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THE VERTICAL BALANCE MANAGEMENT SYSTEM IS MORE SYNCHRONIZED IN CHILDREN WITH CEREBRAL PARALYSIS THAN IN HEALTHY CHILDREN

© *I.E. Nikityuk[1], G.A. Ikoeva[1, 2], O.I. Kivoenko[1]*

[1] The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia;
[2] North-Western State Medical University n. a. I.I. Mechnikov, Saint Petersburg, Russia

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Introduction. All forms of infantile cerebral paralysis involve motor function defects. In clinical practice, the stabilometrics method is widely used due to its ability to perform detailed analyses of the mechanisms of disturbance and restoration of postural control in patients with various cerebral lesions.
Aim. The study aimed to analyze the parameters of orthostatic balance in practically healthy children and in children with motor disorders caused by infantile cerebral paralysis of various severities.
Material and methods. We examined 6- to 12-year-old children with mild and severe cerebral paralysis and impaired vertical postural control with a preserved ability to self-balance in the principal posture. Each group examined for comparison comprised 10 patients (children with infantile cerebral paralysis, and impaired vertical postural control) and 10 healthy children in the same age range. The stabilometrics method was used, and the statistical evaluation included correlation and regression analyses.
Results. The results revealed that in comparison with the healthy children, the patient group exhibited a decrease in the vertical postural stability, which manifested as pronounced deviations from the nominal values of the stabilometric parameters. However, a strong correlation between the parameters of *S*, *LFS*, and the amplitude *A* of the pressure center was revealed, which significantly exceeded that of the healthy children, being most pronounced in cases of severe infantile cerebral paralysis. This indicates a more ordered center of pressure trajectory and, consequently, a higher synchronization of the vertical balance management system in children with infantile cerebral paralysis compared with that in healthy children.
Conclusion. The use of correlation and regression analysis to study the vertical balance of patients provides a deeper understanding of the mechanisms used by the postural control system in patients with infantile cerebral paralysis to maintain a complex multilevel structure of the musculoskeletal system in equilibrium in the process of standing still. Increased ordering of the center of pressure trajectory of statokinesiograms of children with infantile cerebral paralysis can be considered as a dynamic indicator of postural control deficiency.

Keywords: infantile cerebral paralysis (ICP), postural control, stabilometrics, center of pressure trajectory.

СИСТЕМА УПРАВЛЕНИЯ ВЕРТИКАЛЬНЫМ БАЛАНСОМ У ДЕТЕЙ С ЦЕРЕБРАЛЬНЫМ ПАРАЛИЧОМ БОЛЕЕ СИНХРОНИЗИРОВАНА ПО СРАВНЕНИЮ СО ЗДОРОВЫМИ ДЕТЬМИ

© *И.Е. Никитюк[1], Г.А. Икоева[1, 2], О.И. Кивоенко[1]*

[1] ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России, Санкт-Петербург;
[2] ФГБОУ ВО «СЗГМУ им. И.И. Мечникова» Минздрава России, Санкт-Петербург

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Введение. Все формы детского церебрального паралича (ДЦП) влекут за собой дефекты двигательной функции. В клинической практике широко используется метод стабилометрии, который показывает высокую информативность при анализе механизмов нарушения и восстановления контроля позы у больных при различных церебральных поражениях.
Цель исследования. Изучить параметры ортостатического равновесия у практически здоровых детей и у детей с двигательными нарушениями, развивавшимися на фоне детского церебрального паралича различных степеней тяжести.
Материал и методы. Обследованы дети с легкой и тяжелой степенями ДЦП в возрасте от 6 до 12 лет с нарушениями контроля вертикальной позы при сохранной способности к самостоятельному балансу в основной

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стойке. Каждая группа пациентов состояла из 10 человек, для сравнения обследованы 10 здоровых детей того же возраста. Использован метод стабилометрии, статистическое исследование включало корреляционно-регрессионный анализ.

