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Parameters of radiographic coxometry in reconstructive operations on the hip joint as part of multilevel surgical interventions in children with cerebral palsy

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Purpose Study the parameters of the hip joint in the short- and long-term postoperative periods in patients with severe types of cerebral palsy, accompanied by pathology of the hip joint, who underwent multilevel interventions, including its reconstruction. Study hip joints at stages depending on the interval between operations (between surgery on the first and second joints in bilateral CP), age of patients as well as an assessment of the intact joint development in unilateral dislocations. **Materials and methods** This study included 124 children with spastic types of cerebral palsy who underwent surgical orthopedic reconstructive treatment at the RISC for RTO in the period between 2012 and 2016. Their mean age at the start of treatment was 7.01 ± 2.47 years (range: 3 to 13 years). Coxometry indices were evaluated depending on the interval between operations (between surgery on the first and second joints in bilateral CP), patient's age, and the development of intact joint in unilateral CP was also studied. **Results** Multilevel interventions, including VDO and operations that restore limb weight-bearing are favorable for the development of the hip joint if the initial Reimers index is more than 40 % in both unilateral and bilateral hip dislocation. In unilateral dislocation (Reimers' index more than 40 %) and contralateral adduction or adduction flexion contracture combined with torsion of the segment and the difference in limb length that impede postural management, even with the Reimers' index less than 40 %, surgical treatment with VDO on the contralateral extremity provides a favorable development of the second hip joint. In unilateral VDO performance, on the contralateral limb, it is necessary to perform adductotomy in adduction contracture of the joint (without dislocation) to prevent lateralization and degradation of the situation towards subluxation. Failure to perform this element of the operation increases the risk to 11.8 % (with an age of younger than 8 years old) and to 14.3 % (8 year or older) of the progression of the migration index of more than 7 % per year or the development of hip subluxation. Moreover, by performing unilateral DVO in patients over 8 years of age, there is a risk of an increase in the Reimer's index of the contralateral joint by more than 7 % per year, even if simultaneous bilateral adductotomy is performed. **Conclusion** In hip dysplasia requiring reconstructive intervention in children with severe cerebral palsy, hip joint surgery should be combined with restoration of bilateral muscle balance, especially adductors, as well as with elimination of contractures of the knee and ankle joints, foot deformities to create favorable conditions for postural management in early and late postoperative period.

Keywords: cerebral palsy, dislocation of the hip, multi-level single-stage orthopedic interventions, outcome, surgical treatmentt

INTRODUCTION

Hip dislocation in children with cerebral palsy is a common pathology. This orthopedic complication is present in patients of any level according to the Gross Motor Function Classification System (GMGCS), but strictly correlates with the severity of neurological and motor disorders. Hip subluxation and dislocation occur in 60–90 % in patients with GMFCS levels IV–V [1] and, frequently are accompanied by serious postural disorders (passive and active), pain, difficulties in performing hygienic procedures, and the risk of early coxarthrosis [1– 3]. Moreover, unilateral dislocations are combined with the oblique position of the pelvis and can contribute to the development of scoliosis [4, 5]. Orthopedic disorders at the level of the hip joints are associated with contractures of the knee and ankle joints, deformities of the feet, which significantly reduces the child's functional abilities, complicates passive verticalization, use of shoes, and therefore worsen the quality of life [6–8]. It is known that correct verticalization of patients with severe CP types is extremely important both for the anatomical and functional development of internal organs and the musculoskeletal system, including the hip joint [9].

It is known that varising osteotomies may increase the neck-to-shaft angle of the femur that might result in dislocation recurrence [3, 10–12]. On the other hand, it is proposed to increase the varisation up to 100° in severe cerebral palsy (GMFCS levels IV, V), despite the increased risks of avascular necrosis of the femoral head [13, 14]. However, the authors of those works do not consider the role of restoring the limb weight-bearing, since the reconstruction of the hip joint is performed separately.

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Current approaches to surgical treatment of hip dislocation in children with cerebral palsy involve a combination of varising de-rotation osteotomy (VDO) of the femur with tendon-muscle repair and performing, when indicated, pelvic osteotomies, accompanied by restoration of support function of the entire limb, including due to the elimination of orthopedic problems around the knee and ankle joints and foot [15].

A lot of publications describe the natural history of hip dislocation using coxometry in children with severe cerebral palsy, the influence of axial load, postural management and botulinum therapy on the prevention of this condition [9, 16]. However, little attention is paid to the changes in the radiographic parameters of the hip joints after reconstructive interventions. In the long term, only changes in the cervical-diaphyseal angle, Wiberg angle or migration index (Reimer's index) are studied and only in isolated surgical interventions on the hip joint [11, 17–19].

The aim of our work was to study the parameters of coxometry in the preoperative, short and late postoperative periods in patients with severe cerebral palsy, accompanied by pathology of the hip joint, who underwent multilevel interventions that included reconstruction of the hip joint. In addition, the development of hip joints was studied depending on the interval between operations (between surgery on the first and second joints in bilateral disorder), age of the patients, as well as the development of an intact joint in unilateral dislocation.

This work follows the standards of the Helsinki Declaration of the World Medical Association "Ethical Principles for Conducting Scientific Medical Research with Human Participation" as amended in 2000 and the "Rules of Clinical Practice in the Russian Federation" approved by Order of the Ministry of Health of the Russian Federation of June 19, 2003 No. 266.

MATERIAL AND METHODS

This study included 124 children with spastic cerebral palsy who underwent surgical orthopedic reconstructive treatment at the RISC for RTO in the period between 2012 and 2016. The legal representatives of children gave written consents to the publication of the data without identification. The average age at the start of treatment was 7.01 ± 2.47 years (range, 3–13). According to GMFCS levels, the distribution was as follows: level III – five patients, level IV – 70 patients, level V – 49 patients.

