POSTURAL DEFICIENCY IN CHILDREN WITH SPINAL STENOSIS

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Introduction. Stenosis of the spinal canal can be accompanied by abnormalities of gait and body balance. At the same time, changes occurring in the postural control in children with spinal stenosis remain unexplored.

Aim. To study postural stability in children with spinal stenosis and assess the imbalance of the body depending on the level of stenosis localization.

Material and methods. This study investigated 14 patients, aged 10–17 years, with stenosis of the spinal canal. The first group consisted of seven patients with spinal stenosis due to congenital deformity of the thoracic spine with spinal cord compression at the stenosis level. The second group consisted of seven patients with spondylolisthesis of the L_5 vertebra body of grades 3–4, accompanied with spinal cord root compression. The control group consisted of seven healthy children of the same age. We used stabilometry, and statistical study included correlation-regression analysis.

Results. A significant deviation of the stabilometric parameters was noted only in the first group of patients ($p < 0.05$). In the same group, a strong correlation was found between the parameters of statokinesiogram: area S, length L, amplitude A, and mean power level of the spectrum of $f\,60\%$, which were much higher than those of healthy children, which may indicate a pathologically high synchronization of the vertical balance control system of the body. Other changes were revealed, such as a strong relationship between L/S and A at normal stabilometric parameters and a moderate force between L/A and $f\,60\%$, indicating postural deficiency in the group of patients with stenosis at the level of the lumbosacral spine.

Correlation-regression analysis for assessing the postural balance in both groups of patients showed a correlation between parameters L, S, A, and $f\,60\%$, which were significantly higher than those in healthy children and most pronounced in the thoracic localization of stenosis.

Conclusion. The system of maintaining vertical balance of the body in children with stenosis of the spinal canal at the level of the thoracic spine has a more pronounced deficiency than that in patients with stenosis of the canal at the lumbosacral level. To reveal hidden violations of the postural balance, the relationship between length, area, amplitude, and mean power of the statokinesiogram must be evaluated.

Keywords: spinal stenosis; kyphosis; scoliosis; spondylolisthesis; stabilometry; center of pressure trajectories; postural balance; postural deficiency.

ПОСТУРАЛЬНЫЙ ДЕФИЦИТ У ДЕТЕЙ СО СТЕНОЗОМ ПОЗВОНОЧНОГО КАНАЛА

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Введение. Стеноз позвоночного канала может сопровождаться нарушениями походки и баланса тела. При этом остаются неизученными изменения, происходящие в системе постурального контроля у детей со стенозом позвоночного канала.

Цель работы — изучить постуральную стабильность у детей со стенозом позвоночного канала и провести оценку нарушений баланса тела в зависимости от уровня локализации стеноза.

Материал и методы. Проведено обследование 14 больных в возрасте от 10 до 17 лет со стенозом позвоночного канала. В первую группу вошли 7 пациентов со стенозом позвоночного канала в результате врожденной деформации грудного отдела позвоночника с компрессией спинного мозга на уровне стеноза, во вторую — 7 пациентов со спондилолистезом тела L_5 позвонка 3–4-й степени, сопровождающимся компрессией корешков

спинного мозга. Группу контроля составили 7 здоровых детей того же возраста. Использован метод стабило-метрии, статистическое исследование включало корреляционно-регрессионный анализ.

Результаты. Значимое отклонение стабилометрических параметров от нормы отмечено только в первой группе пациентов ($p < 0,05$). В этой же группе обнаружена сильная корреляционная связь между параметрами статокинезиограмм (площадь S, длина L, амплитуда A и средний уровень мощности спектра $f\,60\,\%$), значительно превышающая таковую у здоровых детей, что может указывать на патологически высокую синхронизированность системы управления вертикальным балансом тела. В группе пациентов со стенозом на уровне пояснично-крестцового отдела позвоночника выявлены иные изменения: при нормальных стабилометрических параметрах определена сильная зависимость между L/S и A и средней силы — между L/A и $f\,60\,\%$, что также указывает на наличие постурального дефицита.

Применение для оценки постурального баланса корреляционно-регрессионного анализа в обеих группах пациентов выявило корреляционную связь между параметрами L, S, A и $f\,60\,\%$, значимо превышающую таковую у здоровых детей и наиболее сильно выраженную при грудной локализации стеноза.

Заключение. Система поддержания вертикального баланса тела у детей со стенозом позвоночного канала на уровне грудного отдела позвоночника имеет более выраженный дефицит, чем у больных со стенозом канала на пояснично-крестцовом уровне. Для выявления скрытых нарушений постурального баланса необходимо оценивать соотношения показателей длины, площади, амплитуды и средней мощности статокинезио-граммы.