Результаты. Результаты настоящей работы показали, что в группе детей с ДЦП, имеющих двигательные нарушения, по сравнению со здоровыми детьми наблюдается снижение стабильности вертикального баланса, проявляющееся выраженными отклонениями от номинальных значений стабилометрических параметров. Однако при этом выявляется корреляция между параметрами: площадью *S*, *LFS* и амплитудой *A* центра давления, значительно превышающая таковую у здоровых детей и наиболее сильно выраженная при тяжелой степени ДЦП. Это свидетельствует о более упорядоченной траектории центра давления и, следовательно, более высокой синхронизированности системы управления вертикальным балансом у детей с ДЦП по сравнению со здоровыми детьми.

Заключение. Использование корреляционно-регрессионного анализа для изучения вертикального баланса пациентов дает более глубокое понимание механизмов, используемых системой постурального контроля у больных ДЦП для поддержания сложной многоуровневой структуры скелетно-мышечной системы в равновесии в процессе спокойного стояния. Повышенная упорядоченность траектории центра давления статокинезиограмм детей с ДЦП может рассматриваться как динамический показатель дефицита постурального контроля.

Ключевые слова: детский церебральный паралич (ДЦП); постуральный контроль; стабилометрия; траектория центра давления.

Introduction

Infantile cerebral palsy (CP) is a common and difficult to treat nervous system disease affecting children. The pathology is based on the organic lesioning of the nervous system of the fetus and newborn. Primary manifestations of CP that lead to persistent disability are locomotor function violations. These manifestations form the basis of pathological stereotypes of posture and walking that are associated with CP. All forms of CP entail motor function defects, including disorders of the systems controlling body balance. Postural stability is a fundamental prerequisite for the development of motor function in children [1]. In clinical practice, the stabilometry method is widely used to analyze motor function. This method is highly informative in analyzing motor disorder mechanisms and guiding postural control restoration efforts in patients with various cerebral lesions [2, 3]. Methods for assessing the ability of patients with CP to maintain an erect posture are based on descriptive (summary) statistics, including the analysis of indices of pressure center fluctuations, such as oscillatory trajectory length and average deviation [4]. However, in recent decades, a new method for studying postural control has been proposed. According to this method, the act of retaining an erect posture can be represented as a stochastic process, in which randomness or regularity can be considered from the point of view of probability theory [5]. Despite the high variability and randomness of individual stabilometric parameter indices in certain patients, specific patterns have led to the formation of averaged statokinesiograms, which are parameter scatter plots. Stochastic processes for assessing postural control violations in patients with neurodegenerative diseases estimate pressure center oscillation parameters, producing a correlation analysis [6]. Analyzing the dynamic characteristics of pressure center trajectories can be more informative than descriptive statistical methods, particularly for pathologies where changes in postural balance are difficult to detect [7].

Aim. The study aimed to analyze orthostatic balance parameters in virtually healthy children and in those with CP, either with or without motor disorders of various severities.

Materials and methods

We examined 20 patients with CP, aged 6–12 years, with no pronounced disorders of higher nervous activity and those with erect posture control disorders with a preserved ability to self-balance for up to 2 min in the normal standing position. These patients were divided into two groups depending on their demonstrated motor development according to the GMFCS classification [8]: Group 1 included 10 pediatric patients with mild CP, with a mean age of 9.1 ± 3.42 years, and Group 2 included 10 patients with severe CP, with a mean age of 8.9 ± 4.38 years. Parents of all patients voluntarily offered informed consent for their children to participate in the study.

To quantify vertical stability, all patients underwent the stabilometric study using the computer stabilometric complex MBN–Biomechanics (MBN, LLC, Russia). For comparison, we determined normative stabilometric parameter values in 10 healthy children of the same age group.

The studies were conducted according to the standard functional test procedures with open (OE) and closed eyes (CE), with the registration of pressure center displacement parameters. Children with visual impairments were permitted to use glasses for visual correction. Based on the stabilograms, we calculated the following parameters: the length of the trajectory traversed by the pressure center L (mm), area S (mm^2) of the statokinesiogram, ratio of the length of the statokinesiogram to its area LFS (mm^{-1}), and mean amplitude of oscillations of the pressure center A (mm).

