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Foot Function Disorders in Children with Severe Spondylolisthesis of L5 Vertebra

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Abstract

Background. In children with spondylolisthesis, there are still unexplained aspects in the relationship of the degree of L5 displacement with the severity of the clinical picture and neurological disorders. At the same time, aspects of the mutual aggravating influence of the indicated spinal disorder on the condition of the feet have not been studied. Therefore, the problem of identifying disorder of foot function in children with spinal L5 spondylolisthesis is relevant. ***Aim of the study*** — to evaluate the deviations in parameters of the transverse and longitudinal arches of feet in children with severe L5 spondylolisthesis. ***Materials and Methods.*** In the period from 2016 to 2018, 12 children aged 14.1 y.o. [12,7; 15,5] were examined with L5 spondylolisthesis body of grade III–IV, accompanied by stenosis of the spinal canal at the same level and by compression of the roots of the spinal cord. Imaging diagnostics included multispiral computed tomography (MSCT) and magnetic resonance imaging (MRI). To estimate the function of the feet, double-bearing and single-bearing plantography was used. The data for the control group included only plantographic examinations of 12 healthy children of the same age. ***Results.*** In patients with spondylolisthesis, the mean value of the anterior *t* and intermediate *s* plantographic bearing indices were significantly lower than those of healthy children. At the same time, in tests with an increased load on the foot in patients, there was no significant increase in the mean anterior *t* and medial *m* indices, which indicates the dynamic rigidity of the transverse and medial longitudinal arches. The value of the lateral plantographic index *l* showed its significant pathological increase compared with the normal value at double-bearing load, which indicates the static rigidity of the lateral longitudinal arch. Correlation analysis demonstrated that, against the normal state, the bearing ability of the feet in sick children is realized through a pathological strengthening of the functional relationship between the arches of the foot at double-bearing load and a non-physiological reduction of the interaction between arches at single-bearing load. ***Conclusion.*** In children with severe forms of spondylolisthesis, the parameters of plantographic characteristics indicate the rigidity of the arches of the feet and the distortion of their bearing pattern. It is necessary to take into account the aggravating effect of rigid feet on the state of the spine and include the examination of the bearing function of the feet in the algorithm for the comprehensive diagnosis of children with spondylolisthesis.

Keywords: spondylolisthesis, children, plantography, plantographic indices.

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Background

Despite the long history of spondylolisthesis research, various aspects of this pathology remain poorly understood. The complexity of studying spondylolisthesis in children derives from the lack of clear interdependence between L5 displacement degree and the pattern of general spinal column alterations [1]. Challenges in evaluation of spinal pathology processes due to spondylolisthesis in children and adolescents are usually tried to be explained by rapid growth of patients as well as by individual features of biomechanical restructuring during progressive displacement of vertebra in the growing body [2].

Until present, however, there are some still unexplained aspects of relationship between L5 displacement and the severity of the clinical picture and neurological disorders. Thus, in some children the clear clinical manifestation of neurological deficit is observed at initial degrees of L5 displacement, while in other patients the symptoms are vague even with considerable vertebral displacement. Lumbar spondylolisthesis can be accompanied by radiculopathy signs due to tensioned and compressed nerve roots manifested by numbness, tingling or weakness in lower limbs [3] or up to severe pain syndrome [4]. In cases of considerable spinal canal stenosis in the lumbosacral spine the vertebra-radicular conflict [5] can be accompanied not only by gait disorder [6] but to result in foot deformities [7].