The inclusion criteria were the following:

– patients with cerebral palsy who underwent surgery for hip dislocation, but who also had simultaneous surgical interventions for contractures of the knee joints and/or contractures of the ankle joints and foot deformities;

– period of patients follow-up was at least 30 months.

The following parameters were taken into account during the radiographic assessment: Reimers index, Acetabular Index (AI), Acetabular Depth Index (ADI), neck-to-shaft angle (NSA), Wiberg angle. Radiography was performed in all patients before and after surgical treatment, and then annually in standard position with neutral rotation of the hips (if possible) and taking into account flexion contractures in the hip joints [17, 20, 21].

Considering the influence of age on the prognosis of the hip joint development in the postoperative period as well as the importance of achieving the fastest symmetry and support on the extremities [22–25], findings of coxometry were evaluated separately in groups of patients who underwent surgical treatment before 8 years of age and after this age. Moreover, the Reimers index of more than 40 % was taken as a criterion for absolute indications for VDO [20]. Coxometric radiographic findings are known to correlate with the quality of life in children with severe cerebral palsy (GMFCS levels IV–V) [18].

Thus, two large groups were formed (group 1 were children under eight years old, and group 2 was children of eight years of age and older). Within each group, radiographic indices were examined by sequential bilateral reconstructive intervention (where the obligatory element was the VDO) with an interval between the operations of six months or less (subgroups 1a and 2a, respectively); in unilateral dislocation, the development of the hip joint of the operated (1b and 2b, respectively) and intact one where the Reimers index was less than 40 % (1c and 2c, respectively). In addition, in our study in children younger than eight years of age, we examined the dynamics of coxometry when performing VDO on the second side one year or more after the surgery (group 1d) on the first limb, when the initial Reimers index was more than 40 % for both joints, and the intervention on the second side was planned initially but postponed due to somatic problems [26]. Finally, we examined separately the radiographic parameters of the hip joints, operated secondarily with a small interval with the initial Reimers index of less than 40 %, but where the indications for the VDO were pronounced torsion of the femur, length discrepancy

of the limbs that made postural management difficult (group 1e). Among patients over 8 years of age there were no cases that could be assigned to the subcategories "d" and "e".

In the postoperative period, all patients were verticalized with support on the operated limb 10–21 days after the intervention. In the long-term period, recommendations were given on orthosis fitting, postural correction, and regular monitoring at follow-ups were appointed to implement the recommendations.

The quantitative data obtained were subjected to statistical processing using the AtteStat 13.1 software (Russia). The statistical study included descriptive statistics: mean values (M) and standard deviation (SD). Comparative studies were performed using the Wilcoxon test for paired samples (to check the differences between the two samples including the equality of means between the indicators before treatment and in the long term). The difference in measurement of values between researchers was evaluated using the coefficient of variation. Differences were considered statistically significant at $p < 0.05$.

RESULTS

Table 1 presents data on average age, levels of motor activity (GMFCS), and elements of operations for patients with unilateral and sequential bilateral reconstructive interventions

It should be noted that almost all patients required extension of the adductor muscles during bilateral reconstructive interventions, while in unilateral operations the contralateral limb was in the abduction position and no adductotomy was required. It should also be noted that in 41 cases, patients underwent certain interventions previously to lengthen the triceps muscle of the lower legs, which did not require a re-operation, especially in patients older than 8 years.

Changes in the studied parameters for groups 1a (52 children, 104 joints) and 2a (20 children, 40 joints) are presented in Table 2.

Table 1

Summary of interventions performed

		Age			
		Up to 8 years of age		8 years and older	
		Bilateral sequential VDO	Unilateral VDO	Bilateral sequential VDO	Unilateral sequential VDO
Number of patients		52	31	20	21
Mean age, years		5.8 ± 1.03	5.3 ± 1.17	9.6 ± 1.67	10.0 ± 2.41
GMFCS level, number	III	–	2	1	2
	IV	33	13	12	13
	V	19	17	7	6
Elements of interventions; number					
Pelvic osteotomies		40	15	14	12
Open reduction		3		4	
Adductotomies		92	31	34	22
Lengthening of knee joint flexors		60	24	28	12
Lengthening of m. triceps		36	25	4	6
Shortening of m. tibialis post.		32	6	10	6
Osteotomies /arthrodesis on the foot		29	2	12	4

Table 2

Changes in coxometry parameters in patients with bilateral VDO with an interval between operations of less than 6 months

Parameter	Group	Period			
		Before operation	Operation	After 10-12 months	After 20-30 months
Reimers index (%)	1a	61.2 ± 25.8	2.0 ± 10.6*	3.3 ± 6.6*	6.1 ± 9.6*
	2a	62.4 ± 22.7	0.4 ± 1.7*	3.2 ± 5.7*	3.7 ± 4.6*
AI (°)	1a	30.8 ± 8.1	23.1 ± 6.8	22.6 ± 7.3	22.4 ± 15.8
	2a	29.4 ± 6.1	20.4 ± 7.7	18.9 ± 6.9	20.0 ± 4.6
NSA (°)	1a	161.1 ± 10.1	119.8 ± 8.2*	120.2 ± 15.1*	122.8 ± 15.3*
	2a	158.1 ± 12.4	118.6 ± 6.9*	117.7 ± 9.6*	121.2 ± 9.0*
ADI	1a	4.9 ± 1.2	4.7 ± 4.0	4.3 ± 0.8	4.3 ± 0.7
	2a	4.5 ± 0.91	4.3 ± 0.94	4.2 ± 0.7	3.9 ± 0.5
Wiberg's angle (°)	1a		25.8 ± 6.8	27.0 ± 7.9	30.3 ± 7.9
	2a		32.8 ± 6.7	37.6 ± 16.0	34.9 ± 7.0

* Significant difference with preoperative values according to the Wilcoxon test.

