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# Changes in the kinematic parameters of gait in children with cerebral palsy after multilevel interventions with the initial patterns of true equinus gait and jump gait

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**Introduction** Cerebral palsy is the most common cause of motor disorders that occurs in early childhood and is present throughout life. The incidence rate of the disease is 1/500 newborns. About 17 million people with cerebral palsy live in the world. According to domestic epidemiologists, the reported incidence of cerebral palsy in Russia is from 2.2 to 3.8 per 1,000 births. Spastic cerebral palsy types are 80% of all the cases. **Purpose** Analysis of changes in the kinematic parameters of gait after multilevel interventions in children with cerebral palsy with the initial true equinus gait and jump gait patterns. **Material and methods** This retrospective study included 64 children (26 girls, 38 boys) with cerebral palsy and spastic diplegia. The average age was  $8.7 \pm 2.41$  years. All patients corresponded to levels I or II of impaired motor function (GMFCS: I/II = 14/50). **Results** All patients showed a significant improvement in the kinematic parameters of gait throughout the observation period. Deviation from the normal values decreased almost four times in the whole group of patients. **Conclusion** Multilevel single-event orthopedic interventions improve the kinematic and kinetic parameters of the gait of the entire biomechanical chain in the lower extremities. In addition to the local effects of surgical interventions (elimination of orthopedic disorders such as contractures and deformities of bones and joints of the lower extremities), there are long-term changes in the reduction of energy-consumptive compensatory movements.

Keywords: cerebral palsy, true equinus gait, jump gait, torsion deformities, orthopedic surgical treatment, gait analysis

## INTRODUCTION

The incidence of cerebral palsy is two to five cases per 1,000 newborns [1–4]. According to Russian epidemiologists, the reported rate of cerebral palsy in Russia is from 2.2 to 3.8 per 1,000 births. Spastic cerebral palsy types are about 80 % of all the cases registered [5–8].

Despite the fact that cerebral palsy is a stable encephalopathy, it is orthopedic complications that are the main cause of progressive motor activity deterioration in children with cerebral palsy [9–11]. The pathogenesis of the disease implies that the initial spastic syndrome gradually leads to muscle retraction and the appearance of contractures requiring surgical treatment. The modern concept of operative orthopedic treatment of children with cerebral palsy is multilevel surgical interventions on all components of the biomechanical chain in the limbs. It makes the child capable to use both limbs while learning to walk correctly or close to correct walking, independent or with auxiliary means [12–17]. Moreover, the methods of operative correction should result in early weightbearing, early passive and active mobilization of the joints after the interventions [18]. Another important point in planning surgical treatment is the analysis of walking disorders. Based on a computer gait analysis, the main pathological patterns in spastic diplegia were identified [19–23]. Lofterød B. et al. [24], Simon S.R. et al. [25] point to the critical importance of gait analysis both for understanding the pathology of movements and for planning surgical interventions and control in the long term period [26].

If computer analysis of kinematic, kinetic and dynamic electroneuromyographic findings is unavailable, observation scales are recommended that are based on studying goniometric findings of motion video recording in orthogonal planes [27–29]. Novacheck T.F. et al. [28] and Read H.S. et al. [30] showed that the Edinburgh visual gait score correlates with the Gillette Gait Index and the Gillette Functional Assessment Questionnaire (FAQ), which allows it to be used for clinical purposes given that the experience to work with the 3D gait laboratory analysis has been gained.

We retrospectively examined the results of using single-event multilevel orthopedic surgery (SEMLS) in patients with true equinus gait, jump gait, asymmetric

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gait (a combination of the first two) patterns and compared gait parameters using the Edinburgh scale in the preoperative period, one year after surgery and in the long term. The types of the pathological gait indicated above are similar in parameters, so the results of their surgical correction could be shown together [31, 32]. We also should point out that it is impossible to study the effect of a single surgical treatment element on the final result within the framework of SEMLS. Therefore, the impact of surgical correction was studied in the groups of patients with similar interventions and anatomical locations [33, 34].