To generate descriptive statistic study results, we verified all quantitative characteristics were normally distributed. Because the indicators were found to be non-normally distributed, we estimated group parameters by determining median (Me) and an interquartile range of 25–75 (Q_1–Q_2). For the assessment of intergroup differences, a one-sided t-test and Mann–Whitney U-test were used. The threshold level for statistical significance was $p < 0.05$. To analyze the relationship between two parameters, a correlation analysis was used with the nonparametric Spearman coefficient r_s. A correlation was considered strong at $r_s \geq 0.7$, with an average at $0.3 < r_s < 0.7$ [9]. In case of negative correlation, correlation coefficient values were interpreted in the same way as for positive dependence. Regression analysis was used to find a function describing the relationships between parameters.

Statistical processing of data was performed using SPSS 12.0 and Statgraphics Centurion 16.2.

Results

Group 1 included 10 pediatric patients with mild CP, with a mean age of 9.1 ± 3.42 years. Group 2 included 10 pediatric patients with severe CP, with a mean age of 8.9 ± 4.38 years.

Results of motor skill development, according to the GMFCS classification, in patients with CP are shown in Fig. 1. Patients with mild and severe CP were clinically heterogeneous. Mean GMFCS levels were 1.4 ± 0.16 (mild CP) and 3.3 ± 0.15 (severe CP), and the between-group differences were statistically significant ($p < 0.05$).

Despite significant differences in the levels of motor functions between pediatric patients with mild and severe CP, apparent postural balance abnormalities were identified in both groups, as indicated by quantitative stabilometry measures (Table 1). There was a statistically significant increase in the average values of length L, area S, and oscillation amplitude of pressure center A of statokinesiograms in patients with CP compared with those in healthy children ($p < 0.05$). In both groups, these stabilometric parameters displayed a wide scatter. The values of the parameter LFS also significantly decreased from normative ranges in all patients with CP ($p < 0.05$).

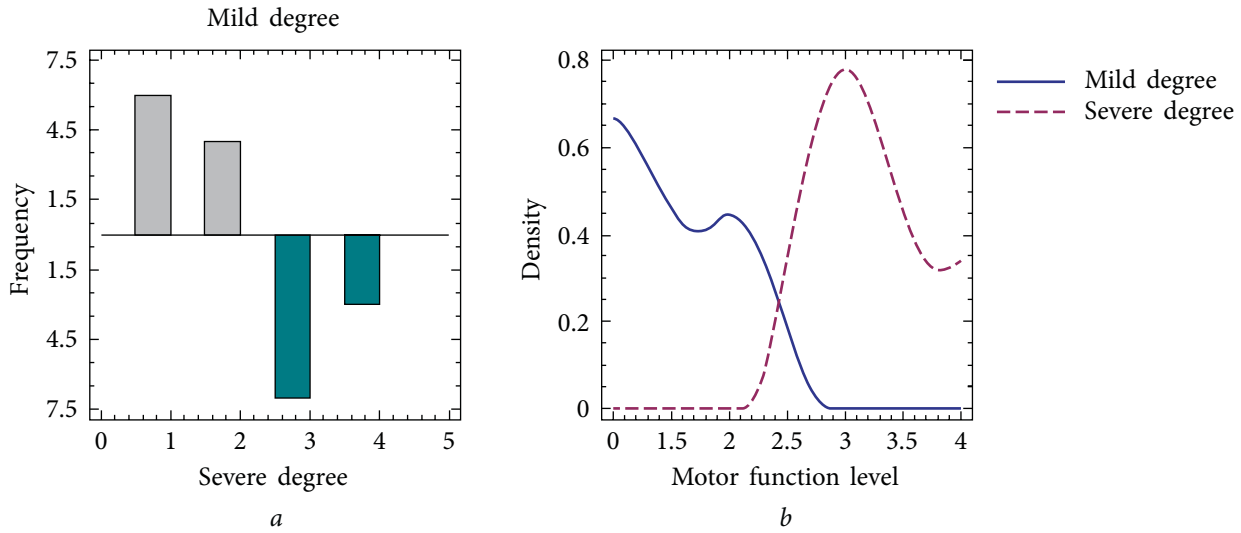

Fig. 1. The level of motor functions in patients with infantile CP on the GMFCS scale: *a* represents the distribution of level values; *b* represents density curves of level values

Table 1

Comparative quantitative indicator characteristics of statokinesiograms of healthy children and patients with different CP severities [median (*Me*) and interquartile range of 25–75 (Q_1–Q_2) are presented]