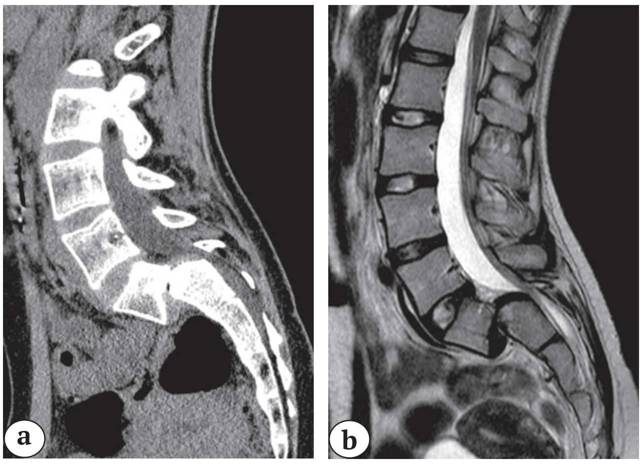

Fig. 1. Female patient, 17 y.o. L5 spondylolisthesis of grade IV. Deformity and spinal canal stenosis at lumbosacral spine: a — MSCT; b — MRI

Biomechanical diagnostic methods for functional disorders of locomotor system are rather widespread in the clinical practice [8], but the aspects of aggravating influence of spinal disorders on feet condition in children are not sufficiently studied. There are rare publications covering interrelation of spinal diseases with foot deformity and the presented data is controversial [9, 10]. Considering the above, the issue of identification of foot function disorder in children with spinal column pathology is still relevant.

Aim of the study — to evaluate the deviations in parameters of the transverse and longitudinal arches of feet in children with severe L5 spondylolisthesis.

Material and Methods

Study design. Single stage retrospective study in the period from 2016 to 2018.

Patients. The authors analyzed medical histories and results of imaging diagnostics of the main group of children — 12 patients of average age 14,1 [12,7; 15,5] with L5 spondylolisthesis, grade III-IV. Severity of spondylolisthesis was determined by Meyerding classification [11]. Grade III was reported for 5 patients, grade IV — in 7 patients (Fig. 1).

All patients suffered from spondylolysing spondylolisthesis. Control group included 12 healthy children of the same age who underwent only plantographic examination.

Inclusion criteria. The study included patients with L5 spondylolisthesis of grades III and IV accompanied by spinal canal stenosis at the same level and spinal cord roots compression. All patients demonstrated symptoms of radicular syndrome of varying severity.

Exclusion criteria. I and II grade spondylolisthesis, neurological disorders of A, B and C type by Frankel scale with paresis and contractures of lower limbs. Also we excluded the patients with pronounced supination contractures of different etiology due to impossibility to establish reference points and make calculations of plantographic indices due to lack of bearing ability of the head of the first metatarsal on one or both feet. Children with bilateral longitudinal flatfoot of grade II and above diagnosed by classical method of Godunov [12] were also excluded from the study while it was impossible to determine foot indices.

Methods. The following imaging techniques were used to evaluate L5 displacement and spinal cord roots positioning: roentgenography, multispiral computer tomography (MSCT) and magnetic resonance imaging (MRI). X-ray examination was performed in two standard planes with functional trials on the Philips Digital diagnost system (Netherlands), MSCT — on the Philips "Brilliance 64" system (Netherlands) by low-doze protocol for each age group, with volumetric (3D) and MRP-reconstruction of obtained images in frontal, sagittal and axial planes. MRI was performed on the Philips Panorama NFO 1.0T. system (Netherlands) according to the standard protocol.

Examination of foot bearing function was performed on soft- and hardware diagnostic system Podoscan (MBN Scientific&Medical company, Russia) by a refined method to identify plantographic features and evaluate parameters of foot arches [13]. Dynamic foot function was evaluated under various weight load: half body weight load on each foot (double-bearing) and whole body weight load on one foot (single-bearing). Plantographic indices of arches were calculated by correlation of local load on the arch to overall load on the arch [14]. To do so plantogrammes had reference points connected by lines (Fig. 2) to calculate indices of foot bearing ability: anterior — t = KE/BC, medial — m = GS/GO, intermediate — s = PW/PO and lateral — l = MN/HO. Above indices reflect condition of foot arches: t — transverse, m — medial longitudinal, s — intermediate longitudinal, l — lateral longitudinal.