## MATERIAL AND METHODS

This retrospective study included 64 children (26 girls, 30 boys) that had spastic diplegia due to cerebral palsy. Mean age was  $8.7 \pm 2.41$  years. All had either GMFCS level I or II (GMFCS: I/II = 14/50).

The study was conducted in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association "Ethical Principles for Medical Research Involving Human Subjects" as amended in 2013 and the "Rules of Clinical Practice in the Russian Federation", approved by order of the Ministry of Health of the Russian Federation dated June 19, 2003 No. 266. Patients, patients' parents, and / or their legal representatives signed an informed consent for surgery and publication of the data without identification.

All the patients underwent single-event multilevel surgeries. One intervention included an average of  $6.3 \pm 1.46$  surgical elements. The elements are given in Table 1. In addition, some patients underwent correction of torsion deformities of the femur in the period from 12 to 15 months after the initial intervention: 12 subjects (24 femurs).

Gait analysis using the Edinburgh visual gait score was performed before surgery, one year after the intervention and two to three years after the initial operation.

To determine the functional abilities of independent walking, the Gillette questionnaire (FAQ) [35] was used at the same time.

AtteStat 12.0.5 software was used for statistical data processing. Descriptive statistics showed the average value of the parameter and its standard deviation. Spearman's rank correlation score was used to link the Edinburgh score and FAQ. The chi-square test determined the significance of differences in the Edinburgh scale in patients with or without clinically significant torsion deformities. The specificity and sensitivity of the combination of maximum deviations of the "knee progression angle" – "trunk maximal lateral shift" were determined as a test for identifying indications for surgical correction of torsion deformities of the femur.

Table 1 Elements of primary surgical interventions

Surgical element	Number
Lengthening of medial knee flexors	122
Lengthening of abductors, m. gracilis	64
M. gastrocnemius aponeurotomy, lengthening of the Achilles tendon	115
Subtalar arthrodesis	62
Shortening of m. tibialis posterior tendon	24
Detorsion osteotomy of the femur	8
Detorsion osteotomy of the tibia	8
Total	403

# RESULTS

Average values of 17 parameters of the Edinburgh scale studied are shown in Table 2. There was a significant improvement in the kinematic gait parameters in children in the period of observation and a four-fold reduction of deviation from the normal values for the whole group. Most significant improvements were observed in the support phase of gait: initial contact, heel lift, maximum dorsiflexion of the foot, peak knee extension, peak hip

extension, trunk lateral shift, foot and knee orientation relative to the motion axis while in the non-support phase those were maximum ankle dorsiflexion, peak knee flexion, clearance, peak hip flexion, knee position in terminal swing immediately before the contact with the supporting surface.

Comparison of the total of the Edinburgh scale with FAQ values found a significant negative correlation in

the period before treatment and two to three years after the initial operation (Table 3). A study of changes in the parameters in patients during the first year after surgery revealed that torsion of the femur which was undetected or unrepaired at the initial stage of treatment, required a repeated intervention in 12 patients 12 to 15 months after the primary operation. Figures 1 and 2 present the distribution of cases depending on gait analysis and FAQ values for a period of 12 months after the initial operation, illustrating the effect of uncorrected torsion on the outcome of treatment in the mid-term follow-up. As mentioned above, torsion deformities were surgically corrected in 12 patients in the period from 12 to 15 months after the initial intervention.

A separate analysis of the treatment results is presented in Table 4. We believe that the loss of correlation between the changes in motor activity and gait analysis parameters during the period of 12 months after surgery is due to the fact that patients with and without torsion deformity correction were

analyzed together. Significant values of negative correlation in the period from two to three years after the initial operation, when torsion had been already eliminated in all patients, lead to the same conclusion.

Thus, multilevel interventions provided a significant improvement in the kinematic parameters of gait analysis in the long-term period both for patients with true equinus gait (Fig. 3) and for children with jump gait (Fig. 4).

