correction of deformities of long bones in pediatric patients, controlled growth that is temporary hemiepiphysiodesis with figure-of-eight plates and screws became widespread [10, 11]. This method allows minimally invasive elimination of deformities of long bones in the same plane by unilateral "inhibition" of growth zone functioning. Controlled growth is extremely effective in correcting the "articular" deformities of the long bones in the frontal plane. This method has limited use in multi-plane deformities and has restrictions in the treatment of deformities associated with shortening because it does not enable segment lengthening.

To our knowledge, no data are available regarding the consistent use of controlled growth and transosseous osteosynthesis in pediatric patients with deformities of the long bones.

This study aimed to evaluate the treatment results for congenital deformities of the lower extremities through consistent application of controlled growth and distraction osteosynthesis.

Materials and methods

A retrospective analysis of the treatment results in 38 patients with congenital deformities of the long bones was performed.

Group 1 comprised 17 pediatric patients, and treatment involved methods of transosseous osteosynthesis and controlled growth sequentially.

Group 2 (comparison group) included 21 pediatric patients. The segment deformity was

Table 1

The distribution of patients as per nosology

Diagnosis	Group 1	Group 2
	Number of patients	
Congenital shortening and deformity of the hip	11	15
Fibular hemimelia (ectromelia)	6	6

Table 2

Patient distribution as per sex

Sex	Group 1	Group 2
	Number of patients	
Male	10	9
Female	7	12

elongated and corrected in these pediatric patients using the method of transosseous osteosynthesis.

All the patients were treated during August 2010 to 2017 in the Department No. 1 of the Turner Scientific and Research Institute for Children's Orthopedics. The distribution of patients as per nosology and sex at the time of surgical treatment is presented in Tables 1 and 2.

In group 1, the average age was 7.6 ± 3.4 years, while that in group 2 was 9.6 ± 2.9 years.

The study inclusion criteria for patients in both the groups were as follows:

1) the presence of deformity in combination with shortening;
2) the presence of functioning growth zones; and
3) apex of deformity (at least one with multilevel deformities) at the level of the joint or epiphysis.

We analyzed the following indicators:

For patients of group 1:

- the period required for deformity correction using the method of controlled growth (from the moment of surgery to plate removal) as the period of controlled growth;
- the extent of elongation;
- the amount of displacement of bone fragments in width because of restoration of the reference values of the mechanical axis and angles of the segment;
- external fixation index (EFI);
- the number of complications.
- For patients of the group 2:
- the extent of elongation;
- the amount of displacement of bone fragments in width because of restoration of the reference values of the mechanical axis and angles of the segment;
- EFI;
- the number and nature of complications.

In group 1, we treated femoral deformities in 11 cases and tibial deformities in 6 cases. According to the practical classification of the deformities of long bones [12], in 10 cases, there were complex deformities (two- and three-plane multicomponent), and in seven cases, there were deformities of medium degree of complexity (one-, two- and three-plane, and two- and three-component). In most cases (14), the valgus component of the deformity was eliminated using controlled growth; only in three cases, the varus component was removed. In all cases, if there was a deformity in the sagittal plane, antecurvation took place. Recurvation component of deformity was not noted in any case for hip or tibial deformities. The values of the reference lines and angles [9, 13] as well as the values of the angular components of the deformities are presented in Tables 3 and 4. It is also noteworthy that in all cases, in the presence of the torsion component, external torsion was observed with femur deformity, and internal torsion was observed with tibial deformity. In nine cases, the sequence of surgical treatment was as follows: first, deformity correction in the frontal plane using controlled growth, followed by elongation and correction of the remaining components of the deformity. In eight cases, elongation and correction of the deformity were performed first, followed by a relapse tendency of the deformity and hemiepiphysiodesis. In eight cases of tibial deformity

Table 3

Референтные линии и углы для деформаций бедра (до лечения)

Indicator	Normal values	Group 1	Group 2
Frontal plane			
Valgus			
DMA	0–10 mm inwards	29 ± 5 mm outwards	31 ± 4 mm outwards
MLPFA, °	85–95	70 ± 6	72 ± 7
MLDFA, °	85–90	72 ± 3	76 ± 6
Deformity angle, °		23 ± 6	20 ± 8
Sagittal plane			
Antecurvation			
APDFA, °	73–84	65 ± 5	71 ± 7
Deformity angle, °		15 ± 7	13 ± 7
Transversal plane			
External torsion, °		30 ± 7	27 ± 8

Note: MLPFA — mechanical lateral proximal femoral angle; MLDFA — mechanical lateral distal femoral angle; DMA — deviation of the mechanical axis; APDFA — anatomical posterior distal femoral angle.