Ключевые слова: стеноз позвоночного канала; кифоз; сколиоз; спондилолистез; стабилометрия; траектория центра давления; постуральный баланс; постуральный дефицит.

Introduction

Spinal stenosis refers to decreasing anteroposterior size of the spinal canal and narrowing of the lateral recess, which could lead to local compression of the nerve structures and/or dysfunction of the blood supply to spinal cord [1]. Depending on the level of the lesion, narrowing of the spinal canal may be accompanied by gait [2] and balance impairments [3], which can be objectively assessed by stabilometry [4].

On that account, it is necessary to address the diagnostic issues and treatment methods for patients with disorders associated with spinal stenosis. In the Russian and foreign literature, the methods and sequences of high-accuracy diagnostic measures for spinal stenosis were clearly described. Also, various options of surgical interventions in dorsal and lateral approaches for elimination of the causes of vertebromedullar conflict have been elucidated. This problem has been studied particularly in adult patients with degenerative-dystrophic diseases of the lumbar and lumbosacral spine, accompanied by spinal stenosis at this level [5, 6].

However, there are no studies published on the description and assessment of the changes occurring in the postural control system in children with spinal stenosis. In addition, it is essential to evaluate the postural dysfunction caused by neural structures compression at different vertebral levels.

This study aims to investigate the postural stability in pediatric patients with spinal stenosis and to assess the effect of the level of stenosis localization on body balance.

Material and methods

In total, 14 patients aged 10–17 years (mean age, 14.8 ± 1.25 years), who had instrumentally confirmed (computed and magnetic resonance tomography) spinal stenosis, were examined.

The pediatric patients examined were divided into two groups depending on the level of stenosis localization. The group I consisted of seven patients with thoracic spinal stenosis and compression of the spinal cord at the level of stenosis. The spinal stenosis in group I patients was due to congenital deformity of the thoracic spine caused by abnormal development of the vertebral bodies.. On the other hand, group II consisted of seven patients with lumbar spinal stenosis, where the spondylolisthesis of the L_5 vertebral body of degree 3–4 was accompanied by spinal stenosis at this level and compression of the spinal cord roots. All pediatric patients were able to stand without support, and there were no cerebellar or proprioceptive disorders in the neurological status, the presence of which in turn significantly affects the development of postural imbalance [7].

In regard to vertical stability, a stabilometric study (MBN — Biomechanics software and hardware

complex, Moscow) was conducted in both groups. For comparison purpose, the standard values of stabilometric indicators were determined in seven healthy children from the same age group.

The parameters of the displacement of the center of pressure (CP) of the body, namely the length of the trajectory passed by the CP L (mm), square S (mm^2), and the ratio of length to the statokinesiogram L/S (mm^{-1}), were registered by using the standard method with eyes open and closed. The average values of the amplitude of oscillations of the CP A (mm) and the level of 60% of the spectrum power f 60% (Hz) in the frontal and sagittal planes were calculated [8]. Additionally, the ratio of length to the amplitude L/A was calculated.

The stabilograms were analyzed in accordance with the principle of statistical mechanics, wherein the movement of the CP of human body during quiet standing can be modeled as a system of paired correlated random parameters [9].

A criterion value of $p < 0.05$ was considered statistically significant. The degree of relationship between the two variables was studied using a correlation analysis with nonparametric Spearman coefficient r_s. The correlation was considered strong at $r_s \geq 0.7$, medium at $0.3 < r_s < 0.7$, and low at $r_s \leq 0.3$ [10]. With the negative correlation dependence, the module of correlation coefficient was interpreted in the same way as the positive dependence. Regression analysis was used to search for the function describing the relationship between the signs.

The data obtained was statistically processed using computer program SPSS 12.0 and Statgraphics Centurion 16.2.

Results

Disorders of postural balance were determined in patients with stenosis of the thoracic spine, as indicated by the stabilometric parameters (Table 1). Compared with the healthy children, group I patients showed significantly higher mean values of L and S, as well as tended to have higher amplitude of A.