When analyzing the results of treatment of patients in whom torsion deformity correction was included in the treatment program, it was found that the combination of maximum deviations in the parameters "knee progression angle" and "trunk maximal lateral shift" of the Edinburgh scale in the initial analysis of gait correlates with clinically significant torsion deformities that were corrected as part of the first intervention or after 1 year. We should stress the high sensitivity and specificity of this combination as a diagnostic test (Table. 5).

Table 2

Average values of Edinburgh visual gait score for the entire group

Parameter	Before surgery	Follow-up, 12 months	Follow-up, 2-3 years	
Initial contact	2.0	0.83	0.75	
Heel lift	1.93	0.7	0.5	
Maximum ankle dorsiflexion	1.73	0.3	0.21	
Hind-foot varus/valgus	1.2	0.1	0.13	
Foot progression angle	1.43	0.77	0.54	
Knee progression angle	1.2	0.7	0.46	
Peak knee extension	1	0.13	0.13	
Peak hip extension	0.8	0.13	0.13	
Pelvic obliquity at Mid-Stance	0.93	0.63	0.5	
Pelvic rotation at Mid-Stance	0.73	0.5	0.3	
Trunk Peak Sagittal Position	1.07	0.6	0.58	
Trunk maximum lateral shift	1.53	1.23	0.75	
Clearance	0.9	0.27	0.13	
Maximum ankle dorsiflexion	1.47	0.4	0.33	
Peak knee flexion	1.1	0.37	0.125	
Knee terminal swing position	1.46	0.1	0.04	
Peak hip flexion	1.2	0.13	0.08	
Total	42.7	15.3	11.3	

Table 3
Correlation of Edinburgh scores and FAQ

Period	Edinburgh score	FAQ	Spearman
Before surgery	42.7	3.8	-0.825
After 12 months	15.3	6.3	-0.491
After 2–3 years	11.3	7.7	-0.845

# Genij Ortopedii, Vol. 25, no 4, 2019

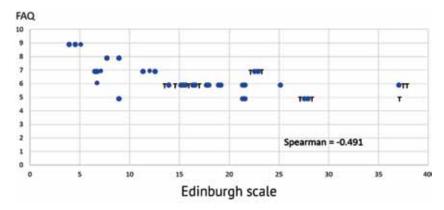


Fig. 1 Distribution of all cases, including torsion deformities not corrected, depending on gait analysis and FAQ values 12 months after the initial intervention. Cases with clinically significant torsion deformities are marked with "T"

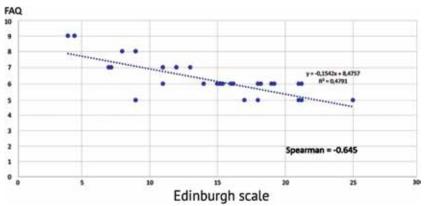


Fig. 2 Distribution of cases without torsion depending on the values of gait analysis and FAQ 12 months after surgery. Inverse correlation values become significant

 $Table\ 4$  Correlation for Edinburgh scale and FAQ findings are presented separately with or without torsion deformities

	Before treatment		After 12 months		After 2–3 years	
	Without torsion	With torsion	Without torsion	With torsion	Without torsion	With torsion
Edinburgh score	42.5	43.2	13.4	23.2	9.75	14.6
FAQ	3.7	4.1	6.5	6.0	7.9	7.2
Spearman	-0.836 (p = 0.9999)	-0.873 (p = 0.9995)	-0.645 (p = 0.9989)	-0.194 (p = 0.7043)	-0.842 (p = 0.999)	-0.776 (p = 0.9958)

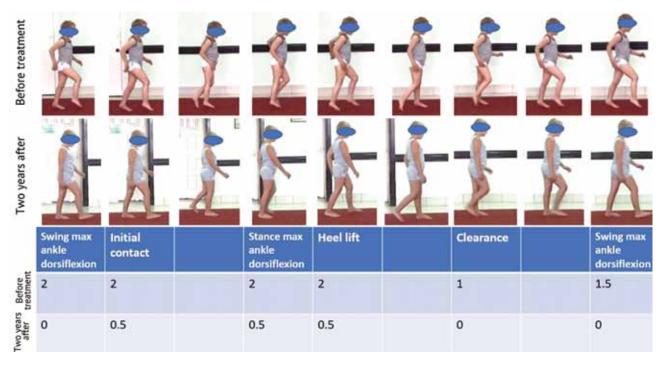


Fig. 3 Changes in gate analysis values in a patients with an initial true equinus gait pattern