Table 4

Reference lines and angles for tibial deformities (before treatment)

Indicator	Normal values	Group 1	Group 2
Frontal plane			
Valgus			
DMA	0–10 mm inwards	33 ± 8 mm outwards	
MMPAT, °	85–90	102 ± 3	98 ± 7
MLDAT, °	86–92	76 ± 4	74 ± 7
Deformity angle, °		21 ± 3	19 ± 5
Varus			
ДМО	0–10 mm inwards	24 ± 5 mm inwards	–
MMPAT, °	85–90	79 ± 4	–
MLDAT, °	86–92	106 ± 4	–
Deformity angle, °		15 ± 5	–
Sagittal plane			
Antecurvation			
APPAT, °	77–84	66 ± 5	70 ± 3
AADAT, °	78–82	89 ± 4	92 ± 7
Deformity angle, °		14 ± 7	18 ± 4
Transversal plane			
Internal torsion		27 ± 7	

Note: MMPAT — mechanical medial proximal angle of the tibia; MLDAT — mechanical lateral distal angle of the tibia; DMA — deviation of the mechanical axis; APPAT — anatomical posterior proximal angle of the tibia; AADAT — anatomical anterior distal angle of the tibia.

correction, hemiepiphysiodesis was performed both in the proximal and distal portion of the growth zone.

In group 2, femoral deformities were treated in 15 cases and tibial deformities were treated in six cases. The values of the reference lines and angles as well as the values of the angular components of the deformities are shown in Tables 3 and 4. In all the cases, in the presence of a deformity in the frontal plane, there was a valgus component; varus was not observed in any case. In the presence of a deformity in the sagittal plane, antecurvation was registered. In all the cases, in the presence of a torsion component, external torsion was observed in the deformities of the femur, and internal torsion was noted in tibial deformities. Moreover, in 12 cases, the deformities were complex, and in nine, they were of an average degree of complexity (one-, two-, and three-plane and two- and three-component). In eight cases, the deformity correction was two-level; therefore, two-level osteotomy was performed.

The achievement of accurate deformity correction at the transosseous osteosynthesis stage that is, 100% compliance of the achieved values of the mechanical axis of the segment for direct projection, the anatomical axis of the segment for lateral projection, and the angles formed by their intersection with articular lines with the range of reference values, so-called reference lines and angles, was an inclusion criterion. In all cases, a unit based on Orto-SUV computer navigation was used as a repositioning unit [3, 6]. An indispensable condition for assessment of the deformity, determination of its apex and control of correction was the performance of panoramic radiographs of the lower limbs and computed tomography (CT) in the presence of a torsion component of the deformity in the preoperative period.

Statistical analyzes were performed using Microsoft Excel 2016. For the quantitative variables, mean (*M*) and standard deviation (*SD*) values were calculated. Student's *t*-test was used to determine the statistical significance of the differences between the average values.

Study results

The results are presented in Table 5. The period of controlled growth in group 1 was 485.1 ± 77.1 days. The elongation in both the groups did not differ significantly; for group 1, it was 49.9 ± 8.8 mm, while for group 2, it was 47.7 ± 8.9 mm ($p \geq 0.05$). The period of distraction in group 1 was 55.6 ± 16.5 days, while in group 2, it was 50.9 ± 9.7 days ($p \geq 0.05$). The period of deformity correction in group 1 was 11.5 ± 4.1 days and that in group 2 was 17.9 ± 3.1 days ($p \geq 0.05$). The EFI in the group 1 was 46.7 ± 10.3 days/cm and that in group 2 was 48.7 ± 10.5 days/cm ($p \geq 0.05$). The displacement of bone fragments in width for group 1 was 1.5 ± 1.7 mm, while that for group 2 was 9.6 ± 5.5 mm ($p \geq 0.05$).

The observed complications are presented in Table 6.

In group 1, complications were recorded in 53% of the patients, and in 4 patients, there were at least 2 complications.

At the hemiepiphysiodesis stage, in one case, exact correction in the frontal plane was not achieved. That is, 2 years after hemiepiphysiodesis of the femur, the valgus component of the deformity was not eliminated. The deviation of the mechanical axis was 12 mm outwards, and the mechanical distal lateral angle of the femur was 78°. Considering the recommendations regarding the duration of controlled growth that should not exceed 2 years, it was decided to remove the figure-of-eight plate and perform the second stage of treatment. In one case, one of the screws of the figure-of-eight plate was broken, and an unplanned deformity hypercorrection was observed. We associate this complication with noncompliance with the recommended terms for performing radiographs and doctor visits for consultation by the patient's parents. Thus, the recommended period was exceeded by 4 months for unexplained reasons. However, this complication did not affect the final results. At the second stage of treatment, the deformity was eliminated via transosseous osteosynthesis.

In five cases, after the external fixation device (EFD) was removed, contracture of the knee joint was noted. Furthermore, in three cases, the contracture was flexion. In these patients, the range of movements was 15°/0°/0°, 30°/0°/0°, and 40°/0°/0° (the flexion deficit was 145°, 130°, and 120°). In two cases, the contracture was extension. In these patients, the range of movements was 160/20/0° and 150/15/0° (the extension deficit was 20° and 15°). In all the cases described, the restoration of knee joint function was achieved through rehabilitation and restoration measures.