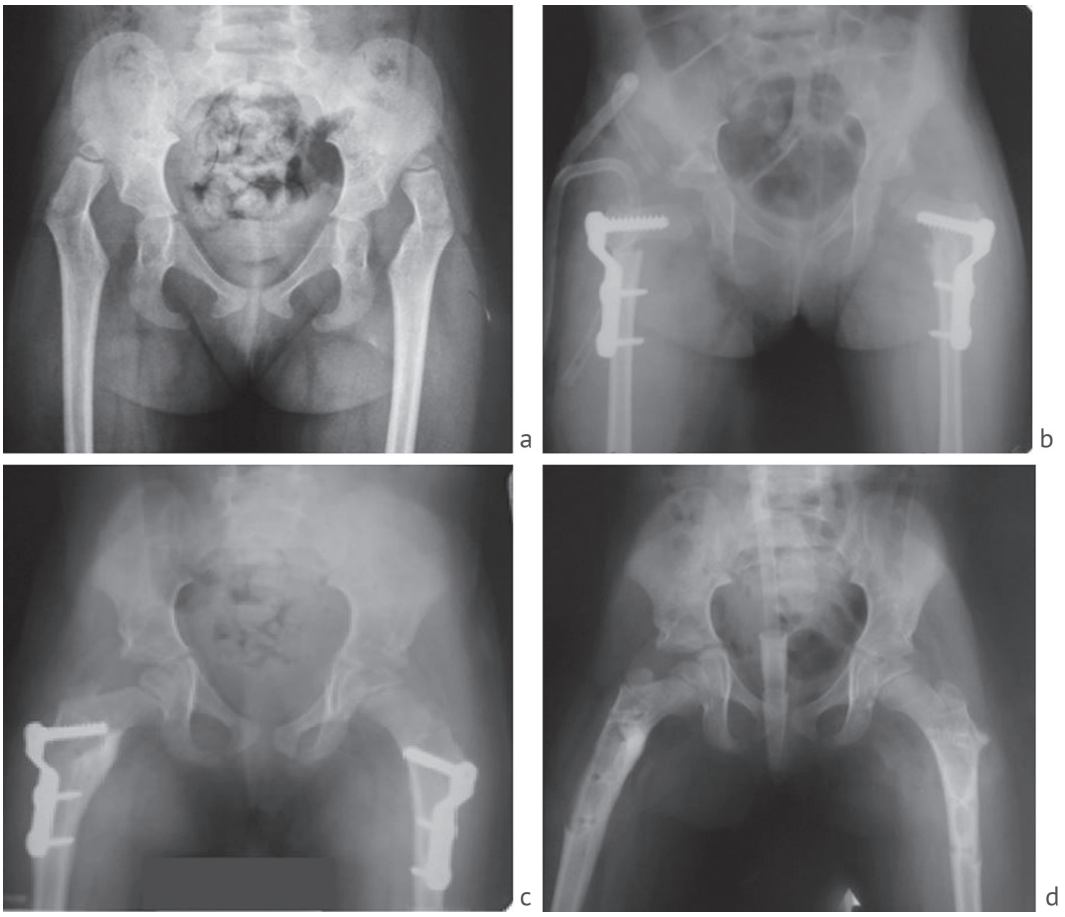

Fig. 1 Bilateral VDO + acetabuloplasty according to San Diego with a short interval between operations (3 weeks). Patient B., 6 years old, GMFCS level IV. AP Radiographs of the pelvis: ***a*** before surgery: Reimers index 100 % on the right and left; AI 35° on the right and left; ADI 2.5 on the right, 3.6 on the left; ***b*** after surgery: Reimers index 0 %; AI 18° on the right, 17° on the left; ADI 4.2 on both sides; Wiberg angle of 27° on the right, 25° on the left; ***c*** one year after the operation: Reimers index 0 % on both sides; AI 13° on the right, 18° on the left; ADI 3.8 on the right, 3.9 on the left; Wiberg angle of 37° on the right, 35° on the left; ***d*** two years after the operation: Reimers index 0 % on both sides; AI 15° on the right, 16° on the left; ADI 3.4 on the right, 3.8 on the left; Wiberg angle 36° on the right, 35° on the left

In the long-term period, for both groups, one can note a tendency to maintain the correct relationship between the femoral head and acetabulum, as well as an improvement in indicators illustrating the development of the acetabulum (Wiberg index, AI and ADI). For NSA, a characteristic increase was seen, but it was slightly expressed (1–2°). Reimers index values, on average, remained within normal range. However, in the late period after surgery, we found two cases (two joints, 1.9 %) in group 1a that had this indicator exceeding 30 % (with an annual increase of more than 10 %). In both of these cases, there was no correct and full orthosis support in the postoperative period; a significant radiological deterioration in indices was combined with the development of flexion-adduction contracture of one of the hip joints, which also made it difficult for the patients to stand upright.

Changes in the studied parameters for groups 1b (34 patients) and 2b (21 patients) are presented in Table 3.

In the long-term period, in groups 1b and 2b, correct relationship between the femoral head and acetabulum was preserved, taking into account the Wiberg index and AI. The increase in NSA did not exceed 1–2° per year. The Reimers index grew moderately, not exceeding 7 % per year. The development of the contralateral joint (for patients in groups 1b and 2b) where the values of the Reimers index at the time of treatment initiation did not exceed 40 %, and surgical treatment with VDO was not initially planned is presented in Table 4.

