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Supporting function of the feet in children with severe forms of idiopathic scoliosis before and after surgical treatment

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Abstract

Background Idiopathic scoliosis in children can cause noticeable changes in the musculoskeletal system including the feet and the relationship between spinal deformity and impaired biomechanics of the feet is important to learn in the case. **The purpose** was to explore plantographic characteristics of feet in children with severe idiopathic scoliosis before and after surgical correction of the curve using transpedicular spinal systems. **Material and methods** Foot support indices were measured in 18 children aged 14-17 years with grades III and IV idiopathic scoliosis Lenke types I, III, V and VI. The results were compared with plantographic findings of 18 healthy children. **Results** The medial index m was within normal limits with a double-support load in patients with idiopathic scoliosis before spinal surgery. The rest of the indices were significantly reduced irrespective of the extent of the foot load. Double-support load tests showed a pathologically strong correlation between the medial and median support indices m ~ s. The spring function of the foot arches was intact. The frontal balance of the spine correlated with the foot support indices. Patients developed no foot rigidity at 9–10 days of surgery and showed an increased asymmetry in the arches of the contralateral feet and an abnormal increase in the relationship between the foot support indices m, s and t with no correlation between the frontal balance of the spine and the plantographic characteristics. **Conclusion** Children with severe idiopathic scoliosis were shown to develop impaired biomechanics of the feet with decreased contact area between the feet and the support surface, and a pathological increase in the functional relationship of the arches. Impaired biomechanics of the feet appeared to aggravate at a short term following correction of spinal deformity.

Keywords: idiopathic scoliosis, children, the support surface of the foot, plantography, support indexes

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INTRODUCTION

Scoliosis is the most common spinal deformity in childhood [1]. Despite considerable efforts to identify the etiopathogenesis of idiopathic scoliosis, there is no significant progress in understanding the causes of spinal curvature. Idiopathic scoliosis (IS) is a polyethological disease caused by genetic factors, neurological dysfunctions, hormonal and metabolic disorders, skeletal growth abnormalities, and biochemical factors. There is growing support for the possibility of an underlying sensorimotor integration disorder during ambulation in IS patients [2]. Biomechanical methods are used to assess sensory disorders in IS patients [3]. IS in children is associated with musculoskeletal changes including the feet, and biomechanical studies offer important information about the feet [4]. Impaired supporting function of the feet in IS children leads to the progression of spinal deformity [5], and causes back pain and neurological disorders [6]. There are researches focusing on the clinical role of the relationship between spinal deformity and impaired distribution of plantar pressure.

Clinical and scientific aspects of the kinematic 'spine – foot' chain emphasize the study of the "descending" effect of scoliosis on plantar pressure [7, 8] and a possibility of an "ascending" effect on the curvature through correction of the feet biomechanics [9, 10]. Therefore, plantar pressure parameters are used for the assessment of the supporting function of the feet in children, and provides additional insight into various musculoskeletal diseases and the vertebral column, in particular.

The purpose was to explore plantographic characteristics of feet in children with severe idiopathic scoliosis before and after surgical correction of the curve using transpedicular spinal systems.

MATERIAL AND METHODS

The results of a plantographic study of IS patients performed between 2019 and 2020 were reviewed in a prospective case-control study. The inclusion criteria were a clinically established diagnosis of "idiopathic scoliosis grade III or IV as classified by V.D. Chaklin; patients aged 14 to 17 years; Cobb angle of 40 to 136°. The exclusion criteria were patients younger than 14 years; Cobb angle less than 40°; previous spinal surgery; motor and sensory disorders, and segmental disorders of the spinal cord.

The study group included 18 patients (2 boys and 16 girls). Radiographs of the spine were produced to determine the type of the curve and mobility of the scoliotic arch. Magnetic resonance imaging was used to rule out intracanal pathology and evaluate the spinal cord. Right–sided curve was diagnosed in 13 (72.2%) children and 5 (27.8%) had left-sided involvement. The curve was localized in the thoracic (Lenke I, n = 10), thoracolumbar (Lenke III, n=4) and lumbar spine (Lenke V, n = 3). One patient had S-shaped scoliosis (Lenke VI). Preoperative mean Cobb angle was 73.2 ± 5.68° and the mean thoracic kyphosis was 26.6 ± 4.22 °.