Table 5

Treatment results

Parameters	Group 1	Group 2	P^1
Period of controlled growth, days	485.1 ± 77.1	–	–
Extent of elongation, mm	49.9 ± 8.8	47.7 ± 8.9	≥ 0.05
Period of distraction, days	55.6 ± 16.5	50.9 ± 9.7	≥ 0.05
Period of correction, days	11.5 ± 4.1	17.9 ± 3.1	≥ 0.05
EFI, days/cm	46.7 ± 10.3	48.7 ± 10.5	≥ 0.05
AD^2, mm	1.5 ± 1.7	9.6 ± 5.5	≤ 0.05

Note: [1] Differences between groups are statistically significant at $p \leq 0.05$; AD — the amount of displacement of bone fragments in width because of restoration of the reference values of the mechanical axis and the angles of the segment; EFI — external fixation index.

Table 6

Complications

Parameters	Group 1	Group 2
Insufficient correction of deformity	1	–
Fracture of parts of the surgical hardware	1	–
Contracture of joint(s)	5	7
Dislocation or subluxation in the joint	–	2
Formation of atrophic regenerate	–	3
Refracture	–	3
Deformity recurrence	7	8
Dislocation of the patella	–	2
Total	14	25

In five cases, after dismantling the EFD, and in two cases, after removal of the figure-of-eight plate, a deformity relapse was noted. No patient exhibited recurrence of the torsion component of the deformity. The minimum term for deformity recurrence was 6 months, while the maximum was 2 years. In all seven cases, surgical treatment was used for deformity correction. In addition, in six pediatric patients, repeated hemiepiphysiodesis was used because in all cases, there was a preserved length of the segment. In four cases, repeated haemiepiphysiodesis was effective. The remaining two patients were undergoing treatment at the time of writing this report. In the case of a 15-year-old patient, considering the age, the absence of radiological signs of the growth zones functioning, and the presence of femur deformity (both in the frontal [valgus] and sagittal [antecurvation] planes, corrective osteotomy and plate osteosynthesis were performed.

In all cases, at the stage of transosseous osteosynthesis, inflammatory changes were registered in the area of exits of the transosseous elements and were arrested conservatively. In group 2, complications were noted in 81% of the patients; 6 patients had at least 2 complications.

The contracture of the joint was fixed in seven patients, the contracture of the knee joint in six cases and contracture of the ankle joint in one. In addition, in five cases, the contracture of the knee joint was flexion. The flexion deficit was 134° ± 18° (150°–110°). In one case, the knee joint contracture was combined. In this patient, the amplitude of movements was 90°/20°/0° (the extension deficit was 20°, and the flexion deficit was 70°). In a patient with ankle contracture, the amplitude of movements after EFD removal was 40°/20°/0° (dorsal flexion deficit was 20°). In all the cases described, the restoration of the knee joint function was achieved through rehabilitation and recovery measures.

In two cases, despite knee joint fixation, femur elongation led to subluxation at the knee joint after removal of the transosseous module fixing the knee joint; this required surgical treatment. In three cases, the formation of an atrophic regenerate was observed, leading to the requirement of bone autografting in two cases. In two cases, there was a refracture in the area of distraction regenerate. In one case, the refracture occurred 5 days after dismantling of the compression distraction apparatus (CDA), and in the second case, it occurred after 25 days. In one case, a bone fracture was detected along the opening from under one transosseous element removed. In all these cases, surgical treatment was required at a later stage.

In eight cases in group 2, recurrent deformity was registered. In five cases, repeated osteotomy was performed with transosseous osteosynthesis, and in three cases, osteotomy was performed with external osteosynthesis.

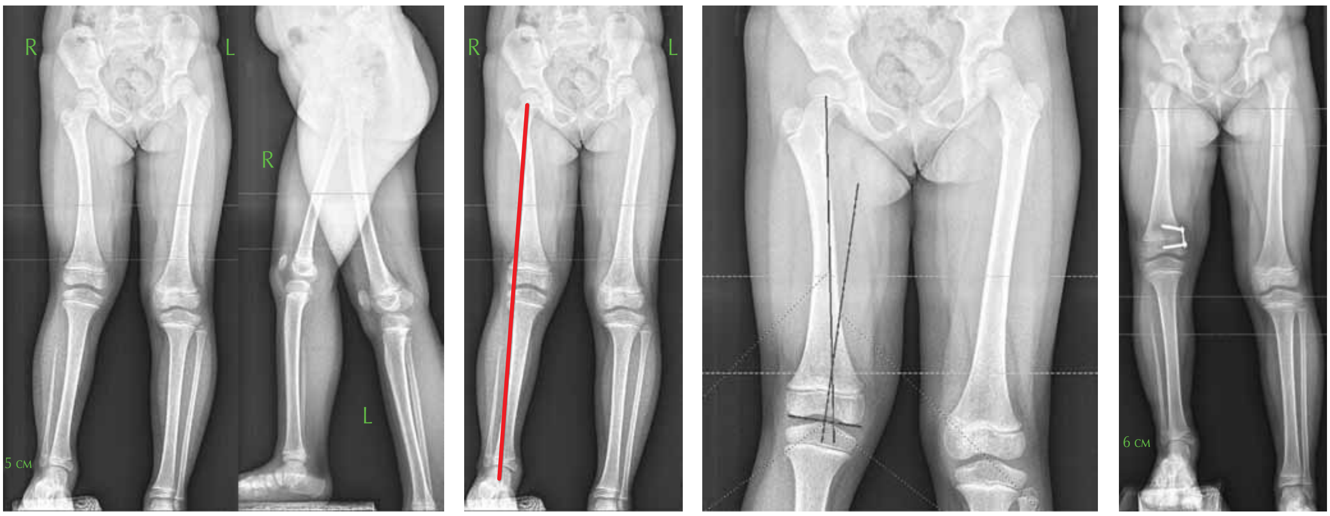
In two cases, deformity correction was complicated by patella dislocation. In both cases, the Ru-Friedland-Volkov surgery was performed.