Parameters	Healthy children *Me* (Q_1–Q_2) n = 10	Mild CP *Me* (Q_1–Q_2) n = 10	Severe CP *Me* (Q_1–Q_2) n = 10
L, mm	643 (591–814)	1233* (733–1431)	1017* (862–1209)
S, mm^2	376 (305–695)	1041* (510–1428)	1358* (862–1830)
LFS, mm^{-1}	1.66 (1.21–1.97)	0.95* (0.72–1.77)	0.82* (0.53–1.12)
A, mm	2.46 (2.09–3.27)	4.73* (2.98–6.05)	4.85* (4.01–7.39)

Note: * significant differences from indices of healthy children, $p < 0.05$.

Differences in stabilometric parameters between patients with mild and severe CP were not statistically significant, and the comparative intergroup evaluation of medians and lower and upper quartiles did not reveal any vertical balance patterns in patients with CP. This may indicate a limited capacity for descriptive statistics to comparatively assess vertical balance abilities in pediatric patients with CP of different severities.

Correlation and regression analysis enabled us to study the dependence of area *S* and the parameter *LFS* of statokinesiograms in both healthy children and children with CP, relative to the amplitude of pressure center oscillation amplitude *A*. To do this, we searched for the curvilinear regression equation, the choice of which was determined by analyzing the data scatter and physiological meaning of regression coefficients. The degree allometric function complied most preferably with this task:

$$y = bx^a,$$

where *a* and *b* are regression coefficients, variable *x* corresponds to the pressure center oscillation amplitude *A*, and variable *y* corresponds to the area *S* or the parameter *LFS*. For the graphic expression of the relationship between stabilometric parameters, regression lines were plotted (Figs. 2–7).

The results of correlation and regression analysis are presented in Table 2.

Correlation analysis showed the average values of the moduli of correlation coefficients in the group of healthy children (0.71) and in pediatric patients with mild (0.82) and severe CP (0.90). In the group of healthy children, two out of four correlation coefficients in the modulus did not

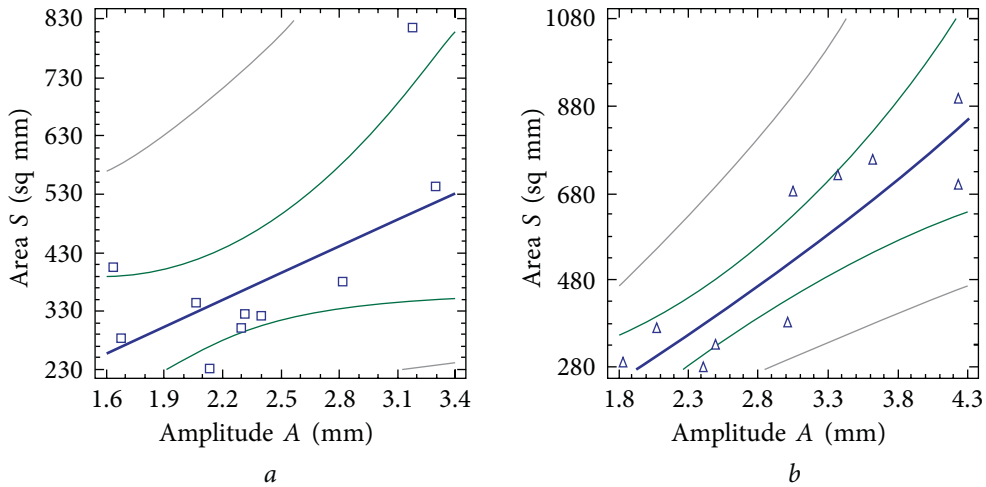

Fig. 2. The regression line (*heavy lines*) and its confidence interval (*fine lines*) for the dependence of the area *S* of statokinesiograms on the pressure center oscillation amplitude *A* in healthy children: *a*, with OE; *b*, with CE