In general, in groups 1c (34 joints) and 2c (21 joints) there was a positive dynamics of indicators reflecting the relationship between the acetabulum and femoral head and the development of the acetabulum – Wiberg, Reimers, and ADI indeces. NSA almost did not change in both groups.

Serious deterioration of the Reimers index was found in four cases in group 1c (11.8 % of cases): an increase of 12–23 % per year. Moreover, the index exceeded 40 % in two cases. Those patients developed

pronounced contracture of the contralateral hip joint, difficulties in verticalization and postural management. It should also be noted that none of those patients had adductomy on the opposite extremity when performing VDO in them. It is important to clarify that in all other cases of performing an adductotomy on the opposite side of the VDO osteotomy in adduction contracture or refusal to perform an adductotomy due to windswept-deformity (abduction of the hip), the Reimers index did not change or decreased, or its increase did not exceed 3 % in a year.

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Table 3

Changes in coxometry parameters in unilateral VDO (unilateral excess of the Reimers index by 40 %)

Parameter	Group	Periods			
		Before operation	Operation	After 10–12 months	After 20–30 months
Reimers index (%)	1b	72.3 ± 23.7	1.5 ± 8.6*	2.9 ± 6.2*	5.3 ± 7.7*
	2b	57.6 ± 23.5	0.4 ± 1.7*	2.2 ± 4.5*	5.2 ± 4.9*
AI (°)	1b	31.7 ± 7.2	21.5 ± 7.3	23.4 ± 7.0	19.3 ± 5.0
	2b	33.9 ± 8.9	22.6 ± 9.3	24.7 ± 7.3	20.2 ± 8.8
NSA (°)	1b	165.0 ± 11.1	122 ± 11.9*	126.3 ± 22.1*	130.6 ± 17.9*
	2b	156.1 ± 12.9	120.1 ± 11.0*	122.7 ± 13.0*	128.2 ± 10.1*
ADI	1b	4.9 ± 1.3	4.6 ± 1.0	4.7 ± 0.8	4.7 ± 0.7
	2b	5.0 ± 1.2	4.4 ± 1.1	4.4 ± 0.6	4.5 ± 1.4
Wiberg angle (°)	1b		27.7 ± 7.11	28.1 ± 6.9	32.0 ± 9.1
	2b		32.6 ± 7.9	27.8 ± 8.6	29.2 ± 7.7

* Significant difference with the preoperative values with Wilcoxon test

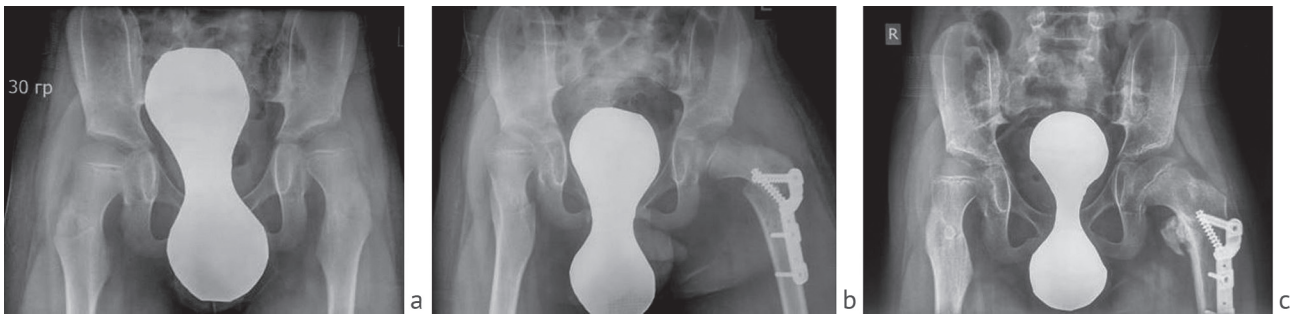

Fig. 2 Increase in the Reimers index on the contralateral joint. Patient N., 9 years old, GMFCS level IV. AP radiographs of the pelvis: ***a*** before surgery: Reimers index 26 % on the right and 43 % on the left; AI 24° on the right and 30° on the left; ADI 4.6 on the right and 4.3 on the left; ***b*** one year after the operation: Reimers index 35 % on the right, 0° on the left; AI 30° on the right, 26 ° on the left; ADI 3.7 on the right, 3.7 on the left; Wiberg angle of 20° on the right, 32° on the left; ***c*** 1.5 years after the operation: Reimers index 39 % on the right, 0 % on the left; AI 25° on the right, 19° on the left; ADI 4.2 on the right, 3.7 on the left; Wiberg angle 12° on the right, 30° on the left

Table 4

Development of the contralateral joint with unilateral dislocation

Parameter	Group	Periods		
		Onset of study	After 10–12 months	After 20–30 months
Reimers index (%)	1c	19.8 ± 12.2	14.9 ± 10.1	9.0 ± 6.7
	2c	17.8 ± 10.7	21.5 ± 12.5	14.2 ± 10.9
AI (°)	1c	17.5 ± 5.3	19.5 ± 54	23.3 ± 6.1
	2c	18.9 ± 6.2	18.9 ± 7.2	19.8 ± 2.9
NSA (°)	1c	162.1 ± 8.6	160.2 ± 12.9	159 ± 16.5
	2c	158.9 ± 8.9	154.6 ± 12.2	157 ± 11.5
ADI	1c	4.8 ± 0.64	4.2 ± 4.1	4.1 ± 0.5
	2c	3.7 ± 0.8	3.9 ± 0.7	3.7 ± 0.8
Wiberg angle (°)	1c	22.5 ± 8.6	31.0 ± 8.8	29.3 ± 7.1
	2c	28.9 ± 6.6	30.9 ± 10.5	25.5 ± 2.6