In group 2, all the patients exhibited inflammatory changes in the area of transosseous elements exit. In one case, it was necessary to remove the transosseous element. In all other cases, local treatment and antibacterial therapy were sufficient to stop the inflammatory process.

Clinical case 1

Patient P., age 5 years, was admitted to the clinic of the Turner Scientific and Research Institute for Children's Orthopedics with a diagnosis of congenital malformation of the right lower extremity. The patient had shortening of the right lower extremity by 6.5 cm with valgus-torsion deformity of the femur and fibular hemimelia (ectromelia) of the right tibia. At admission, the patient and the mother complained of deformity and shortening of the right tibia. After examination and analysis of panoramic radiographs (Fig. 1), we found that the patient had a valgus deformity of the right femur with apex at the level of the knee joint, shortening of the right femur by 5 cm and that of tibia by 1.5 cm. As per CT data, the right thigh also has a torsional deformation component equal to 20°. According to the practical classification, the deformity was regarded as a deformity with an average degree of complexity. Before correction, the distal mechanical angle of the femur was 80°, the anatomical posterior distal angle of the femur was 79°, and the deviation of the mechanical axis was 22 mm outwards.

According to radiographs and CT images, there was marked hypoplasia of the lateral condyle of the right femur. Considering the localization of the deformity, patient age, hypoplasia of the lateral condyle and the external torsion of the femur, we decided to perform two-stage deformity correction. The first stage was temporary hemiepiphysiodesis of the inner portion of the distal growth zone of the right femur with a figure-of-eight plate for eliminating the varus component of the deformity and level the size of the femoral condyles. The postoperative period was uneventful. The function



a *b* *c* *d*

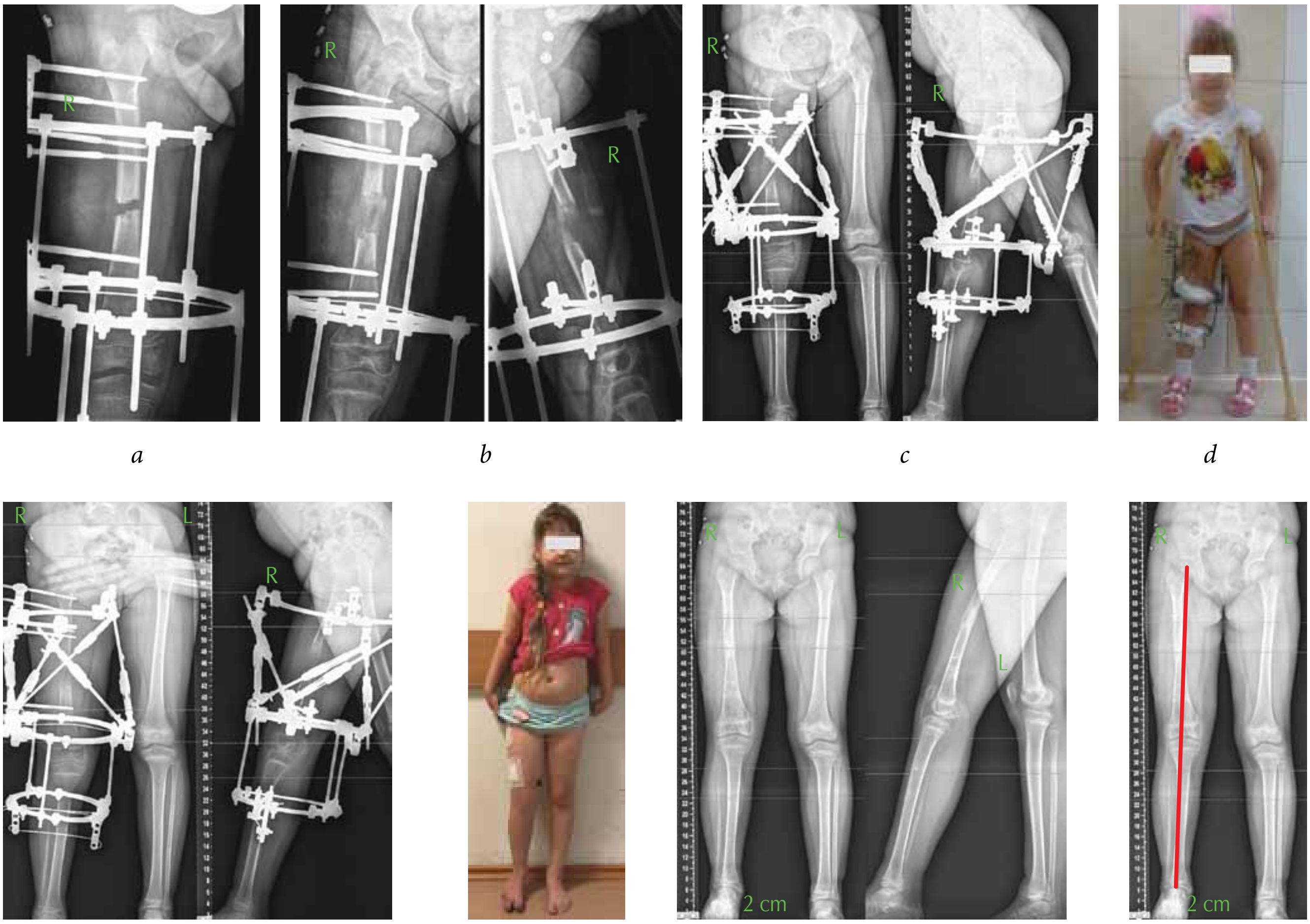
Fig. 1. Patient P. at the first stage of treatment: *a* — preoperative panoramic radiographs of the lower extremities; *b* — a common mechanical axis of the limb is drawn on a panoramic radiograph; *c* — on the radiograph, mechanical axes of the proximal and distal bone fragments are drawn, the apex of the deformity was found; *d* — panoramic radiographs of the lower extremities at the end of the first stage (before removing the figure-of-eight plate)