Table 1

Comparative characteristics of quantitative indicators of statokinesiograms of healthy children and patients with spinal stenosis

Parameters	Groups of the children being examined		
	Healthy children, $n = 7$	Group I, $n = 7$ (thoracic spinal stenosis)	Group II, $n = 7$ (lumbar spinal stenosis)
L, mm	748.3 ± 13.83	1396.4 ± 79.34*	769.9 ± 27.37
S, mm^2	576.3 ± 54.05	1123.1 ± 119.06*	618.6 ± 108.58
L/S, mm^{-1}	1.5 ± 0.17	1.9 ± 0.69	1.5 ± 0.25
A, mm	3.1 ± 0.17	4.2 ± 0.43	3.1 ± 0.36
f 60%, Hz	1.1 ± 0.11	1.3 ± 0.30	1.2 ± 0.03
L/A	250.1 ± 20.36	378.4 ± 84.69	265.3 ± 28.21

Note. * Significant differences from values of healthy children, $p < 0.05$.

There were no significant deviations in L, S, and A in group II patients, which indicates the best postural stability; however, considering the existing pathology, it does not provide a complete picture of the changes in the function of maintaining the vertical balance of body.

In this regard, we conducted a correlation-regression analysis wherein we studied the dependency of the parameters of statokinesiograms in healthy children and patients with spinal stenosis. To do this, we conducted a search for regression equations, the choice of which was determined by the analysis of the scattering diagram and the physiological aspect of the regression coefficients. To study the dependency of the parameter L/S on A of the CP, the exponential allometric function $y = bx^a$ is the most optimal algorithm. The dependency of the parameter L/A on f 60% was linear:

$$y = a + bx,$$

where a and b are regression coefficients, the variable x corresponds to the A or f 60%, and the variable y corresponds to the parameter L/S or L/A.

The results of the correlation analysis are presented in Table 2.

Correlation analysis of (i) the dependency of the parameter *L/S* on the amplitude *A* and (ii) the dependency of the parameter *L/A* on *f* 60% of the statokinesiograms of healthy children and patients with spinal stenosis

Groups of children examined		Spearman correlation coefficient r_s	
		Dependence *L/S ~ A*	Dependence *L/A ~ f* 60%
Healthy children *n* = 7	OE	−0.56	0.29
	CE	−0.47	0.15
Group I, *n* = 7 (thoracic spinal stenosis)	OE	−0.88	0.99
	CE	−0.83	0.90
Group II, *n* = 7 (lumbar spinal stenosis)	OE	−0.96	0.62
	CE	−0.90	0.49

Note. OE — opened eyes; *CE* — closed eyes.

Correlation analysis revealed that in the group of healthy children, the values of the modules of correlation coefficients indicated the average dependence *L/S ~ A*, which did not exceed 0.7. In the same pediatric patients, the dependence *L/A ~ f* 60% was low, as the correlation coefficients were <0.3. This suggests that in the norm, to ensure vertical stability of the body, there is no need for high synchronization of the parameters *L, S, A,* and *f* 60%, the ratios between which are mostly random and chaotic (Fig. 1).

A completely different mechanism of ensuring vertical body balance was observed in the group I patients with thoracic spinal stenosis, which was characterized by a strong correlation between the *L/S* and *A* parameters and between the *L/A* and *f* 60% parameters, up to a straight line (Fig. 2, *b*).

In group II patients, the ratio *L/S ~ A* also turned out to be high, but the correlation *L/A ~ f* 60% was within the average values (Fig. 3, *b*). These facts may indicate various compensatory possibilities in ensuring vertical balance of the body in thoracic spinal stenosis and lumbosacral spinal stenosis.

When the channel of visual afferentation was turned off, the nature of the connection between the considered parameters did not change significantly in all groups of children being examined (see Table 2).

Discussion of the results

In recent decades, the mathematical method proposed for studying postural control shows that the process of maintaining a vertical posture can be represented as a stochastic process, wherein the randomness or regularity can be considered from the point of view of the probability theory [11]. The development of the concept of a stochastic process for assessing impaired postural balance in patients with neurodegenerative diseases occurs in the direction of assessing the ratios of parameters of oscillations in the CP, followed by conducting correlation and regression analysis [12]. This principle of analyzing the dynamic characteristics of the CP trajectory in assessing deviations in postural stability is more sensitive and informative than the methodology of descriptive statistics [13–15].

In the present study, the descriptive statistics showed a significant decrease in the postural stability of the group I patients (with thoracic spinal stenosis) only, which was manifested by a pronounced increase in the *L* and *S* of statokinesiograms as compared to that of healthy children. On the other hand, the group II patients (with lumbar spinal stenosis) did not show any differences in the parameters as compared to the control group.

The use of correlation and regression analysis to assess postural control in both groups of patients has enabled us to identify a correlation relationship between the parameters *L, S, A,* and *f* 60% These parameter values significantly exceeded those of healthy children and were most pronounced in patients with thoracic spinal stenosis.