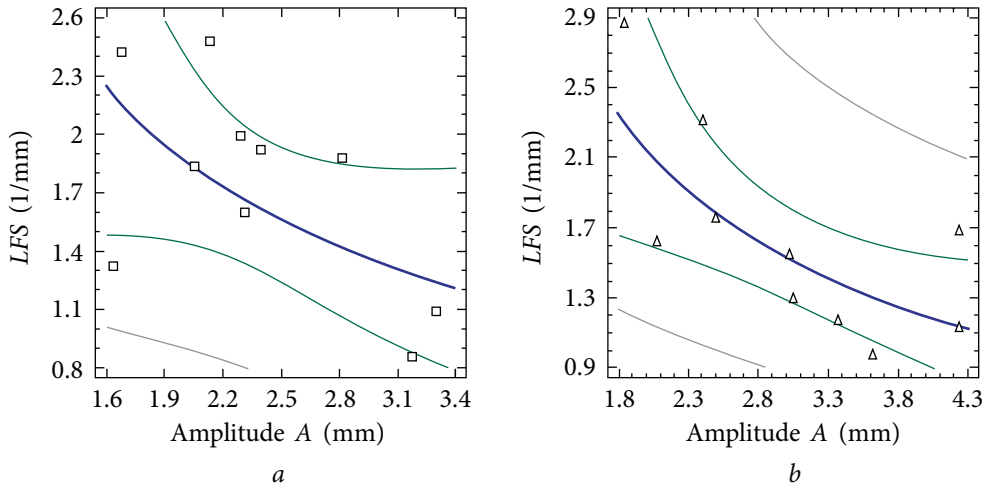

Fig. 3. The regression line (*heavy lines*) and its confidence interval (*fine lines*) for the dependence of the parameter *LFS* of statokinesiograms on the pressure center oscillation amplitude *A* in healthy children: *a*, with OE; *b*, with CE

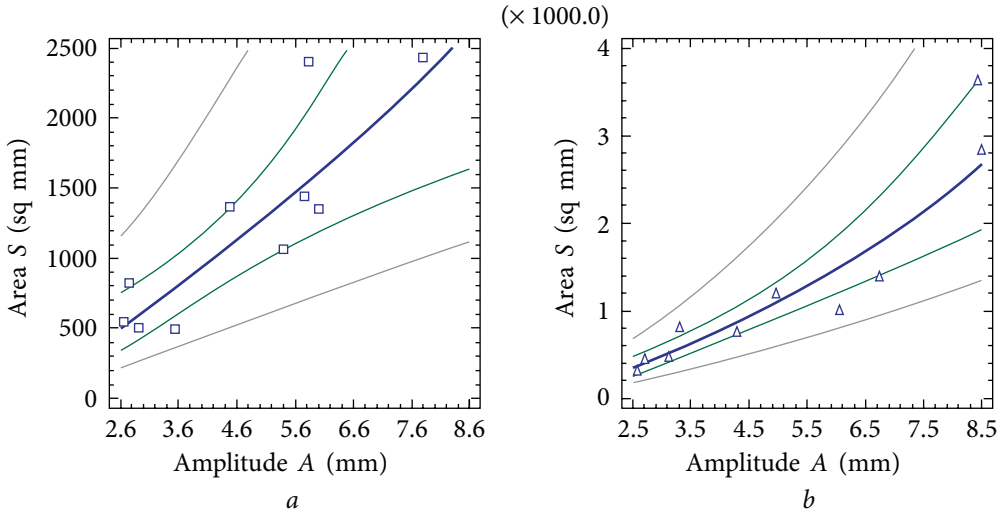

Fig. 4. The regression line (*heavy lines*) and its confidence interval (*fine lines*) for the dependence of the area *S* of statokinesiograms on the pressure center oscillation amplitude *A* in pediatric patients with mild CP: *a*, with OE; *b*, with CE