a *b* *c*

Fig. 2. Patient P. before the second stage of surgical treatment: *a* — photo of the patient; *b* — panoramic radiographs of the lower extremities; *c* — a common mechanical axis of the limb is drawn on a panoramic radiograph

of the knee joint at the time of hospital discharge (5 days postoperatively) was complete. The patient was followed up every 3 months. The deformity was eliminated (Fig. 1, *d*), and the plate was removed 380 days after the primary surgery.

The radiographic results of the panoramic radiographs were evaluated; we found that the distal mechanical angle of the femur was 88°, the anatomical posterior distal femoral angle was 82°, and the mechanical axis deviation was 0 mm. On



a *b* *c* *d*

e *f* *g* *h*

Fig. 3. Patient P. at the second stage of treatment: *a*, *b* — radiographs at the stages of elongation; *c* — panoramic radiographs of the lower extremities after the unit Orto-SUV installation; *d* — photo of the patient with the apparatus; *e* — panoramic radiographs of the lower extremities after the deformity correction; *f* — photo of the patient after CDA dismantling; *g*, *h* — panoramic radiograph after CDA dismantling

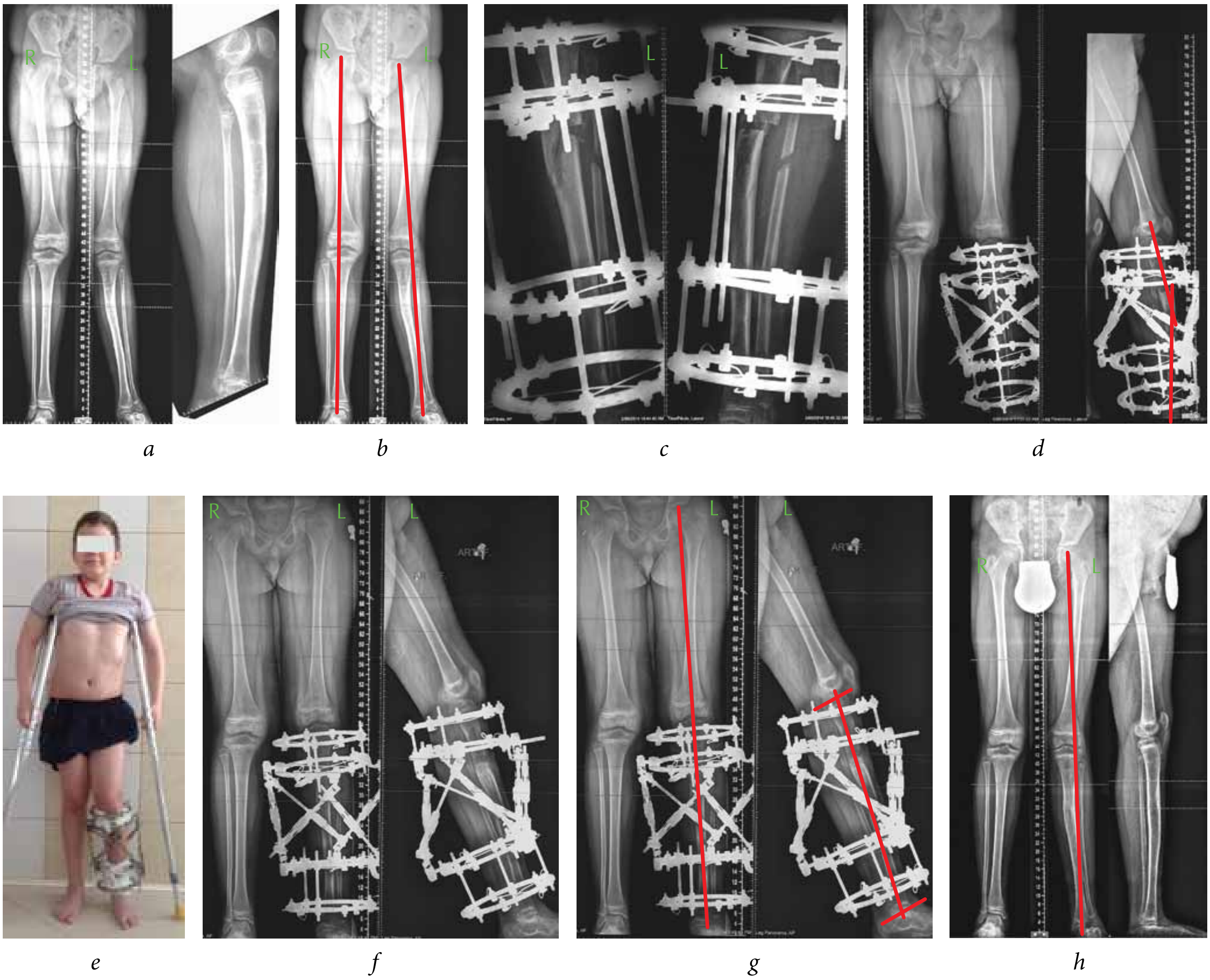


Fig. 4. Patient R. at the first stage of treatment: *a, b* — preoperative panoramic radiographs of the lower extremities (general mechanical axes of the extremities were drawn); *c* — postoperative radiographs; *d* — panoramic radiographs before deformity correction (the Ortho-SUV unit is installed); *e* — photograph of the patient during deformity correction; *f* — panoramic radiographs of the patient after deformity correction; *g* — panoramic radiographs of the patient after deformity correction (the mechanical axis on the direct radiograph and the anatomical axis on the lateral axis were drawn); *h* — panoramic radiographs of the patient 3 months after dismantling of the EFD (relapse of the valgus component of the deformity)

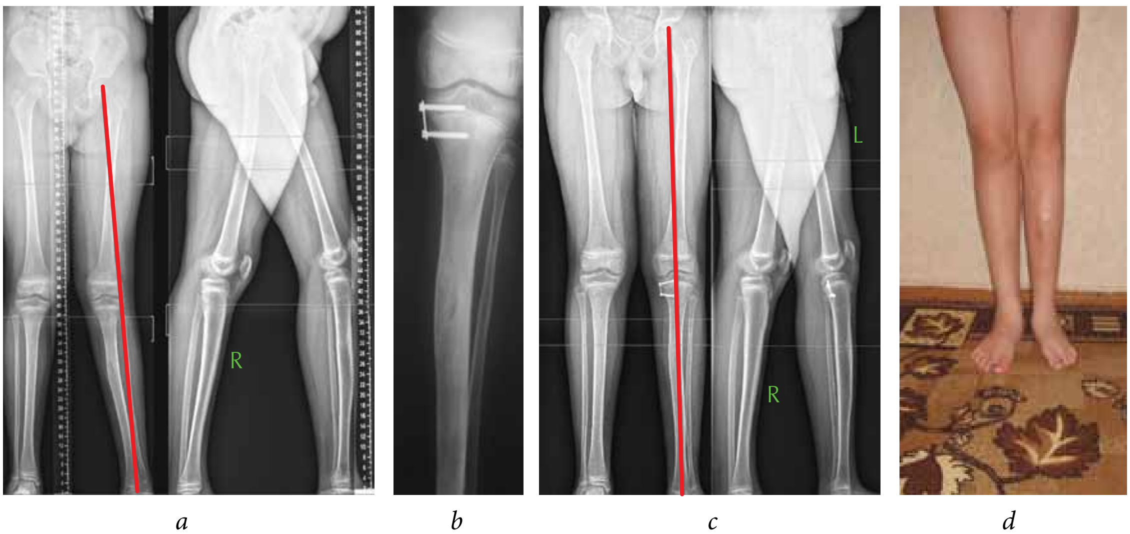


Fig. 5. Patient R. at the second stage of surgical treatment: *a* — panoramic radiographs of the patient before the surgery; *b* — radiographs of the patient after the surgery; *c* — panoramic radiographs of the patient before plate removal; *d* — photo of the patient after plate removal