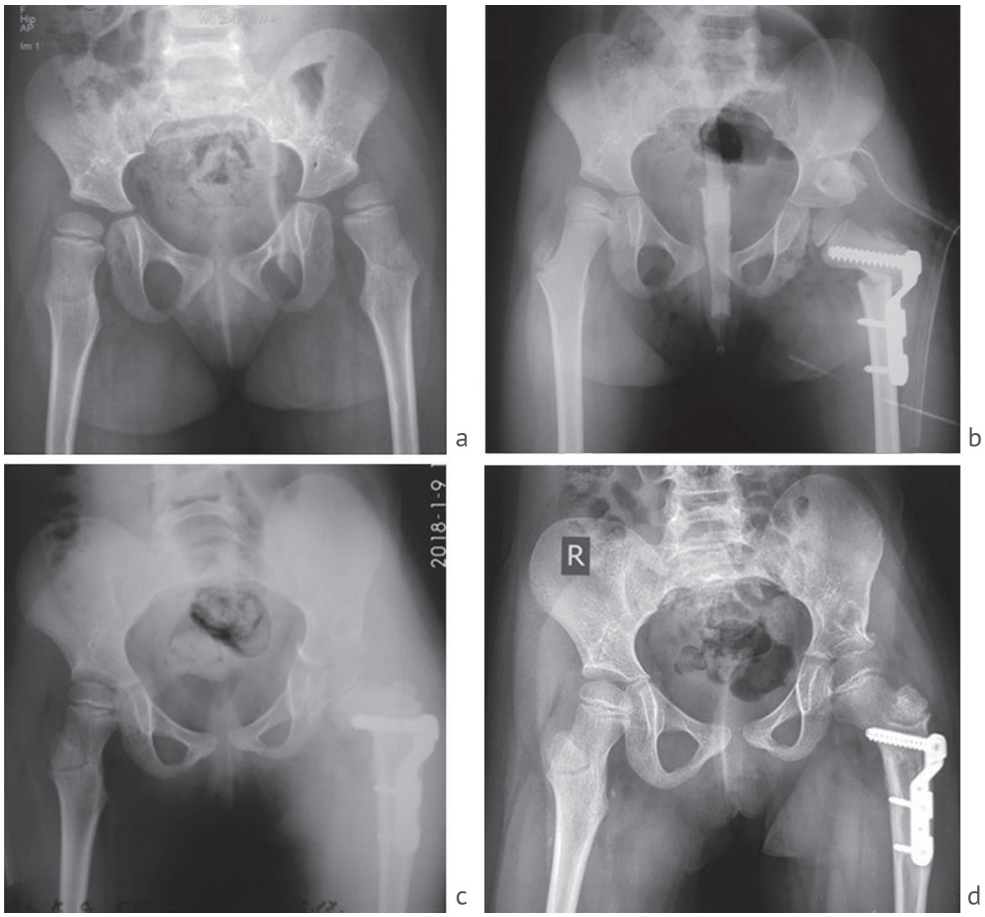

Fig. 3 Improved parameters on the contralateral joint. Patient B., 7 years old, GMFCS level V. AP radiographs of the pelvis: ***a*** before surgery: Reimers index 34 % on the right and 73 % on the left; AI 26° on the right and 33° on the left; ADI 4.0 right, 5.2 left; ***b*** after surgery on the left hip: Reimers index 0 %; AI 17°; ADI 4.6; Wiberg angle 34°; ***c*** one year after the operation: Reimers index 18 % on the right, 0 % on the left; AI 30° on the right, 20° on the left; ADI 3.7 on the right, 4.0 on the left; Wiberg angle 32° on the right, 33° on the left; ***d*** 2 years after the operation: Reimers index 11 % on the right; 8 % on the left; AI 24° on the right, 23° on the left; ADI 4.2 on the right, 5.5 on the left; Wiberg angle 32° on the right, 26° on the left

In group 2c, an increase in the Reimers index of more than 7 % per year (from 14 to 16 %) was observed in three patients (14.3 % of cases). As in group 1c, adductotomy on the opposite side (side of consideration for group 2c) was not performed in patients with VDO in the presence of adduction contracture in those three patients. Those patients were subsequently operated on with VDO. In another 15 children from group 2c, the Reimers index did not change or decreased, or its increase did not exceed 3 % per year, since adductotomy was performed (in adduction contracture) or windswept-deformity was present. Finally, in three more children, an increase in the Reimers index of more than 3 % occurred despite the adductotomy performed at the time of VDO on the opposite side, orthosis at rest and verticalization. It seems the reason for the growth in the Reimers index is a significant increase in the amplitude of limb abduction on the side of the VDO, the difference in leg length and associated with these two factors frequent adduction position in the joint, in which the VDO was not performed. Those three children continue to be under our supervision.

Table 5 presents another unfavorable situation for the hip joint when, for somatic or other reasons, reconstructive surgery on the second hip joint (with a Reimers index of more than 40 %) was postponed for a period of 1–1.5 years (group 1d).

According to the data presented, it becomes obvious that unilateral reconstructive surgery does not improve or even stabilize the radiographic indices for the contralateral hip joint if the Reimers index is more than 40 %. On the other hand, even a later surgery has a positive effect on the development of the hip joint in the long term.

A separate consideration is the development of the hip joint if VDO was performed at the Reimers index of less than 40 %. This situation was observed in 25 patients from group 1a for the second side, who had torsion of the segment and a difference in limb length (after the first operation on the dislocation side) in addition to adduction or adduction-flexion contracture, which significantly complicated postural management (Table 6).