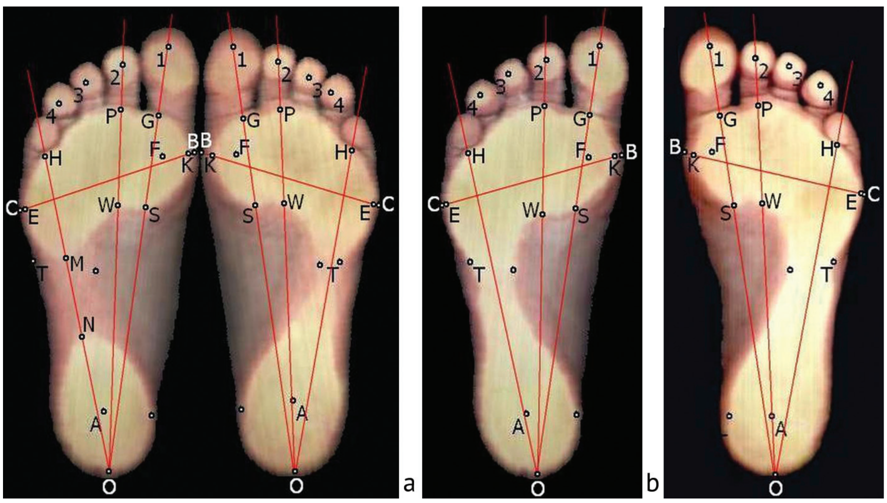
C7PL plumb line drawn from the middle of the vertebral body C7 was used to determine the balance of the spine on radiographs. It corresponded to the sagittal vertical axis (SVA) on lateral radiographs. The distance from SVA to the articular processes S1 (SVA-S1) was measured, and normally should not be greater than 40 mm [11]. When the SVA shifted anteriorly the sagittal balance was positive, and with the posterior shift it was negative. The normal distance from C7PL to the central sacral vertical line, CSVL (C7PL-CSVL) should not be greater than 20 mm and was measured on AP views [12]. When the C7PL was seen off the right CSVL the frontal (coronal) balance was positive, and when seen off the left the balance was negative. The curve was surgically corrected with transpedicular spinal systems and stabilized with posterior bone fusion along the metal construct [13] with significant correction of the main arch achieved.

The biomechanical examination was performed preoperatively and at 9-10 days of the surgery when patients could stand unassisted. The supporting function of the feet was explored with computed plantography. The PodoScan diagnostic system (NMF MBN, Russia) was used to obtain plantar images (plantograms) and evaluate plantar pressure. Plantograms were obtained at different loadings on the feet. With double weight-bearing plantography, pressure was recorded with the child's body weight borne by both lower limbs in a standing position with support on both limbs. With single weight-bearing plantography, the child transferred his body weight from one to another limb standing on one leg (Fig. 1). The control group included 18 healthy children aged 14 to 17 years.

With the images of the plantar surface of the feet, identification lines were drawn using the established technique, with the BC marking the transverse arch of the foot, and OG, OR and HE lines marking the medial, median and lateral longitudinal arches [14]. Rapper points were placed at the intersection of the lines delineating the contours of the contact foot area and the supporting surface. The distance between the rapper points was measured to calculate the support indices: $t = KE/BC$, $m = GS/GO$, $s = PW/PO$ and $l = MN/HO$. The index t (anterior index of the support) indicated the transverse arch of the foot. The indices m, s and *l* (medial, median and lateral) indicated the functionality of the corresponding longitudinal arches.

Statistical analysis was performed with computer software (SPSS 11.5 and Statgraphics Centurion 16.2). The Kolmogorov–Smirnov test and the Shapiro-Wilk tests were used to determine the type of distribution of the variables. The distribution of plantographic measurements in the groups was identified as nonparametric, the Mann-Whitney test was used to compare unrelated samples, and the Wilcoxon test was used to compare related samples. The results were presented as a median (Me) with an interquartile range [Q1-Q2] within the standard range of 25-75 %. Fisher's F-test (ANOVA) was used to compare the variables of the two sampled populations. Correlation analysis using the nonparametric Spearman coefficient rs was used to study the relationship between the two parameters. The threshold level of statistical significance was set at $p < 0.05$.