A more ordered trajectory of the CP indicates a high synchronization of the control system of the vertical balance of body in pediatric patients with partial compression of the spinal tracts, which confirms the phenomenon characteristic of patients with traumatic [16], degenerative [17], and organic [18] lesions of the central nervous system (CNS). It has been proposed to consider the increased orderliness of the postural control
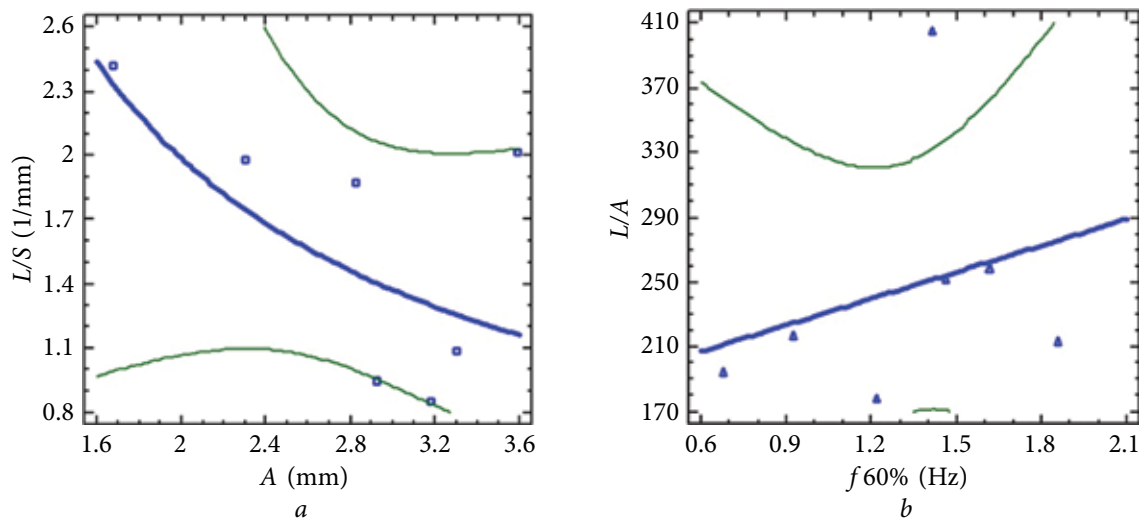
Fig. 1. The regression line (*bold blue*) and its confidence interval (*thin green lines*) indicate the dependency in the healthy children with open eyes: (*a*) the *L/S* parameter on the amplitude *A* of the center of pressure; (*b*) the *L/A* parameter of the average power level of the spectrum *f* 60% of the statokinesiogram
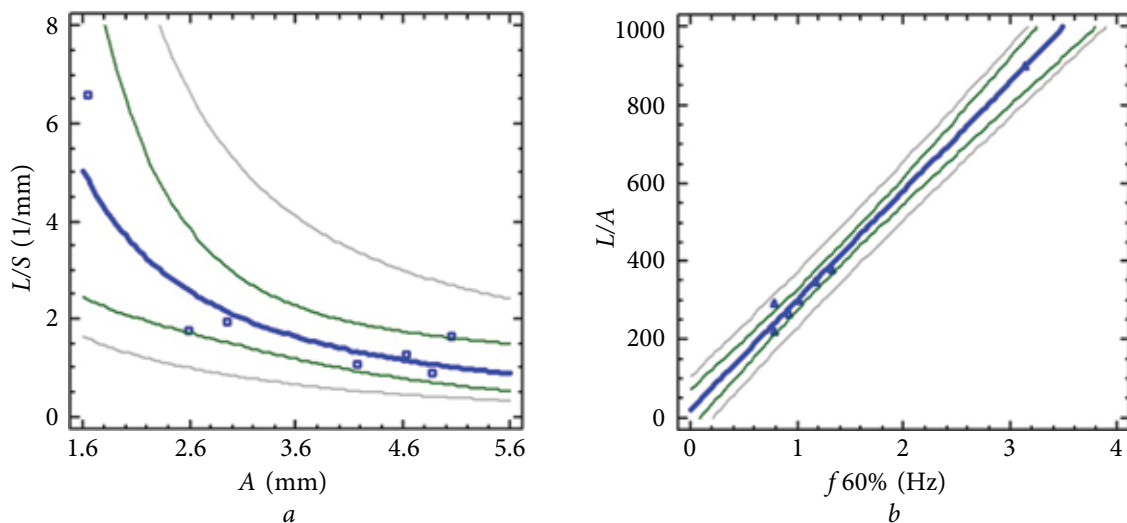