radiographs and computer tomograms, the femoral condyles alignment in size was noted. At the second stage (Fig. 2, 3), 1 month after plate removal, the combined transosseous osteosynthesis of the right femur, corticotomy with osteoclasis of the right femur on the border of the middle and lower third were performed. From day 5 after the surgery, distraction was started along the Ilizarov apparatus rods. The period of distraction was 67 days. After elongating the segment by 55 mm, the Ortho-SUV repositional unit was installed. According to the calculations performed using the computer navigation program, the torsion component of the deformity and residual deformity was corrected. Thereafter, the patient was followed up every month on an outpatient basis. After the radiological signs of bone restructuring of the distraction regenerate were observed, the EFD was dismantled. The fixation period was 227 days, and the EFI was 42 days/cm. After dismantling the CDA, the amplitude of movements in the knee joint was 80°/0°/0°. During the 3 weeks of mechanotherapy and exercise therapy, the amplitude of movements reached 120°/0°/0°.

Clinical case 2

Patient R., age 8 years old, was admitted to the clinic of the Turner Scientific and Research Institute for Children's Orthopedics with a diagnosis of congenital malformation of the right lower limb. The patient had shortening of the right lower extremity due to the tibia by 3 cm and valgus-antecurvational deformity of the left tibia with malformation of the left foot. Earlier, at the age of 6 years, elongation of the left leg was performed in a primary care facility. As per the mother, deformity relapse was noted immediately after the dismantling of the EFD. On admission, the patient and mother complained about the deformity and shortening of the left leg. After examining and analyzing the panoramic radiographs (Fig. 4), we found that the child had a valgus-antecurvational deformity of the left tibia, shortening the left lower extremity by 3 cm. According to the practical classification, the deformity is regarded to be of moderate complexity. Before correction, the mechanical medial proximal angle of the tibia was 99°, the mechanical lateral distal angle of the tibia was 92°, the deviation of the mechanical axis was 34 mm outwards, the anatomical proximal posterior angle of tibia was 64°, and the anatomical distal anterior angle was 98°.

At the first stage (see Fig. 4), a combined transosseous osteosynthesis of the left tibia, osteotomy of the left tibial and fibula bones at the border of the upper third and the middle third were performed. From the fifth postoperative day, distraction was started along the Ilizarov apparatus's rods. The distraction period was 40 days. After elongating the segment by 35 mm, the repositional unit Ortho-SUV was installed. Deformity correction was performed as per the calculations made in the computer navigation program. Following the correction, the mechanical medial proximal angle of the tibia was 86°, the mechanical lateral distal angle of the tibia was 94°, the deviation of the mechanical axis was 0 mm, the anatomical proximal posterior angle of the tibia was 82°, and the anatomical distal anterior angle of the tibia was 80°.

Thereafter, the patient was followed up every month on an outpatient basis. After the radiological signs of bone restructuring of the distraction regenerate appeared, the EFD was dismantled. The fixation period was 168 days. The external fixation index was 48 days/cm. On control radiography performed 3 months thereafter, we noted recurrence of valgus deformity.

Considering the equal length of the extremities, we decided to perform temporary hemiepiphysiodesis of the inner portion of the proximal growth zone of the left tibia as the second stage to eliminate the valgus component of the deformity. The postoperative period was uneventful. The knee joint was fully functional at the time of hospital discharge. Follow-up was performed every 3 months. The deformity was eliminated (Fig. 5), and the plate was removed 525 days after the primary surgery.

Discussion

Controlled growth is widely used for the correction of deformities of the lower extremities in pediatric patients [10, 11, 14, 15].

Several global studies have reported the efficacy of controlled growth in the treatment of idiopathic deformities and deformities with multiple exostotic chondrodysplasia. Few studies have assessed the correction of congenital deformities associated with shortening of a segment, with the use of controlled growth. Therefore, in a multicenter multinational study by B. Danino et al. [14], the treatment results in 537 patients (967 segments) were analyzed. Congenital deformity was noted only in 105 of them. To our knowledge, the present cohort is the largest group of patients with congenital deformities wherein controlled growth was used. According to the data, controlled growth was effective in correcting femur deformities in 70% of the cases and tibial deformities in 80% of the cases. The restrictions on the use of the controlled growth method in the treatment of congenital malformations are obvious [15]; these include the fact that the figure-of-eight plate "works" only in one plane (sagittal or frontal), does not eliminate the torsion component of the deformity, and is incapable of segment elongation. Thus, considering that congenital deformities are rarely "one-plane" and tend to be complex in most cases, multi-plane, including those that contain a torsion component, and are always associated with segment shortening, the use of controlled growth has several restrictions.