Compliance with ethical standards The study was performed in accordance with ethical principles for medical research involving human subjects stated in the Declaration of Helsinki developed by the World Medical Association as revised in 2013. Written informed consent was obtained from all patients for publication of the findings without identifying details.



a b c

Fig. 1 Plantograms of a healthy child showing (a) double weight-bearing plantography; (b) single weight-bearing plantography with weight borne by the left foot; (c) single weight-bearing plantography with weight borne by the right foot. Identification lines were drawn and rapper dots placed

RESULTS

Neither neurological complications nor destabilized metal construct were observed in patients after the surgical treatment. The mean angle of the main arch decreased to 11.6 ± 2.51° after surgical correction of the curve with the mean correction of 84.3% (Fig. 2). The mean thoracic kyphosis was 11.6 ± 2.51°. The height of patients increased by 9.6 ± 0.35 cm with the mean relative increase in height of 5.8 %). No significant correlations were observed between the Cobb angle and plantar pressure in IS patients before and after surgical interventions.

Plantographic measurements in healthy children (Table. 1) showed a twofold increase in the foot loading leading to significant increase in the support indices t, m and s with decreased l index indicating to good elasticity of the foot muscles and ligaments with an adequate spring function.

Preoperative medial index m was within the normal limits with a double-support loading. The rest indices were significantly reduced irrespective of the amount of loading on the foot. However, this did not indicate rigid feet in IS patients with significant changes in all support indices during the transition from a double-support to a single-support loading being characteristic of healthy children. Relative changes in the *Δt, Δm, Δs* and *Δl* in IS patients was also within normal limits (Table 2) that indicated to the foot arches retaining spring functions in IS patients.

There were greater deviations in all postoperative plantographic parameters in IS patients. The medial index m was reduced at a single- and double-support loading. There was a sharp increase in the lateral index of support l at a double-support loading that was not physiological and indicated an excessive increase in the height of the lateral and medial longitudinal arch (Fig. 3). Significant differences in standard deviations of plantographic parameters indicated a pronounced change in postoperative measurements as compared with preoperative ones despite the stable median values. The Δ were within normal limits with relative changes in the parameters during changes in loading. The IS patients experienced no deterioration in the spring function of the feet after surgery aimed at correcting spinal deformity. Functional asymmetry of the contralateral feet of healthy children and IS patients was assessed through comparison of median and quartile measurments of plantographic indices and variance parameters (Table 3).

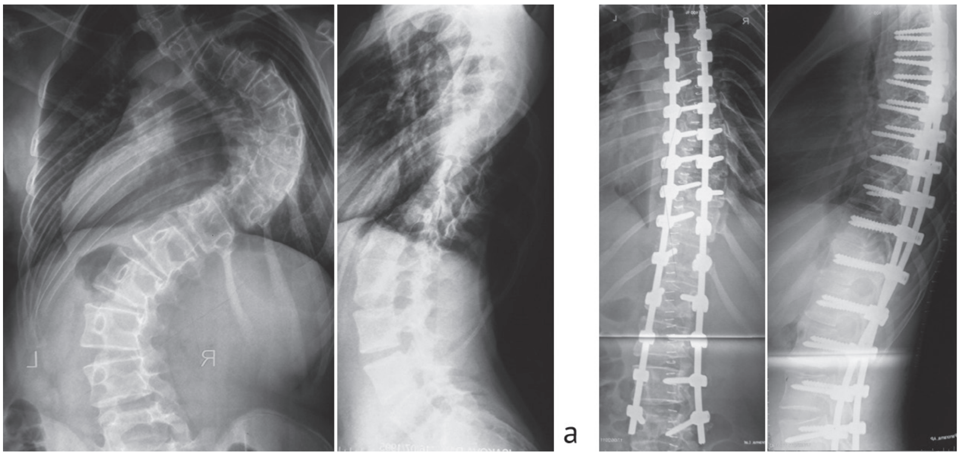


Fig. 2 Radiographs of the spine of a 16-year-old patient K. with right-sided IS grade IV localized in the thoracic spine, Lenke I: (a) preoperative Cobb angle of 120°; (b) Cobb angle measuring 18° after surgical correction of the curve using transpedicular metal construct

Table 1

Absolute parameters of plantographic foot indices of healthy children and IS patients before and after surgery