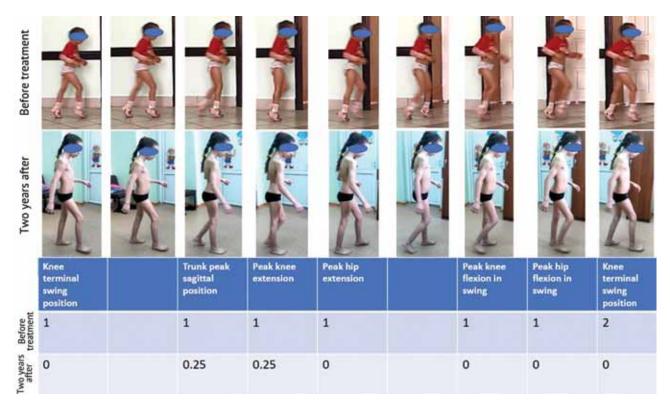


Fig. 4 Changes in gate analysis values in a patients with an initial jump gait pattern

Table 5 Correlation of maximal deviations in parameters "knee progression angle" and "trunk maximal lateral shift" of the Edinburgh scale in the initial gait analysis with clinically significant torsion deformities, prognostic significance

	Knee progression angle	Trunk maximum lateral shift	Incidence of combinations of maximal deviation in these parameters, %	Chi-square test	Sensitivity	Specificity
No torsion	0.9 ± 0.44	1.25 ± 0.43	7.3	p < 0.001	0.772	0.921
Correction of torsion	1.8 ± 0.41	2.0 ± 0.0	84.7			

## DISCUSSION

Cerebral palsy is the most common cause of motor disorders that occurs in early childhood and is present throughout life. The incidence rate of the disease is 1/500 newborns. About 17 million people with cerebral palsy live in the world.

Gait disorders, classified as true equinus gait and jump gait, are characteristic of children with spastic diplegia; these patterns are caused by spasticity and/or retraction of the muscles of the plantar flexors of the feet and flexors of the knee joint [22]. In muscle retraction accompanied by critical deterioration of goniometric parameters, surgical orthopedic treatment becomes reasonable [38–40]. However, in addition to muscle retraction, the objects of surgical treatment in multilevel interventions for these types of gait are foot deformities and torsion of segments [41–51].

The main object of orthopedic surgery for true equinus gait and jump gait is the elimination of contractures of the knee and ankle joints of both limbs [29, 32, 52]. In this case, it is extremely important to exclude unreasonable early surgical interventions (muscle lengthening before critical retraction develops; Achilles tendon lengthening in the absence of soleus muscle retraction; surgery in the age under 5-6 years, when, as a rule, there is no retraction of the muscles yet) [32, 53 –56]. Early unreasonable interventions lead to the development of functional insufficiency of the leg triceps, loss of strength of the eccentric contraction of the triceps (especially the soleus muscle) in the support phase of the gait at the time of kinetic energy absorption, which is accompanied by premature flexion in the knee joint and gradual development of extensor

apparatus failure with the progression of the pattern into the crouch gait [56–58].

The method of choice for triceps lengthening in cerebral palsy is fasciotomy of the calf muscles, which, according to a computer analysis of gait, is accompanied by an improvement in the kinematic parameters of the ankle joint without the development of crouch gait in the long term [52, 57, 59, 60]. It is this effect that was observed in our study, gait parameters and foot kinematics improved in all patients without pathological flexion in the knee joint in the long-term period. In this case, it is extremely important to exclude hyper- or hypocorrection of contractures of the knee joints [55].