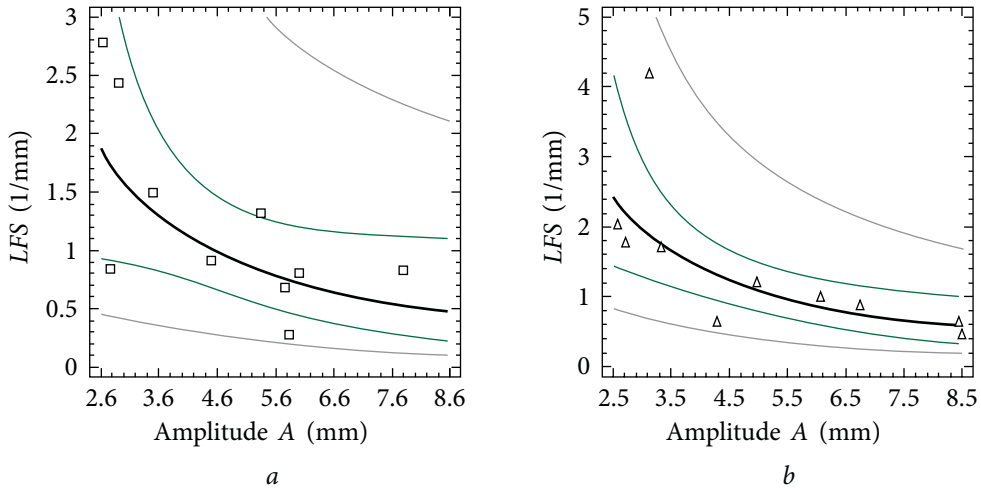

Fig. 5. The regression line (*heavy lines*) and its confidence interval (*fine lines*) for the dependence of the *LFS* parameter of statokinesiograms on the oscillation amplitude *A* in pediatric patients with mild CP: *a*, with OE; *b*, with CE

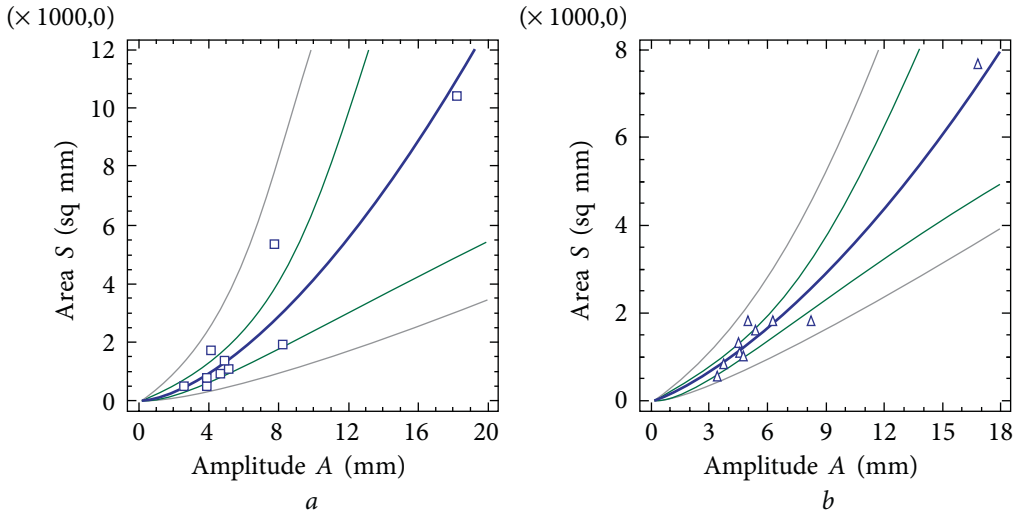

Fig. 6. The regression line (*heavy lines*) and its confidence interval (*fine lines*) for the dependence of the area *S* of statokinesiograms on the pressure center oscillation amplitude *A* in pediatric patients with severe CP: *a*, with OE; *b*, with CE

