УДК 617.58-053.2-07-06:616.718.4-018.46-002
DOI: 10.17816/PTORS6114-22

SPECIAL ASPECTS OF THE SUPPORT FUNCTION OF LOWER LIMBS IN CHILDREN WITH THE CONSEQUENCES OF UNILATERAL LESION OF THE PROXIMAL FEMUR WITH ACUTE HEMATOGENOUS OSTEOMYELITIS

© *I.E. Nikityuk[1], Yu.E. Garkavenko[1, 2], E.L. Kononova[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

Received: 20.11.2017 Accepted: 13.02.2018

Background. Acute hematogenous osteomyelitis in the lesion of the proximal femur causes hypofunction or destruction of the metaepiphyseal growth zone of the femur. Theoretically, this leads to the formation of orthopedic consequences, including shortening of the lower limb.

Aim. The study aimed to examine the plantographic characteristics of the feet in children with a lesion of the proximal femur and analyze the influence of the regularities of plantar pressure distribution in the asymmetry of the load on the lower limbs.

Material and methods. Total 15 pediatric patients aged 6–16 years with consequences of acute hematogenous osteomyelitis of the proximal femur and shortening of the affected lower limb by 1.0–6.0 cm were examined. In addition, 15 healthy children belonging to the same age were examined for comparison. Stabilometry and plantography methods were used, and the statistical study included correlation and regression analysis.

Results. When we conducted tests with a double-support load on the feet, in comparison to healthy children, pediatric patients exhibited a significant decrease in the value of the anterior index of the support *t* in both the affected and unaffected sides. The parameters of other support indices (namely, *m, s,* and *l*) of the contralateral feet in patients were within the normal range, indicating the functional consistency of the corresponding arches of the feet, providing static and dynamic limb support ability. However, the correlation and regression analysis showed that, in comparison with the norm, the foot support ability in pediatric patients is implemented due to the strengthening of the functional relationship between the inner and the medial longitudinal arches of the foot on the intact side and the inversion of the interaction of the longitudinal arches with the transverse arch on the side of the lesion.

Conclusion. In children with consequences of acute hematogenous osteomyelitis of the proximal femur, the parameters of the plantographic characteristics indicate a change in the activity and consistency of the muscles that form all the feet arches on both the affected and intact lower limbs.

Keywords: acute hematogenous osteomyelitis; limb load asymmetry; support surface of the foot; plantography.

ОСОБЕННОСТИ ОПОРНОЙ ФУНКЦИИ НИЖНИХ КОНЕЧНОСТЕЙ У ДЕТЕЙ С ПОСЛЕДСТВИЯМИ ОДНОСТОРОННЕГО ПОРАЖЕНИЯ ПРОКСИМАЛЬНОГО ОТДЕЛА БЕДРА ОСТРЫМ ГЕМАТОГЕННЫМ ОСТЕОМИЕЛИТОМ

© *И.Е. Никитюк[1], Ю.Е. Гаркавенко[1, 2], Е.Л. Кононова[1]*

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

Статья поступила в редакцию: 20.11.2017 Статья принята к печати: 13.02.2018

Актуальность. Острый гематогенный остеомиелит при поражении проксимального отдела бедра вызывает гипофункцию или деструкцию метаэпифизарной зоны роста бедренной кости, что, как правило, приводит к формированию ортопедических последствий, в том числе укорочению нижней конечности.

■ For citation: Nikityuk IE, Garkavenko YuE, Kononova EL. Special aspects of the support function of lower limbs in children with the consequences of unilateral lesion of the proximal femur with acute hematogenous osteomyelitis. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2018;6(1):14-22. doi: 10.17816/PTORS6114-22

Цель исследования. Изучить плантографические характеристики стоп у детей с поражением проксимального отдела бедра и провести анализ закономерностей распределения подошвенного давления при асимметрии нагрузки на нижние конечности.

Материал и методы. Проведено обследование 15 детей в возрасте от 6 до 16 лет с последствиями острого гематогенного остеомиелита проксимального отдела бедра и укорочением пораженной нижней конечности на величину от 1,0 до 6,0 см. Для сравнения обследованы 15 здоровых детей того же возраста. Использованы методы стабилометрии и плантографии, статистическое исследование включало корреляционно-регрессионный анализ.