However, P. Stevens [16] demonstrates the advantages of controlled growth in the correction of congenital femur deformities. Thus, in most cases, congenital deformity of the femur includes the valgus component, the torsion component, shortening, and hypoplasia of the lateral condyle. The figure-of-eight plate, mounted on the medial portion of the distal growth zone, enables not only the elimination of the valgus component of the deformity, but also the leveling of the size of the femoral condyle. This observation served as the main argument for us while choosing a sequential method for the treatment of these defects (controlled growth, followed by transosseous osteosynthesis). Thus, with traditional elongation and correction of the deformity using transosseous osteosynthesis, the elimination of the torsion component of the deformity in the presence of hypoplasia of the lateral condyle of the femur increases the risks of external dislocation of the patella. Conceptually, our ideas are in agreement with the Stevens method in the fact that the first step is to achieve controlled growth for eliminating the valgus component of the deformity and align the condyles in size. In the second stage, Stevens proposes leveling of the length of the limbs via temporary epiphysiodesis of the contralateral, healthy lower limb with two or four figure-of-eight plates, thereby restraining its growth. From our viewpoint, it is a violation of logic that the torsion component of the deformed affected segment is not corrected, and "slowing down" the growth of a healthy leg does not always solve the problem because it can lead to short stature in the child and disproportionate lower limbs in relation to the body and upper limbs.

In addition, in most cases, the apex of the valgus deformity is at the level of the joint. The osteotomy in combination with transosseous osteosynthesis cannot be performed at the apex of the deformity. Moreover, the osteotomy zone relative to the deformity apex is usually located at a sufficiently large distance because of the need for stable fixation of the distal fragment and because passing transosseous elements through the growth zone is unacceptable. In such cases, deformity correction leads to the displacement of bone fragments in width; this, as suggested, may affect the strength of the regenerate. The present results suggest that in group 2, where only transosseous osteosynthesis was used in combination with osteotomy, the width of the secondary displacement was 9.6 ± 5.5 mm, while in group 1, with consistent use of controlled growth and transosseous osteosynthesis, it was 1.5 ± 1.7 mm. In this case, the refracture in group 2 was observed in three cases, while in the study group, this complication was not registered.

To our knowledge, no previous trial has reported on the consistent use of transosseous osteosynthesis and controlled growth. As shown in several studies, the use of the transosseous osteosynthesis method for treating congenital deformities of the hip and tibia is associated with an extremely high risk of complications (50%–150%) [7, 8, 17–20]. In general, our research confirmed this data. Thus, in the study group (group 1), the number of complications was 14 (in 53% of the patients), while in the comparison group (group 2), it was 25 (in 81% of the patients). However, it should be clarified that the complication required surgical treatment only in 7 cases in group 1. In group 2, surgical treatment was necessary for complications in 17 cases.

Previous reports show that the most commonly observed complication is refractures. J. Horn et al. [7] report that 8 out of 81 patients experienced refracture, and Aston et al. [18] found that 56.7% of the subjects experienced refractures. Launay et al. [19] reported that about 28% of the refractories detected by analyzing the results of treatment of 58 patients.

In order to resolve this issue, many researchers [18, 19] have proposed reinforcement of an extended segment. In our study, reinforcement was not applied; however, we noted a relatively lower prevalence of refractures. This may be attributable to the small number of cases analyzed and the fact that in our groups, the EFI was relatively large; in group 1, it was 46.7 ± 10.3 days/cm, while in group 2, it was 48.7 ± 10.5 days/cm.

Moreover, to our knowledge, no previous trial had examined the problem of deformity recurrence after elongation and correction of segment deformity not caused by refracture but associated with the continuation of the asymmetric surgery of the growth zone. Based on the present results, consistent use of controlled growth and external fixation does not reduce the risk of deformity recurrence; there were seven cases in group 1 and eight in group 2. However, in the study group, no patient experienced recurrence of the torsion component of the deformity, and in all pediatric patients with preserved growth potential (6 cases), it was possible to reapply controlled growth. In the comparison group, controlled growth for the treatment of relapses was not used only because this group was mostly retrospective and assistance was provided to children before controlled growth became available in our practice.

Conclusion and summary

The present results indicate that consistent use of methods of transosseous osteosynthesis and controlled growth in the treatment of congenital deformities of the lower extremities is a promising approach in pediatric orthopedics because it reduces the incidence of complications. Repeated use of controlled growth owing to its low morbidity provides an effective solution for the problem of recurrent deformity in a growing child.

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Conflict of interest. Author V.A. Vilensky declares that he is an employe of the company Orto-SUV. The other authors declare no obvious and potential conflicts of interest related to the publication of this article.

Ethical review. Patients and their representatives agreed to the processing and publication of personal data.

Contribution of the authors

V.A. Vilensky — development of a new algorithm of treatment of patients with congenital deformities of the hip and tibia, which constituted the study group. Writing all sections of the article. Literature collection and processing. He performed surgeries to 8 patients.

E.A. Zakharyan — statistical data processing. Participation in the development of a new treatment algorithm. X-ray data processing of 12 patients.

A.A. Pozdeev — performed surgeries to 9 patients. Participation in the development of a new treatment algorithm. X-ray data processing of 8 patients.

T.F. Zubairov — performed surgeries to 6 patients. X-ray data processing of 11 patients.

A.P. Pozdeev — performed surgeries to 8 patients. Management and participation in the development of a new treatment algorithm.

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