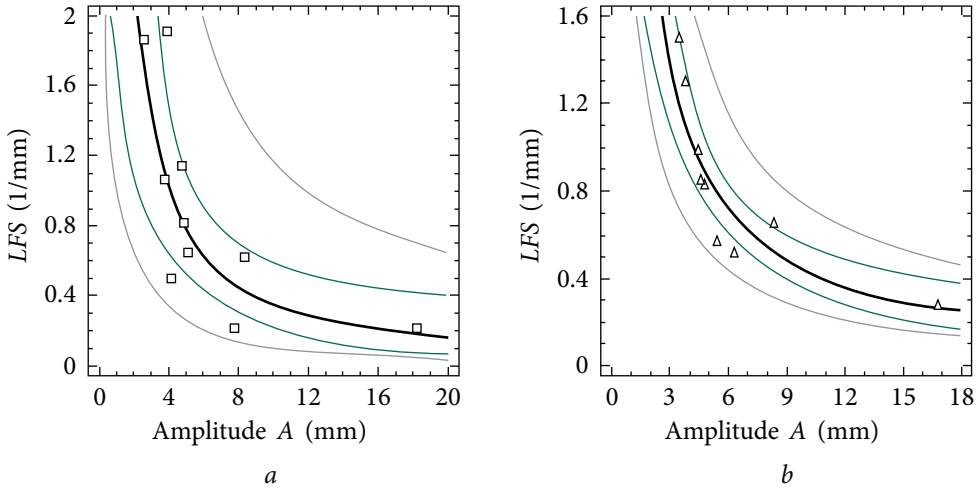

Fig. 7. The regression line (*heavy*) and its confidence interval (*fine lines*) for the dependence of the *LFS* parameter of statokinesiograms on the pressure center oscillation amplitude *A* in pediatric patients with severe CP: *a*, with OE; *b*, with CE

Table 2

Correlation and regression analysis of the dependence of the area *S* and the parameter *LFS* of statokinesiograms in healthy children and in children with infantile CP on the amplitude of the pressure center oscillation amplitude *A*

Children examined		Regression equation		r_s		ΔS, %	Δ*LFS*, %
		S ~ *A*	*LFS* ~ *A*	*S* ~ *A*	*LFS* ~ *A*		
Healthy	OE	$S = 5.1A^{0.96}$	$LFS = 1.2A^{-0.83}$	0.64	–0.58	9.6	7.7
	CE	$S = 4.73A^{1.38}$	$LFS = 1.36A^{-0.85}$	0.88	–0.74	14.1	7.8
Mild CP	OE	$S = 4.92A^{1.37}$	$LFS = 1.71A^{-1.13}$	0.87	–0.65	14.9	9.9
	CE	$S = 4.34A^{1.66}$	$LFS = 1.98A^{-0.81}$	0.95	–0.81	17.1	10.9
Severe CP	OE	$S = 4.44A^{1.68}$	$LFS = 1.65A^{-1.17}$	0.91	–0.82	17.4	10.6
	CE	$S = 4.82A^{1.44}$	$LFS = 1.38A^{-0.96}$	0.95	–0.92	14.7	8.9

Note: OE, open eyes; CE, closed eyes; r_s, correlation coefficient; ΔS, change of area; Δ*LFS*, change in the *LFS* parameter (depending on 10% change in the magnitude of the pressure center oscillation amplitude *A*).

exceed 0.7 and one was slightly higher than 0.7, which suggests that changes in parameters *S, LFS,* and *A* were mostly random (Figs. 2 and 3). Higher values of r_s were found in patients with mild CP (Figs. 3 and 4). The strongest correlation between parameters *S, LFS,* and *A*, graphically represented (Fig. 6 and 7), was found in patients with severe CP.

Regression analysis revealed that postural balance peculiarities in healthy children and in children with CP depended on visual involvement during the testing process. In the group of healthy children, when changing from OE to CE, there was a 10% change in the oscillation amplitude Δ*A*, leading to a significant increase in Δ*S* and, to a lesser extent, in Δ*LFS*. A similar pattern was observed in children with mild CP where the inverse ratio was determined, i.e., when children with mild CP changed from OE to CE, the change in the oscillation amplitude Δ*A* led to a significant decrease Δ*S* and Δ*LFS*, but not to an increase. In all children examined, both healthy and those with CP, there was an increase in the correlation between stabilometric parameters *S*, *LFS*, and *A* during the CE condition.

Discussion

Locomotor function disorders are the main sign in patients with CP, which are characterized by unstable postural balance expressed in higher pressure center oscillation values than normative values [10]. To ensure an independent erect posture in these patients, it is necessary to preserve the vertical balance management system, which simultaneously controls the exact muscle coordination and synchronization for nearly the entire musculoskeletal system. In this, the central nervous system in patients with CP continues to perform complex analyses of the incoming information from various sensory systems – visual, proprioceptive, vestibular, and exteroreceptive – to produce a coordinated muscle action [11]. Afferent integration inconsistencies in such patients [12], complicated by disorders affecting the interaction of the excitable area with the striatopallidal system and thalamencephalon [13], jointly negatively affect postural control [14, 15].