Fig. 2. The regression line (*bold blue*) and its confidence interval (*thin green lines*) indicate the dependency in the patients with stenosis of the thoracic spine with open eyes: (*a*) the *L/S* parameter on the amplitude of oscillation *A* of the center of pressure; (*b*) the *L/A* parameter of the average power level of the spectrum *f* 60% of the statokinesiogram
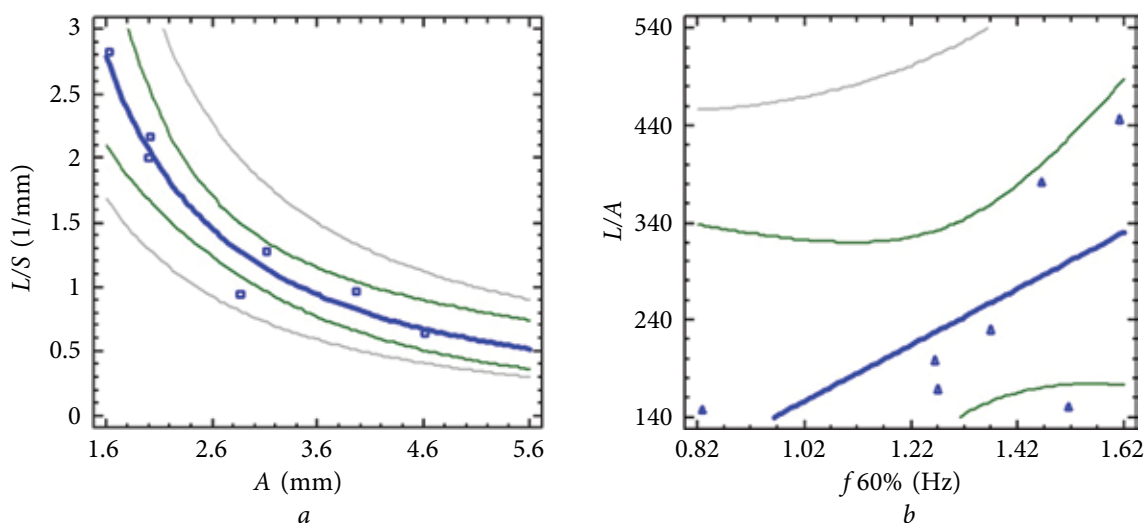

Fig. 3. The regression line (*bold blue*) and its confidence interval (*thin green lines*) indicates the dependency in the patients with stenosis of the lumbosacral spine with open eyes: (*a*) the *L/S* parameter on the amplitude of oscillation *A* of the center of pressure; (*b*) the *L/A* parameter of the average power level of the spectrum *f* 60% of the statokinesiogram

system in patients with various CNS lesions as a dynamic indicator of its deficiency; however, this phenomenon is yet to be clearly elucidated [19]. This statement is consistent with the concept that more ordered parameters of biological processes indicate less effective physiological control over them [20]. Taken together, the findings explain the severity of postural deficiency in patients with thoracic spinal stenosis, in which there is kyphoscoliotic deformity of the spine in addition to spinal disorders. Therefore, failure to maintain vertical posture in pediatric patients with lumbosacral spinal stenosis is latent in the standing position, but the condition can be aggravated during walking due to manifestations of radicular ischemia.

Conclusion

The findings indicate that patients with thoracic and lumbosacral spinal stenosis have postural deficiency, which is most pronounced in patients with thoracic stenosis. The tension in the work of the statokinetic system is probably caused by both segmental disorders of the spinal cord conductive function and a biomechanically different strategy for maintaining the vertical balance of the body in patients with congenital spinal deformity. The results obtained in group II patients showed that a similar postural deficiency is also manifested in the case of lumbosacral spinal stenosis; however, the severity of its manifestations is leveled by an absence of gross anatomical changes of the spinal column.

Conclusively, further studies of the vertical balance of the body of patients with spinal stenosis with correlation and regression analysis could elucidate the underlying mechanisms of postural control system in maintaining body balance. Our study shows promising results in terms of quantitative assessment of the state of adaptive resources of the statokinetic system in this category of patients in response to therapeutic measures.

Additional information

Conflict of interest. The authors declare no obvious and potential conflicts of interest related to the publication of this article.

Ethical review. Parents of all patients voluntarily signed an informed consent to participate in the study and to publish personal data.

Contribution of the authors

I.E. Nikityuk, E.L. Kononov were involved in data acquisition, data analysis, review of publications on the topic of the article, and writing the text of the manuscript.

S.V. Vissarionov performed the staged and final editing of the article text.

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