Index (× 10^{-2})		Группы обследованных детей					Mann-Whitney U test
		healthy (1)	IS				
		Me [Q_1 – Q_2], n = 18	pre-op (2) Me [Q_1–Q_2], n = 18	*p*	*p*-value	postsurgery (3) Me [Q_1– Q_2], n = 18	
Double-support weight-bearing	*t*	94.2 [92.2 – 96.4]	90.2 [85.7 – 91.9]	0.644	0.116	89.7 [86.8 – 91.9]	$p^{1-2} < 0.001$ $p^{1-3} < 0.001$
	m	22.5 [20.6 – 24.0]	21.8 [20.4 – 23.2]	0.183	0.000	21.2 [19.4 – 22.3]	$p^{1-2} = 0.253$ $p^{1-3} = 0.019$
	s	23.6 [22.6 – 25.4]	22.9 [21.0 – 24.3]	0.195	0.193	22.2 [20.3 – 23.5]	$p^{1-2} = 0.05$ $p^{1-3} = 0.001$
	l	5.7 [0 – 20.8]	15.7 [0 – 44.1]	0.055	0.859	33.0 [16.0 – 49.8]	$p^{1-2} = 0.028$ $p^{1-3} < 0.001$
Single-support weight-bearing	*t*	**96.3 [95.0 – 97.7]**	**91.7 [88.4 – 94.3]**	0.752	0.001	**92.3 [89.7 – 94.0]**	$p^{1-2} < 0.001$ $p^{1-3} < 0.001$
	m	**25.0 [23.7 – 26.9]**	**22.7 [21.3 – 25.5]**	0.844	0.079	**22.8 [20.9 – 25.0]**	$p^{1-2} = 0.001$ $p^{1-3} < 0.001$
	s	**26.0 [24.3 – 27.9]**	**24.3 [23.1 – 26.8]**	0.086	0.017	**24.0 [22.2 – 25.6]**	$p^{1-2} = 0.044$ $p^{1-3} < 0.001$
	l	**0 [0 – 0]**	**0 [0 – 16.8]**	0.637	0.113	**0 [0 – 27.4]**	$p^{1-2} = 0.015$ $p^{1-3} = 0.013$

l*Note*: *p* – significant differences in the group of patients before and after surgery (Wilcoxon test); p-value, significant differences between standard deviations in the group of patients before and after surgery (F-Fisher tes); $p^{1-2;1-3}$ – significant differences between groups; bold indicates measurements at single-support loading with changes with at least p < 0.05 compared with similar parameters at double-support loading

Table 2

Changes in the plantographic indices of the feet during the transition from a two-support loading to a single-support loading in healthy children and in IS patients before and after surgery

Index (× 10^{-2})	Groups of children				Mann-Whitney U test
	healthy (1)	IS			
	Me [$Q_1 – Q_2$], n = 18	pre-op (2) Me [$Q_1 – Q_2$], n = 18	*p*	postsurgery (3) Me [$Q_1 – Q_2$], n = 18	
Δt	2.1 [0 – 4.0]	3.2 [0.3 – 5.2]	0.897	2.4 [0.5 – 5.1]	p^{1-2} = 0.303 p^{1-3} = 0.408
Δm	2.6 [0.6 – 5.0]	1.9 [-0.2 – 3.0]	0.892	1.5 [0.5 – 3.0]	p^{1-2} = 0.068 p^{1-3} = 0.122
Δs	2.1 [0 – 4.5]	1.9 [0.9 – 3.2]	0.175	1.5 [0.6 – 2.4]	p^{1-2} = 0.923 p^{1-3} = 0.489
Δl	-4.6 [-20.1 – 0]	-6.7 [-22.2 – 0]	0.287	-14.2 [-28.1 – -2.8]	p^{1-2} = 0.248 p^{1-3} = 0.018

Note: *p* – significant differences in the group of patients before and after surgery (Wilcoxon test); $p^{1-2;1-3}$ – significant differences between the groups.