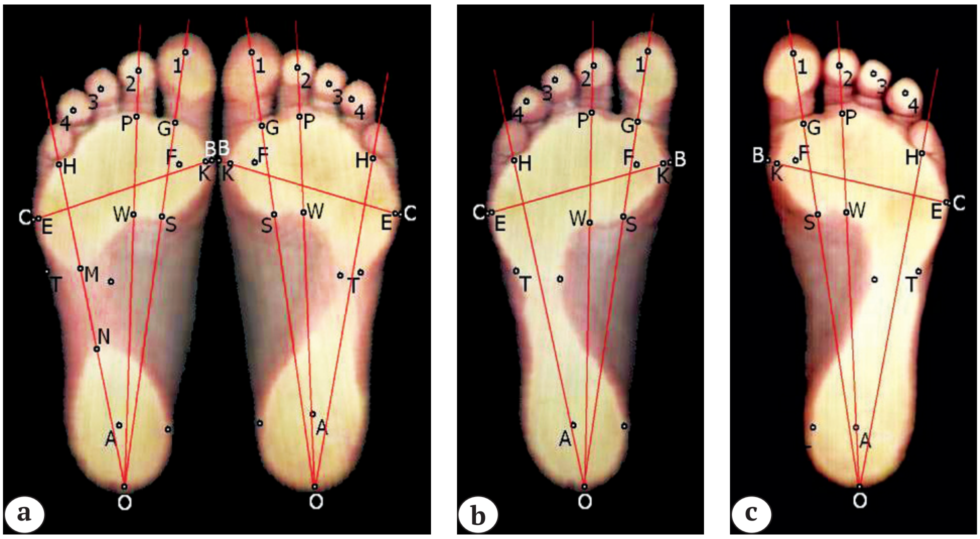

Fig. 2. Reference points on plantogramme of a healthy child, 12 y.o.:
a — in double-bearing load; b — left foot in single-bearing load; c — right foot in single-bearing load.
Letters indicate reference points.

Statistical analysis

Statistical analysis of obtained data was made using SPSS 11.5 (IBM Corp., USA) and Statgraphics Centurion 16.2 software (Statgraphics Technologies Inc., USA). Hypotheses of variation series distribution were tested (Shapiro-Wilk test, Kolmogorov-Smirnov test). Due to the fact that at least in one of the compared groups the quantitative characters did not match the normal distribution law, the authors used Mann-Whitney U-test to compare values of unbound samples, and Wilcoxon test with calculation of Z-criterion for intragroup comparison. The data was presented as a median (Me), inferior and superior quartiles (Q1-Q3). Statistical significance threshold was accepted at criterion value of $p<0,05$. Correlation analysis by non-parametrical Spearman coefficient r_s was used to evaluate the correlation of two attributes, which allowed to examine interrelation of transverse and longitudinal arches (correlation of bearing indices *t*, *m* and *s*, respectively). Correlation was considered strong at $r_s \geq 0,7$.

Results

Clinical examination of healthy children and patients demonstrated no symptoms of connective tissue or muscular dysplasia or external disembriogenetic stigmas. There were no knee and hip contractures. Weight was within age norm.

Plantographic examination of children with L5 spondylolisthesis identified hypoplasia of various severity of one foot in 5 (41,6%) patients. Foot shortening was reported from 1 to 13 mm (mean 5,7±1,86 mm). Considering varying age of patients, foot shortening against the contralateral limb was reflected in relative measurement units — from 1 to 9% (mean 3,8±1,3%). At the same time clinical measurements did not reveal shortening of the lower limb at the side of shortened foot which excluded the factor of asymmetrical load distribution on plantar foot surface. Two (17%) patients demonstrated unilateral longitudinal flatfoot of grade I, and of those two in one child 7 mm difference (about 4%) in feet length was observed while the shortened foot had no flattening signs. Plantographic indices of examined children are presented in Table 1.