Table 5

Coxometric indices in the late execution of VDO on the contralateral limb (on the second hip joint, group 1 d)

Parameter	Periods				
	Before surgery on 1st hip joint	After one year (before the surgery on the 2nd joint)	After operation	After one year	After two years
Reimers index (%)	60.8 ± 20.2	64.7 ± 24.0	1.02 ± 2.13*	1.2 ± 2.7*	2.8 ± 5.5*
AI (°)	30.6 ± 4.7	30.5 ± 6.3	23.5 ± 5.8	20.4 ± 5.3*	19.5 ± 1.7*
NSA (°)	163.8 ± 9.9	162.7 ± 10.9	121.7 ± 4.2*	120.2 ± 9.7*	120.5 ± 12.7*
ADI	4.5 ± 0.6	5.3 ± 1.4	4.8 ± 0.6	4.2 ± 0.3	4.4 ± 0.5
Wiberg angle (°)			26.9 ± 7.4	30.2 ± 9.5	28.8 ± 1.7

* Significant difference with the preoperative values with Wilcoxon test

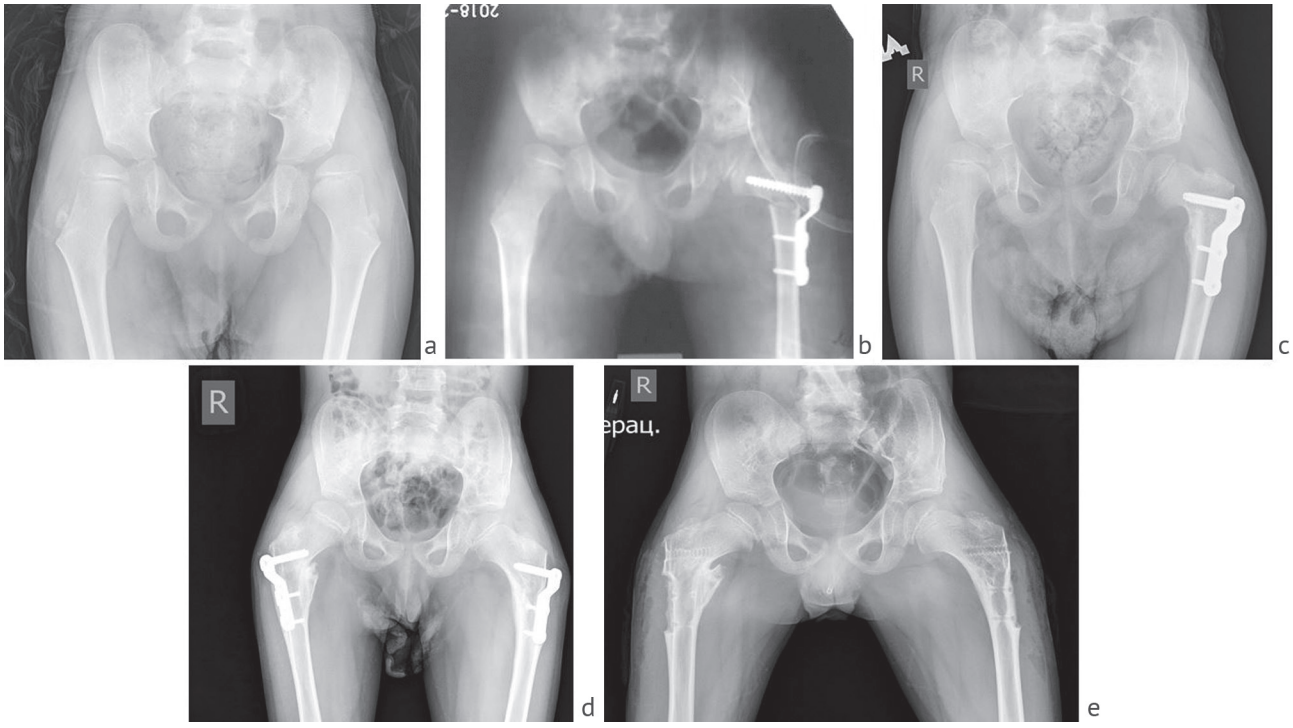

Fig. 4 Bilateral reconstruction of hip joints with a period between operations of 1–1.5 years. Patient M., 4 years old, GMFCS level IV. AP radiographs of the pelvis: ***a*** before surgery: Reimers index 38 % on the right and 73 % on the left; AI 26° on the right and 33° on the left; ADI 4.0 right, 5.2 left; ***b*** after surgery on the left side: Reimers index 0 %; AI 17°; ADI 4.6; Wiberg angle 34°; ***c*** 1 year after surgery on the left: Reimers index 30 % on the right; 0 % on the left; AI 30° on the right, 20° on the left; ADI 3.7 on the right, 4.0 on the left; Wiberg angle 32° on the right, 33° on the left; ***d*** after 0.5 years after surgery on the right: Reimers index 24 % on the right; 0 % on the left; AI 26° on the right, 10° on the left; ADI 3.9 on the right, 3.6 on the left; Wiberg angle 24° on the right, 34° on the left; d 2 years after the operation: Reimers index 0 % on the right; 0 % on the left; AI 20° on the right, 16° on the left; ADI 4.1 on the right, 4.1 on the left; Wiberg angle 32° on the right, 36° on the left

Table 6

Coxometry parameters before and after surgery with an initial Reimers index of less than 40 %

Parameter	Period			
	Before operation	After operation	After one year	After two years
Reimers index (%)	28.7 ± 10.3	1.2 ± 2.9*	5.5 ± 8.2*	10.0 ± 11.3
AI (°)	23.4 ± 7.1	21.2 ± 7.1	20.2 ± 7.04	20.1 ± 6.3
NSA (°)	158.2 ± 12.2	122.7 ± 8.4*	125.4 ± 13.3*	127.8 ± 14.1*
ADI	4.7 ± 1.02	4.4 ± 0.7	4.2 ± 0.8	4.3 ± 0.7
Wiberg angle (°)	18.6 ± 6.3	27.9 ± 7.8	29.2 ± 11.1	29.1 ± 7.3

* Significant difference with the preoperative values with Wilcoxon test

In all the cases, the surgical treatment improved radiographic parameters and the subsequent dynamics of coxometry indices reflects better conditions for the development of the joint that was operated. There were no cases of critical increase in the Reimers index.