Fig. 3 Plantograms of the feet of a 16-year-old patient K. with idiopathic right-sided thoracic scoliosis grade IV, Lenke I at (a) preoperative double-support plantography; (b) double-support plantography 9 days after surgery using a transpedicular metal construct showing increased height of lateral longitudinal arches, reduced contact area of the feet and the supporting surface

Table 3

Characteristics of asymmetry in plantographic indices of contralateral feet of healthy children and IS patients before and after surgery

Index (× 10^{-2})		Groups of children					Mann-Whitney U test
		healthy (1)	IS				
		Me [Q1 – Q2], n = 18	pre-op (2) Me [Q1–Q2], n = 18	*p*	*p*-value	postsurgery (3) Me [Q1– Q2], n = 18	
Double-support weight-bearing	*t*	2,0 [0,1 – 2,5]	4,3 [2,5 – 5,3]	0,601	0,009	2,6 [0,7 – 7,7]	p^{1-2} = 0,006 p^{1-3} = 0,179
	m	2,3 [1,0 – 4,0]	2,3 [1,3 – 3,2]	0,987	0,719	2,1 [1,4 – 3,4]	p^{1-2} = 0,912 p^{1-3} = 0,716
	s	2,1 [1,2 – 3,6]	1,0 [0,8 – 2,5]	0,716	0,802	1,0 [0,8 – 2,7]	p^{1-2} = 0,110 p^{1-3} = 0,117
	l	2,5 [0 – 8,1]	1,1 [0 – 5,9]	0,727	0,416	9,3 [1,8 – 20,6]	p^{1-2} = 0,163 p^{1-3} = 0,033
Single-support weight-bearing	*t*	1,9 [0,1 – 2,3]	2,9 [2,1 – 3,6]	0,189	0,001	3,6 [2,4 – 5,0]	p^{1-2} = 0,005 p^{1-3} < 0,001
	m	1,7 [0,6 – 3,6]	2,7 [0,7 – 4,3]	0,887	0,006	2,6 [1,6 – 3,4]	p^{1-2} = 0,384 p^{1-3} = 0,211
	s	1,3 [0,9 – 3,0]	1,0 [0,7 – 1,7]	0,624	0,001	1,2 [0,7 – 2,7]	p^{1-2} = 0,289 p^{1-3} = 0,669
	l	0 [0 – 0]	0 [0 – 2,5]	0,958	0,974	0 [0 – 9,9]	p^{1-2} = 0,169 p^{1-3} = 0,127

Note: *p* – significant differences in the group of patients before and after surgery (Wilcoxon test); *p*-value – significant differences between standard deviations in the group of patients before and after surgery (F-Fisher tes); $p^{1-2;1-3}$ – significant differences between groups

Significant increase in medians, interquartile intervals and differences between the standard deviations of the asymmetry in plantographic indices of contralateral feet of IS patients is presented in Table 3. This indicates an increase in the asymmetry of the functional activity of the arches of the contralateral feet in patients after surgical correction of spinal deformity. There was a very weak correlation seen in the support indices at double-support weight-bearing in healthy children (Table 4) using correlation and regression analysis of foot support indices (Fig. 4a).

Table 4

Linear correlation between foot support indices in healthy children and IS patients before and after surgery

Groups of children	Correlation index r_s					
	double-support weight-bearing			single-support weight-bearing		
	m ~ t	*s ~ t*	*m ~ s*	*m ~ t*	*s ~ t*	*m ~ s*
Healthy (n = 18)	0.20 (p = 0.234)	0.10 (p = 0.581)	0.34 (p = 0.043)	0.24 (p = 0.159)	0.36 (p = 0.031)	0.58 (p = 0.001)
IS pre-op (n = 18)	0.07 (p = 0.697)	0.07 (p = 0.677)	0.72 (p = 0.000)	0.30 (p = 0.076)	0.30 (p = 0.083)	0.79 (p = 0.000)
IS post-op (n = 18)	0.48 (p = 0.003)	0.44 (p = 0.008)	0.79 (p = 0.000)	0.30 (p = 0.090)	0.18 (p = 0.309)	0.81 (p = 0.000)