Table 1 demonstrated that in healthy children a significant change in bearing indices was reported at transfer from double-bearing to single-bearing stance (meaning, twofold increase of foot load): increase of *t*, *m, s* and decrease of *l* indices, which confirms elasticity of soft tissues in the normal foot. In patients with L5 spondylolisthesis the mean value of *t* and *s* indices was significantly lower than similar parameters in healthy children, both at double-bearing and at single-bearing stance, which can be related to the pathological tendency to supination foot positioning (Fig. 3).

A slight decrease of *m* index was observed. At the same time no significant increase of mean indices values *t* and *m* was observed during test with increased foot load in patients with spondylolisthesis, which indicates dynamic rigidity of transverse and medial longitudinal arches in patients. *l* index in patients demonstrated significant pathological increase against normal values at single-bearing load, which confirms static rigidity of lateral longitudinal arch despite preservation of its elasticity — significant change of this parameter under twofold increase of load.

Correlation analysis of plantographic indices provided examination of linear interrelation of bearing indices in healthy children and in patients (Table 2).

Table 1

Indices of foot bearing in healthy children and in patients with L5 spondylolisthesis

Bearing indices (×10^{-2})		Values of bearing indices (×10^{-2})				
		Healthy children		Children with spondylolisthesis		Mann-Whitney criteria, *p*-value
		Me (Q1–Q2) *n* = 12	Wilcoxon criteria	Me (Q1–Q2) *n* = 12	Wilcoxon criteria	
t	D	91,4 (92,2–95,6)	Z = -3,140 p_3 = 0,02	91,1 (87,4–93,2)	Z = -0,684 p_6 = 0,494	0,005
	O	96,8 (95,6–97,6)		92,6 (91,1–94,5)		0,000
m	D	22,5 (20,1–23,2)	Z = -4,167 p_3 = 0,000	21,3 (17,2–23,3)	Z = -0,657 p_6 = 0,511	0,496
	O	25,0 (23,8–27,1)		23,5 (21,7–27,3)		0,170
s	D	23,4 (22,3–24,8)	Z = -3,198 p3 = 0,001	22,3 (19,6–24,5)	Z = -2,029 p_6 = 0,043	0,051
	O	26,2 (24,6–28,3)		23,5 (21,7–27,3)		0,031
l	D	11,4 (0–28,1)	Z = -3,516 p_3 = 0,000	23,1 (15,6–38,1)	Z = -3,362 p_6 = 0,001	0,576
	O	0 (0–0)		9,2 (6,0–24,1)		0,015

D — double-bearing plantography, O — single-bearing plantography; p_3 — significance of bearing index change at transition from double and single-bearing load in healthy children, p_6 — in patients; *p*-value — significance of value variance between the groups of healthy children and patients.