Thus, multilevel interventions, including VDO and supplemented procedures that restore limb supportability are favorable for the development of the hip joint with an initial Reimers index of more than 40 % both in unilateral and bilateral hip

dislocation. In unilateral dislocation (Reimers index more than 40 %) and contralateral adduction or adduction flexion contracture combined with torsion of the segment and the difference in limb length that impeded postural management, even with the Reimers index less than 40 %, surgical treatment with VDO on the contralateral extremity provides a development of the second hip joint. In the case of performing a unilateral VDO, it is necessary to perform adductotomy for adduction contracture of the joint (without dislocation) on the contralateral side to prevent lateralization and degradation of the situation towards subluxation. Failure to perform this element of the operation increases the risk of the progression of the migration index of more than 7 % per year or hip subluxation to 11.8 % (in an age younger than 8 years) and up to 14.3 % (in the age of 8 years or older). Moreover, in unilateral VDO, there is a risk of an increase in the Reimers index of the contralateral joint by more than 7 % per year even with simultaneous bilateral adductotomy but only in patients older than 8 years.

DISCUSSION

Adoption of an optimal and timely surgical decision for managing the pathology of the hip joint in children with cerebral palsy requires knowledge of the pathogenesis and pathological anatomy of this orthopedic condition [27–29]. The incidence of subluxation and dislocation of the hip in children with cerebral palsy correlates with the severity of motor impairment and is accompanied by a serious deterioration in the quality of life for both the child and his family or caregivers [6, 18, 29–31].

The use of the Gross Motor Function Classification System, as well as the development of a program for monitoring hip dysplasia in children with cerebral palsy are crucial events for understanding the problem, predicting functional outcomes and finding solutions to prevent and treat hip dislocation in children with cerebral palsy [32–34]: systematic start of preventive measures for postural correction and management, botulinum therapy, timely surgery on the tendon-muscle apparatus assisted in reduction of the development of hip dislocation, number of surgical interventions on the hip joint and completely avoid palliative interventions.

Among the radiological indicators of assessing the state of the hip joint, the Reimers index is of primary value along with the acetabular index and the Wiberg index [12, 17, 20, 27, 35, 36]. The NSA, the CCD angle, and the AD index are less prognostic, but in combination with other indicators reflect the dynamics of changes in the morphology of the hip joint during its development and in the postoperative period [11, 21, 37].

Nevertheless, the need for reconstructive surgery in hip joint pathology, according to the literature, is quite frequent. Such interventions and their results remain the subject of discussion [13, 14, 17, 19]. Currently, there is a consensus on the indications for this type of intervention: the migration index (Reimers index) is 40 % or more and its annual increase is 7 % or more [20, 27, 28]. Acetabular dysplasia is secondary. Hagglund et al. [20] observed its spontaneous decrease in the process of residual growth after eliminating lateralization of the femoral head.

A commonly accepted intervention for reconstruction of the proximal femur is varus derotation osteotomy in combination with or without acetabuloplasty and lengthening of adductors, as well as of the iliopsoas muscle [11, 12, 14, 35, 36, 38]. The age of 5 to 7 years is considered optimal for performing interventions, when the period of residual growth remains sufficient for the anatomical formation of the hip joint [18, 22, 23, 28, 39].

The success of this approach was confirmed by various authors in terms of the development of the hip joint in the long term (more than two years after surgery). In one of the first papers that analyzed immediate and long-term results (average follow-up 6.9 years), McNerney et al. [38] indicate a change in the migration index from 66 % before surgery to 5 % after the intervention and its slight increase to 11 % in the long-term. Moreover, the acetabular index changed from 26° to 13° in the short term and to 11° in the long-term period. Karlen et al. [35] with an average follow-up of 56 months showed an improvement in the average migration index from 84 to 8 % in the short term and up to 14 % in the long-term observation period. Jozwiak et al. [14] achieved the required correction of radiological parameters in all patients (25 children, 30 hip joints), but subsequently observed a change in the acetabular index from 22° to 23° in the long term, the migration index from 11 % to 23 % in the long term, Wiberg angle from 16° to 23°, neck-to-shaft angle from 133° to 140°. Reidy K et al. [12] also reported a change in the migration index from 63.6 % before surgery to 2.7 % after the intervention and its subsequent increase to 9.7 % in the long-term period.

Moreover, the NSA changed from 152.3° to 132.6° in the short- and to 137.2° in the long-term period. An increase in the NSA in the long-term period is a generally recognized change [11, 12, 14]. Davids et al. [40] stress a loss of correction by 29 % in the

long-term period of 5 years and 6 months. Miller et al. [13] recommend to create the NSA of 100° in patients incapable of independent motion, and 120° in patients with preserved walking function. Rutz et al. [41] performed reconstructive interventions and produced the NSA of 120–125° in patients with limited but preserved walking function. The scheme of Mazur et al. [11] for patients with GMFCS levels IV–V looks more acceptable: formation of the NSA of 100°–110° at the age of 4–12 years, suggesting a spontaneous increase in the angle by 20° during subsequent growth, and creation of the NSA of 110°–120° in older patients in whom spontaneous growth is close to completion.