This study showed, using descriptive statistics, a significant reduction in postural stability in patients with CP, which manifests as pressure center oscillations during the standing position, more pronounced than those observed in healthy children. This is consistent with the data from other studies [16]. However, the use of descriptive statistics for interpreting intergroup differences in stabilometry for pediatric patients with mild and severe CP was ineffective. We are yet to solve the problem of an accurate identification of postural instability in patients with neurodegenerative diseases. In these patients, an increased deviation of stabilometric parameters from normal values is not a comprehensive characteristic of postural control deficiencies [17]. Therefore, in this study, by analyzing stabilograms, we used the principle of statistical mechanics, which postulates that pressure center motion during standing can be modeled as a system of paired and correlated random parameters [18]. Thus, a stochastic and probabilistic mechanism controls vertical balance [19]. This approach pressure center trajectory analysis is particularly clear and theoretically important because of its higher sensitivity for assessing changes in postural stability [20].

Compared with healthy children, pediatric patients with CP-related motor impairments experience decreased vertical balance stability. This is manifested by pronounced deviations from nominal stabilometric parameter values. However, there is a strong correlation between the parameters of area *S, LFS,* and pressure center amplitude *A*, which significantly exceeds values observed in healthy children and is most pronounced in patients with severe CP. This may indicate a more ordered trajectory of the pressure center and, consequently, a higher synchronization of the vertical balance management system in pediatric patients with CP compared with that in healthy children.

Physiological mechanisms of our results remain unclear and, undoubtedly, require in-depth research. At this stage, we can formulate only hypotheses. Increased pressure center trajectory regularity in pediatric patients with CP may be a dynamic indicator of postural control deficiencies [21]. This concept is aligned with data that indicates that higher pressure center regularity is intrinsic to patients with other nosological forms of central nervous system lesions, such as in those with craniocerebral injuries [22] and Parkinson disease [23]. These data are consistent with the hypothesis of the

so-called "pathological regularity versus healthy complexity" [24], where less "complex" (or more "regular") parameters of biological processes reflect less effective physiological controls.

Conclusion

Despite the fact that gross disorders of the vertical balance are noted in patients with CP because of deviations in movement organization mechanisms at different levels, the vertical balance management system in these patients is more synchronized compared with that in healthy children. The correlation of stabilometric signs with a severe degree of CP is much higher in patients with CP than in those with mild CP. The correlation and regression analysis used to study the vertical balance of patients can provide a deeper understanding of postural control mechanisms used by patients with CP to maintain an equilibrium of the complex multilevel structure of the musculoskeletal system during standing. This is promising in terms of developing a quantitative assessment of motor deficits and resources of patients with CP for determining the best possible therapeutic strategies for restoring patients' postural and locomotor neuronets.

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Information about the authors

Igor E. Nikityuk — MD, PhD, leading research associate of the laboratory of physiological and biomechanical research. The Turner Scientific and Research Institute for Children's Orthopedics. E-mail: femtotech@ mail.ru.

Galina A. Ikoeva — MD, PhD, assistant professor of the chair of pediatric neurology and neurosurgery. North-Western State Medical University n.a. I.I. Mechnikov. Chief of the department of motor rehabilitation. The Turner Scientific and Research Institute for Children's Orthopedics. E-mail: ikoeva@inbox.ru.

Olga I. Kivoenko — MD, neurologist, head of the rehabilitation department. The Turner Scientific and Research Institute for Children's Orthopedics. E-mail: rt-k@yandex.ru.

Игорь Евгеньевич Никитюк — канд. мед. наук, ведущий научный сотрудник лаборатории физиологических и биомеханических исследований ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России. E-mail: femtotech@mail.ru.

Галина Александровна Икоева — канд. мед. наук, доцент кафедры детской неврологии и нейрохирургии ФГБОУ ВО «СЗГМУ им. И.И. Мечникова» Минздрава России. Заведующая отделением двигательной реабилитации ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России. E-mail: ikoeva@inbox.ru.

Ольга Ивановна Кивоенко — врач-невролог, заведующая реабилитационным отделением ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России. E-mail: rt-k@yandex.ru.