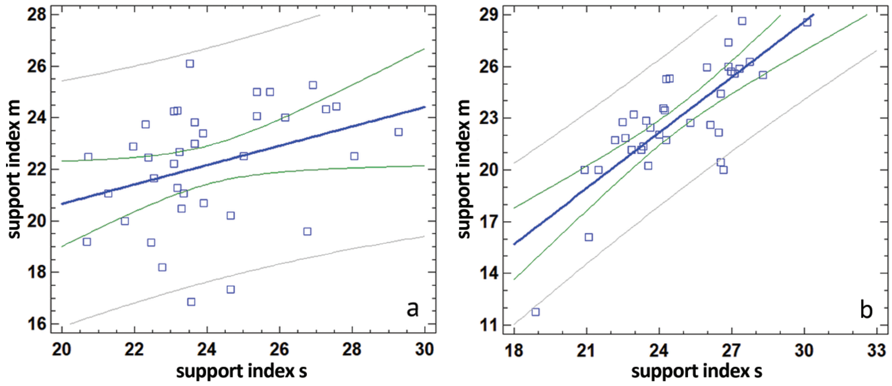


Fig. 4 Regression line (bold) and the confidence interval (thin lines) to assess the correlation between the indices of foot support (medial m and median s) at double-support weight-bearing (a) in healthy children; (b) in IS children before surgery

There is normally an unsystematic change in the size of the foot along the frontal and sagittal axes at double-support weight-bearing that is characteristic of the adequate spring function of the transverse and longitudinal arches of the feet in healthy children [15]. The correlation between the medial and median indices of support m ~ *s* increased at single-support weight-bearing that could be explained by greater musculoskeletal requirements and increased energy costs in maintaining balance with the support of one lower limb. The correlation between the median and anterior *s ~ t* indices and between the medial and anterior *m ~ t* remained weak

A strong correlation between the medial and median indices of support *m ~ s* was revealed in IS patients at double-support weight-bearing (Fig. 4b) and indicated a greater functional relationship between the medial and median longitudinal arches of the feet compared to the norm. The correlation between the *s ~ t* and *m ~ t* indices remained weak as seen in healthy children. Tests with an increased loading the correlations between the support indices did not change and was similar to that in healthy children. IS patients showed dynamics in the correlations between the indices of support at double-support weight-bearing after the operation as compared with preoperative parameters. This was manifested by a significant increase in correlations between all indices *m, s* and *t*. Correlations between the support indices remained similar to that of healthy children at single-support weight-bearing.

Frontal and sagittal imbalance of the spine was observed in 2 IS patients preoperatively. Isolated frontal and sagittal imbalance was noted in one patient. The imbalance was subcompensated in the patients. The mean frontal balance before surgery was 5.0 [-10.5 ÷ 15.5] mm and the mean sagittal balance was -3.0 [-8.5 ÷ 18.0] mm. One patient retained frontal and sagittal subcompensation of the trunk balance after surgical correction of the curve that was less as compared to the preoperative level. Physiologically adequate frontal and sagittal spine alignment was restored in the rest cases. The mean frontal balance became 5.5 [3.0 ÷ 7.5] mm and sagittal – 10.5 [6.0 ÷ 18.5] mm. Although the median balance measurements did not change significantly after surgery, there was a sharp increase in variance in the frontal balance (p-value (Fisher's F-criterion) = 0.016) with a decrease in C7PL-CSVL distances (Fig. 5a). A significant increase in variance was also observed in the sagittal balance (p-value (Fisher's F-criterion) = 0.029) with significant and multidirectional changes in the SVA-S1 distances (Fig. 5b). Therefore, dynamics in the sagittal balance was less pronounced as compared to the frontal alignment.

Correlation analysis revealed a relationship between the modular values of the frontal balance and the asymmetry of the plantographic parameters of the contralateral feet in patients before surgery: positive, with the medial index of the support m and negative with the anterior index of the support t (Table 5).

The modular values of the balance appeared to be significant in the correlation analysis that indicated no correlation between the direction of the lateral displacement of the spine and an increased loading on the foot of the corresponding side. Hypothetical overloading of the corresponding lower limb with a lateral deviation of the trunk was not the cause of the asymmetry of the functional activity of the contralateral arches in IS patients. The asymmetry of the supporting feet function could be seen as the adaptive reaction to compensatory changes in the links of the kinematic musculoskeletal chain during the formation of the curve. There were no correlations noted at a short term of the deformity correction due to the new adaptive mechanisms developing in the musculoskeletal system to ensure vertical position for the body. No significant correlations in the sagittal balance of the spine and the supporting parameters of the foot were revealed before or after surgical interventions.