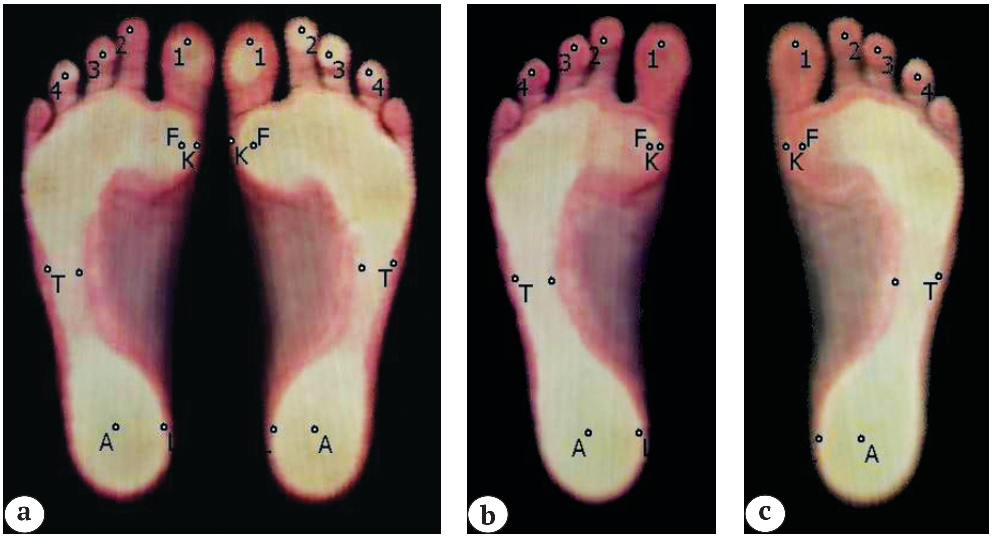

Fig. 3. Plantogrammes of patient, 13 y.o., L5 spondylolisthesis of grade IV:
a — at double-bearing load;
b — at single-bearing load — left foot;
c — at single-bearing load – right foot. Supination of anterior foot is observed in single-bearing stance resulting in decrease of bearing ability of head of the first metatarsal at both feet

Table 2

Correlation between bearing indices in healthy children and in patients with severe L5 spondylolisthesis

Group of children (feet)	Correlation coefficient r_s					
	Double-bearing plantography			Single-bearing plantography		
	m~t	*s~t*	*m~s*	*m~t*	*s~t*	*m~s*
Healthy children (n = 24)	0,12 (p = 0,2125)	0,11 (p = 0,3696)	0,23 (p = 0,2892)	0,13 (p = 0,8547)	0,34 (p = 0,2698)	0,57 (p = 0,0911)
Children with spondylolisthesis (n = 24)	0,62 (p = 0,0662)	0,77 (p = 0,0325)	0,84 (p = 0,0000)	0,57 (p = 0,0601)	0,38 (p = 0,2165)	0,54 (p = 0,0019)

p — significance of obtained value of correlation coefficient.

Interrelation between transverse and longitudinal bearing indices was very weak and statistically insignificant in the group of healthy children, which confirms independent loading of arches at even body weight distribution between the feet. Loading tests with intermittent body weight transfer to each foot demonstrated that in healthy children there is an increased correlation between medial and intermediate longitudinal arches *m* and *s*, with that correlation coefficient significance is approaching but not reaching the critical 0,05 value. It's worth noting that relation between transverse and longitudinal foot arches remains weak and insignificant.

Another bearing pattern was observed in the group of patients with L5 spondylolisthesis. At double-bearing load on feet, in contrast to healthy children, the authors observed strong correlation between all foot arches. Correlation between medial and intermediate longitudinal arches as well as between intermediate longitudinal and transverse arches was significant.

At transit to single-bearing stance the examined patients demonstrated a reverse pattern — despite higher energy consumption to keep their balance, there was a decrease of functional relationship between foot arches, which was characterized by decrease in all correlation coefficients, and significance of correlation was preserved only between medial and intermediate longitudinal arches.

Discussion

Foot is one of the key structural elements of the human locomotor system that provide static and motor function and represents an integral morpho-functional unit upon which motor function depends [15]. The authors of the present paper did not find any particular, instrumentally confirmed data in the literature, which would describe morpho-functional features of feet in children with L5 spondylolisthesis. Unilateral foot shortening in growing children with L5 spondylolisthesis which is observed in the present study can be attributed, on the one hand, to the hypofunction of metaepiphyseal bone cartilage due to trophic damage as demonstrated in the study of J.C. Nguyen et al [16]. On the other hand, in the earlier own research the authors observed alterations in activity of growing cartilage along complete absence of any cell-humoral influence on the cartilage [17]. Thus, it can be supposed that slowing of foot growth in patients with spinal disorders occurred due to inhibition of bone growth areas along with imbalance in load distribution within foot structures resulting in inadequate changes in mechanical stimulus [18].

As known, one of the main foot function is spring bearing, resulting in foot arches ability to absorb shock energy during walking or running. The most absorbing function is performed by medial longitudinal arch which acts like a spring in normal condition. The authors of the present paper utilized functional plantography method which allows to compare spring foot function in healthy children and in patients according to the data of V.S. Anosov et al, as well as to report foot rigidity in patients with spondylolisthesis [19]. The present study revealed foot arches rigidity in patient with L5 spondylolisthesis despite preserved elasticity of intermediate and medial longitudinal arches.