According to Gorton G.E. et al. [55], Terjesen T. et al. [60], the improvement / normalization of ankle joint motion was not accompanied by compensatory changes in the kinematic parameters of the hip and knee joints. In our study, we noted an improvement in the parameters of movements in the hip and knee joints, regarding this situation as a remote effect of improving the kinematics of the ankle joints and correction of foot deformities.

In particular, normalization/improvement of knee joint extension the before the initial contact, which improves the orientation of the foot at the beginning of the support phase, was also emphasized in a study of Adolfsen S. et al. [31].

Among other positive effects of the operation, we found a decrease in excessive compensatory flexion of the knee and hip joints in the non-support phase in combination with an improvement in clearance, which is a consequence of an increased dorsiflexion of the foot. Previously, other researchers also observed this outcome of the orthopedic intervention [31, 55].

Исследования, основанные на изучении кинематических и кинетических параметров походки, показали, что увеличение/нормализация тыльной флексии стопы в опорную фазу сопровождается устранением патологических величин плеч рычагов в сагиттальной плоскости [30, 59] и сдвигом момента максимальной генерации энергии концентрического сокращения трицепса к концу опорной фазы [29, 51].

Studies based on the analysis of the kinematic and kinetic gait parameters showed that an increase/normalization of foot dorsiflexion in the support phase is accompanied by elimination of pathological values of the lever arm in the sagittal plane [30, 59]

and a shift in the moment of maximum generation of energy of concentric contraction of the triceps to the end of the support phase [29, 51].

Ounpuu S. et al. [21], 2002; Theologis T. et al. [61] pointed out the need to eliminate torsion deformities of the limbs to normalize the lever arms in the frontal plane and make walking less energy-consuming. However, with respect to the correction of torsion deformities in children, there is sufficient uncertainty associated with a weak correlation between the anatomical values of torsion and gait analysis parameters [49]. In adult patients with spastic paralysis, the results of correction based on anatomical parameters are much more predictable [62]. Thus, the elimination of torsion deformities may be delayed until the active limb growth is completed [47].

However, clinically significant torsion deformities that cause functional difficulties during regular daily physical activities will require correction in childhood. Interventions on the soft tissues do not results in a significant elimination of pathological rotation of the femur [63]. Our study showed that the criterion for detorsion osteotomy indication as a part of multilevel interventions in children with true equinus gait and jump gait patterns is a combination of extreme deviations of the Edinburgh scale parameters such as knee progression angle with trunk maximum lateral shift in the support phase. This test (criterion) has high specificity and sensitivity.

In general, orthopaedic interventions in children with cerebral palsy is aimed at correction of deformities to improve the biomechnicas of walking, joint contracture elimination for improving daily activities and functional abilities, reduction in power consumption that is due to biomechanical disorders, prevention and decrease of pain due to early arthritis, deformities, elimination of obstacles to use regular footwear and orthoses [47, 62, 64, 65, 66]. Analysis of gait kinematic and kinematic parameters makes the surgeon revise the treatment plan by excluding or adding surgical elements [24].

Our study confirms that multilevel interventions significantly improve most gait parameters, both directly dependent on retraction and deformity in a particular anatomical region, and indirectly due to compensatory biomechanically malposition and function of the distant segments. Diagnosis and quantification of torsion deformity should be considered first, which is based in childhood primarily

on the assessment of the kinematic parameters of gait. Correction of torsion deformities should be

performed simultaneously with the elimination of joint contractures and deformities of the feet.

### CONCLUSION

Multilevel single-event orthopedic interventions improve the kinematic and kinetic gait parameters of the entire biomechanical chain in the lower extremities. Along with the local effects of surgical interventions, there are long-term changes in the reduction of energy-consumptive compensatory movements. According to the Edinburgh visual gait

score, the combination of maximum deviations of the knee progression angle with trunk maximum lateral shift in the support phase substantiates the indications for correction of torsion deformities. The use of kinetic and kinematic parameters and their analysis based on quantitative data is mandatory in orthopedic surgery of cerebral palsy.

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