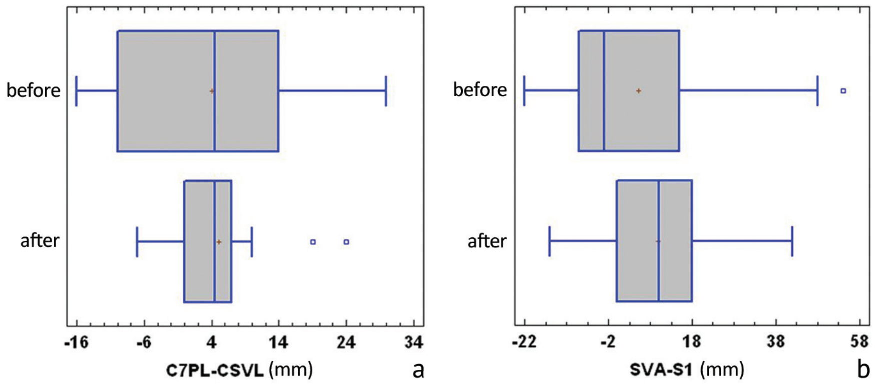


Fig. 5 Diagrams of trunk balance in IS patients before and after correction of the curve (a) frontal balance; (b) sagittal balance

Table 5

Multiplicative correlation between the balance of the spine and the asymmetry of the plantographic parameters of the contralateral feet in IS patients before and after surgery

Groups of children	Correlation index корреляции r_s					
	Frontal balance – feet			Sagittal balance – feet		
	|C7PL-CSVL| ~ *m*	|C7PL-CSVL| ~ *s*	|C7PL-CSVL| ~ *t*	SVA-S1 ~ *m*	SVA-S1 ~ *s*	SVA-S1 ~ *t*
IS pre-op (n = 18)	0.68 (p = 0.002)	-0.18 (p = 0.471)	-0.51 (p = 0.030)	-0.12 (p = 0.650)	-0.23 (p = 0.349)	-0.18 (p = 0.513)
IS post-op (n = 18)	-0.11 (p = 0.674)	-0.33 (p = 0.183)	0.03 (p = 0.899)	-0.32 (p = 0.191)	-0.28 (p = 0.264)	0.20 (p = 0.427)

Note: the symbol | | indicates the modules of the values of the frontal balance

DISCUSSION

There is controversy regarding mechanisms of biomechanical disorders developing in the musculoskeletal system of IS children. Despite the pronounced scoliosis disorders of the vertical balance in patients were reported as either moderate [16] or absent [17]. There is a biomechanical mismatch of segment coordination in the spine and the feet system reported in scoliosis [18]. This leads to an imbalance of the feet and deviations in plantar pressure in the patients as compared with healthy children [19]. The foot provides the contact of the musculoskeletal system with the supporting surface and is the most important biomechanical link that ensures the human static-locomotor function [20]. A vaulted structure is characteristic for the human foot to provide adequate and balanced muscle tone of the distal parts of lower limbs in normal functioning [21]. The present study revealed differences in the foot support strategy of healthy children and IS patients. The analysis of absolute values of plantographic indices in patients indicated a decrease in the contact area of the feet and the supporting surface before and after surgery with an increase in regional plantar pressure and was characteristic for IS patients [22]. The feet of IS patients were not rigid with a significant change in the transverse and longitudinal arches and a change in loading indicating the retained spring function. The IS patients demonstrated adequate spring foot function, and shock loads affecting the lower extremities at the time of support at walking and running that were absorbed by the feet and did not reach the upper joints of lower limbs, pelvic and spinal articulation.