Correlation analysis demonstrated that in normal situation with double-bearing load a random load distribution between arches was an adequate state of spring function of transverse and longitudinal arches. At twofold load increase on the foot there was a tendency for synchronized function of medial and intermediate longitudinal arches resulting, probably, from higher energy consumption to keep the balance in conditions of decreased bearing surface while standing on one foot. Previous research of the authors demonstrated that it provides balancing foot function to maintain vertical body positioning at any support irregularities [20].

In patients with severe spondylolisthesis the authors observed a pathologically strong functional relationship between foot arches at double-bearing load and abnormal decrease in relationship between arches at single-bearing load, which can indicate inadequate spring and bumper function of foot arches due to their rigidity. Such difference in bearing foot pattern of patients can result from neuromuscular malfunction of lower limbs due to L5 displacement leading to spinal cord roots compression and partial conduction block of compression-ischemic character at L1-L5 levels. Such disorder of afferent and efferent relationship of lower limbs with central neural system may result in rigidity of foot arches [21] and disorder in spring function [22]. The authors suppose that in children with spondylolisthesis along the vertebra-radicular disorder there is a change in corticospinal mechanism of feet bearing resulting from impaired afferent-efferent signals passage. Due to changes in the centrally regulated locomotor functions in such patients some adapting compensatory mechanisms arise to support body balance. It's very likely that such compensatory mechanisms are realized by selective alteration in activity and synchronizing of lower leg muscles and change of the foot arches pattern [23]. In the authors opinion such adaptive strategy allows to ensure vertical positioning and to enable movements despite unfavorable functioning. Thus, plantography parameters can indicate restructuring of normal motor algorithm into pathological algorithm for the complex standing position in patients with severe L5 spondylolisthesis.

The authors should note aggravating influence of feet rigidity on spinal column. It's known that decrease of elastic foot properties along its rigidity lead to decrease of the shock absorbing properties resulting in increased shock load and vibration influence on all joints and organs [24]. More rigid muscular-ligamentous structure of the foot can't smoothly absorb the incoming load and there is a high probability of anatomical damage of the whole locomotor system [25]. In the result, spinal column and spinal cord of the patient becomes less protected against external mechanical exposure during walking, running and jumping. In such a situation spring function of the foot not only fails to protect vertebras from constant micro trauma and related degenerative and dystrophic processes, but inevitably leads to rapid progressing of irreversible lesions of intervertebral joints [26].

Thus, foot alterations formed as a compensatory mechanism due to changes in lumbar-sacral spinal motion segment provide aggravating influence and increase disease progression during further child growth. Considering all those facts, identification of elasticity features and shock absorbing properties of feet in children with severe spondylolisthesis is highly important for early diagnostics of function of foot arches, where dysfunction results in unfavorable consequences for the whole locomotor system and restrictions in its adaptive properties.

In all patients with severe L5 spondylolisthesis the parameters of plantographic examination indicate the rigidity of foot arches and distortion of bearing pattern. Compared to healthy children the bearing ability of feet in patients with spondylolisthesis is realized by pathological enhancement of functional relationship between foot arches at double-bearing load and abnormal decrease of arches relationship at single-bearing load. It's necessary to take into account the aggravating effect of rigid feet on spinal column and to include examination of bearing foot function into the algorithm of complex diagnostics for children with L5 spondylolisthesis.

Publication ethics: All patients provided written informed consent. All procedures performed in this study involving human participants were in accordance with local ethic committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Competing interests: The authors declare that there are no competing interests.

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Authors' contribution

I.E. Nikityuk — design of research, collection and statistical data processing, review of publications related to the topic of the study and writing the manuscript.

S.V. Vissarionov — collection and analysis of materials, review of publications related to the topic of the study, writing of paper text, step-by-step and final editing of the manuscript.

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