In our series of patients, we observed similar changes in the coxometric parameters in the long-term period after surgery: a slight increase in the migration index and an increase in the NSA. However, the change in these indicators was accompanied by an improvement in the ADI and Wiberg angle, which reflects the concordant development of the proximal femur and acetabulum and preserved concentricity of the joint components.

We observed an increase in the Reimers index of more than 10 % per year only in 1.9 % of cases with sequential bilateral intervention (VDO), where the reason could be the lack of adequate orthosis support and the failure of proper postural management with axial load. In literature, recurrence rates of subluxations and dislocations of the hips are ambiguous. Sankar et al. [22] reported one hip dislocation recurrence out of 14 reconstructive interventions. Jozwiak et al. showed one dislocation and 6 subluxations (23 %) after 30 reconstructive interventions in the long-term period [14].

Rutz et al. [41] found two hip dislocation recurrences in the long-term period after 168 interventions. Reidy et al. [12] stated that only 96.5 % of operated hip joints were considered stable in the long-term period with a Reimers index of less than 33 %. According to McNerney et al., out of sixty-one hip reconstructions in the long-term period, six had a migration index of more than 33 %, five cases of subluxation and one of coxa magna. The authors associate all cases of radiological recurrence of subluxation with errors in performing surgical interventionы [38]. However, none of the above series of patients had multilevel interventions performed, including the correction of contractures of the knee and ankle joints and deformities of the feet. Moreover, methods and approaches to postural correction in the postoperative early and long-term period were not demonstrated.

The vertical posture is important not only for the development and functioning of the cardiac, respiratory system, for the function of the intestine and urinary system in children with severe types of cerebral palsy, but also for the development of the hip joint, prevention of early coxarthrosis, critical osteoporosis, and pathological fractures [9, 18, 27, 42]. It is known that the systemic nature of cerebral palsy is accompanied by the pathology of not only the hip joint [7, 15]. Intervention in the area of the knee joint, ankle joint, and foot is required in order to improve the sitting posture, the possibility of full verticalization with support on the limb, and comfortable use of shoes. We showed previously the importance of multilevel interventions to achieve the required anatomical and functional result in children with hip dislocation in cerebral palsy [15]. The present study confirms previous statements.

Another controversial issue in the literature is the need to perform bilateral VDO in a unilateral dislocation when the migration index of 40 % or more is only on one side. A number of authors defend the position of performing VDO only on the side of subluxation/dislocation. Carr et Gage [43] observed only 0.9 % of cases with progression of the lateralization of the femoral head. Gordon et al. [44] did not show deterioration in radiological parameters in the long-term period. Settecerri et al. [45] performed VDO of the contralateral hip in two out of 48 children who had previously undergone unilateral correction of hip dysplasia. On the other hand, a bilateral approach in a unilateral dislocation also finds its supporters. Noonan et al. [46] operated on the contralateral hip joint in 15 out of 35 children in the long term after the initial intervention on the first joint. Canavese et al. [47], in a similar situation, performed 12 interventions in 27 children. Owers et al. [48] combined a unilateral VDO with bilateral intervention on soft tissues to restore muscle balance in unilateral hip dislocation.

Larsson et al. [19] support the tactics of performing VDO only on the dislocation side, provided that muscle balance is restored, and a program for monitoring the development of the hip joints, including adequate postural management, is used.

When analyzing the development of the second joint after the surgery on the dislocation side, we observed smooth formation of an intact hip joint only under the condition of performing bilateral intervention on the soft tissues, restoring the balance; however, adequate postural management is required as a condition. We did not observe lateralization of the femoral head and the progression of the Reimers index on the non-operated side in the late period in the case of windswept-deformation.

On the other hand, the unilateral soft tissue release on the side of the dislocation and VDO in bilateral adductor

contracture and / or the absence of postural correction, including compensation for the difference in limb length after correction of the unilateral hip dislocation in our series led to subluxation in three children (11.8 % cases of unilateral dislocation) under 8 years of age, which required its correction by performing VDO. In older children, the dysfunctional development of the intact hip joint occurred in 6 cases (28.6 %), of which surgical interventions have already been performed in three cases. In all cases when reconstructive intervention on the second joint was programmed and performed with an initial migration index of less than 40 %, the development of the second joint ran smoothly and without degradation of radiological indices. We believe that bilateral release of soft tissues to restore muscle balance should be mandatory in unilateral dislocation in order to create conditions for postural correction and to implement a program for monitoring hip development in children with GMFCS levels IV–V. However, the issue about the programming of VDO on the second side when the Reimers index is less than 40 % should be decided individually, taking into account the severity of contracture, as well as the capabilities of adequate shape, time and necessity of the orthosis application and postural management. In unilateral dislocation, we recommend performing VDO on the contralateral joint within the first year after the first operation, even before the appearance of formal indications (migration index of 40 % or more), if correct orthotic and postural correction is impossible.

We also state that bilateral soft tissue release in bilateral subluxation (Reimers index of more than 40 % on both sides) did not lead to an improvement in coxometrical indices in none of the case in patients where the second VDO was delayed for more than a year due to medical contraindications or other reasons.

CONCLUSION

Hip joint surgery should be combined with restoration of bilateral muscle balance, especially adductors, as well as with elimination of contractures of the knee and ankle joints, foot deformities in hip dysplasia requiring reconstructive interventions in children with severe cerebral palsy to create favorable conditions for postural management in early and late postoperative period.

Our study showed that this approach helped to maintain favorable conditions for the development of both hip joints as well as of joints that had low values of the migration index at the onset in which varus derotation osteotomy was not performed.

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