The asymmetry of the distribution of plantar pressure between the contralateral feet revealed in IS patients was consistent with the data reported by other authors [23]. Patients showed a preoperative correlation between the asymmetry of the functional activity of the arches of the contralateral feet and frontal malalignment of the trunk. Correlations between the frontal (coronary) balance and the distribution of plantar pressure in IS children were also reported by other researchers [24]. Understanding of the correlations between body segments is essential since impaired plantar pressure in idiopathic scoliosis is associated with the risk of progression of spinal deformity due to gait changes [25]. The surgical correction of the curve in our series allowed significant correction of the main arch of curvature and improvement of the frontal balance, a significant increase in body length and a significant upward shift of the center of the body mass. These factors led to a changed relationship in the kinematic links of the musculoskeletal system and a new supporting strategy of the feet at a short term. The increase in the asymmetry of plantographic characteristics at a short term could occur due to the transformation of the mechanisms in maintaining the spinal balance with decreased mobility of fused spine [26]. New patterns of motor activity developed due to the involvement of new muscle groups including those of lower limbs to ensure the stability of the vertical position of the body [27]. That additionally facilitated formation of a new supporting strategy for the foot that was evaluated by correlation analysis. Correlations of the support indices showed that the adequate spring function of the normal foot was provided by a weak functional relationship between all arches at a double–support weight-bearing and an increased relationship between the longitudinal arches at a single–support weight-bearing.

This could be explained by the fact that a decreased support area at standing on one lower limb makes an upright position difficult to maintain, and the locomotor system activates the balancing function of the foot with increased synchronization of the medial and median longitudinal arches [14]. The feet of IS patients fail to provide appropriate support function due to the reduced contact area with the horizontal surface. There is increased functional relationship between the longitudinal arches with a double-support weight-bearing before surgery as compared with normal feet. Correlation between all arches of the foot was stronger in IS patients with a decreased supporting area of the foot during the transition from a double-support to a single-support loading. The so-called dynamic inversion of the foot support strategy was observed after spinal surgery. This was manifested by the reverse mechanism as compared to normal foot: sufficiently strong correlations between all arches of the foot at a double–support load and a strong relationship between the longitudinal arches at a single support. A similar adaptive paradoxical foot support strategy was reported in children with spinal stenosis and compression of spinal cord roots secondary to spondylolisthesis [28]. Neurological disorders were not detected postoperatively in IS patients after surgical correction of spinal deformity with no compression-ischemic blocks of nerve impulses. There was no gross neuromuscular dysfunction of the lower limbs with characteristic rigidity of the arches [29] and impaired spring function [30].

The spinal cord developed into a new anatomical condition after the curve correction that could lead to the changes in the conduction of afferent and efferent neurons and affect the corticospinal mechanism of the foot support. Therefore, the central regulation of locomotor functions in IS children changes after spinal surgery and triggers the formation of adaptive mechanisms for the body maintaining an upright position. A decreased contact area of the feet and the supporting surface and an inverse support strategy of the feet characterized by a pathological increase in the functional relationship in the arches have been shown to be important adaptive reactions of the musculoskeletal system in the kinematic 'spine and feet' chain in IS children. The disturbed loading distribution in the feet leads to a change in proprioceptive impulses from the mechanic receptors of the feet and affects the afferent control and regulation of the locomotor function of the musculoskeletal system [31]. Although the abnormal foot support aggravated in the patients at a short term, it did not clinically affect the stereotype of the gait. The motor activity of inpatients corresponded to the timing and severity of the interventions until they were discharged from the hospital to receive outpatient treatment. Since IS is caused by dysfunction of sensorimotor integration [32] modified proprioceptive signals from the feet aggravated impaired sensory and motor processes and provoked the progression of scoliosis [33]. Understanding the mechanisms of impaired supporting function of the feet in IS children is substantial for identifying patterns of musculoskeletal dysfunctions. The knowledge should be used for the development of new technical systems to impact the spinal kinematics and improve the methodology of complex conservative treatment of IS children early of the curve formation.

CONCLUSION

1. Children with severe idiopathic scoliosis were shown to develop impaired biomechanics of the feet with decreased contact area between the feet and the supporting surface, and a pathological increase in the functional relationship of the arches.

2. Deviation of the trunk in the frontal plane in IS patients was shown to correlate preoperatively with the asymmetry of the functional activity of the arches of the contralateral feet that subsided at a short term of the curve correction.

3. Despite the absence of neurological complications impaired biomechanics of the feet appeared to aggravate at a short term following correction of spinal deformity with the progression in the decreasing contact area of the feet and the supporting surface, increasing asymmetry in the contralateral foot parameters and an inversion in the support strategy with altered loading.

4. The aggravating effect of a modified support strategy of the feet on the spinal malalignment is important for appropriate diagnosis of IS children and rehabilitation program aimed at correcting the plantar pressure.

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