Результаты. У больных детей, по сравнению со здоровыми, в тестах с двуопорной нагрузкой на стопы было выявлено значимое снижение величины переднего индекса опоры *t* как на пораженной, так и на непораженной стороне. Параметры других индексов опоры, а именно *m*, *s* и *l*, контралатеральных стоп пациентов находились в границах нормальных значений, что указывает на функциональную состоятельность соответствующих сводов стоп, обеспечивающих статическую и динамическую опороспособность конечностей. Однако корреляционно-регрессионный анализ показал, что по сравнению с нормой опороспособность стоп у больных детей реализуется за счет усиления функциональной взаимосвязи между внутренним и срединным продольными сводами стопы интактной стороны и инверсии взаимодействия продольных сводов с поперечным на стороне поражения.

Заключение. У детей с последствиями острого гематогенного остеомиелита проксимального отдела бедра параметры плантографических характеристик свидетельствуют об изменении активности и согласованности работы мышц, формирующих все своды стоп как пораженной, так и интактной нижней конечности.

Ключевые слова: острый гематогенный остеомиелит; асимметрия нагрузки на нижние конечности; опорная поверхность стопы; плантография.

Background

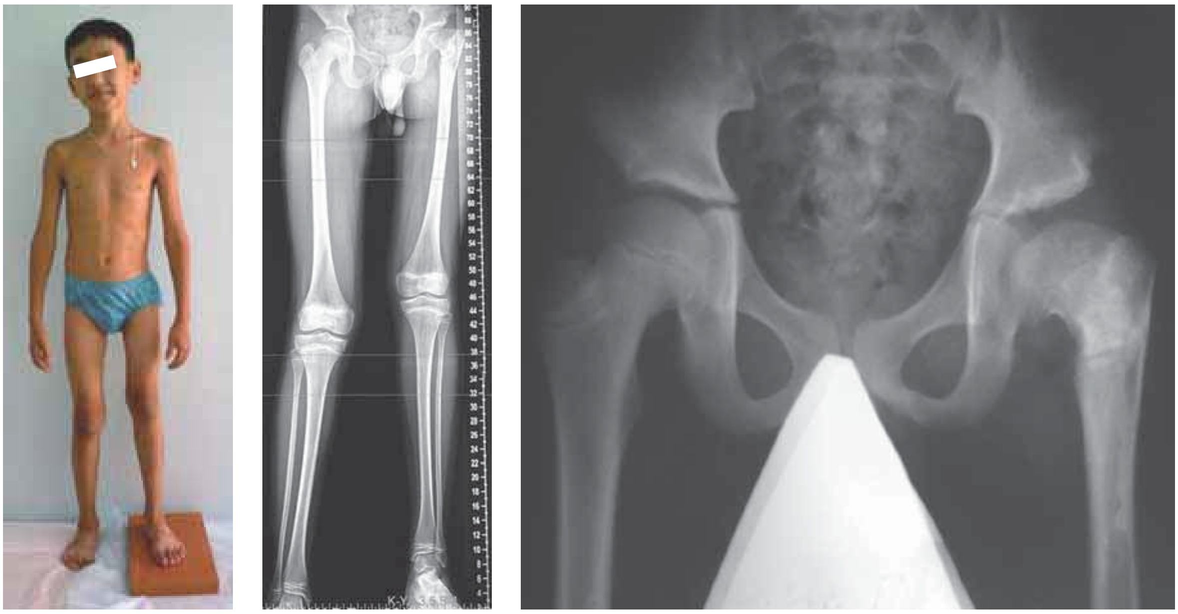
Acute hematogenous osteomyelitis in the proximal femur causes hypofunction or destruction of the meta-epiphyseal growth area of the femur, which may result in orthopedic consequences, including shortening of the lower limb [1]. Because body weight is unequally distributed between contralateral limbs, the load on the limbs is asymmetrical with lower limbs of different lengths [2, 3]. In this state, normal locomotion is affected because the required arbitrary control increases energy consumption [4]. In terms of functionality, the affected limb has a reduced adaptive capacity compared with a healthy one [5]. The body strives to provide the affected side with an optimal level of functioning, including compensating for the additional reserves. As a result, the intact lower limb functions under conditions that are less than optimal [6]. The limits of adaptive reserves of the intact lower limb have not been studied, but there are data on the unfavorable effect of prolonged exposure to increased load on joints and degradation of the hyaline cartilage [7]. To address these challenges, a quantitative assessment of load asymmetry on the lower limbs is very important for the process of orthopedic rehabilitation [8]. When assessing abnormalities in the musculoskeletal system, determining the morphofunctional characteristics of the feet [9] provides information about the loading plantar characteristics in patients with pathology of the lower limbs [10].

This study analyzed the plantographic characteristics of the feet in children with proximal femur lesion, including how load asymmetry alters plantar pressure distribution on the lower limbs.

Materials and methods

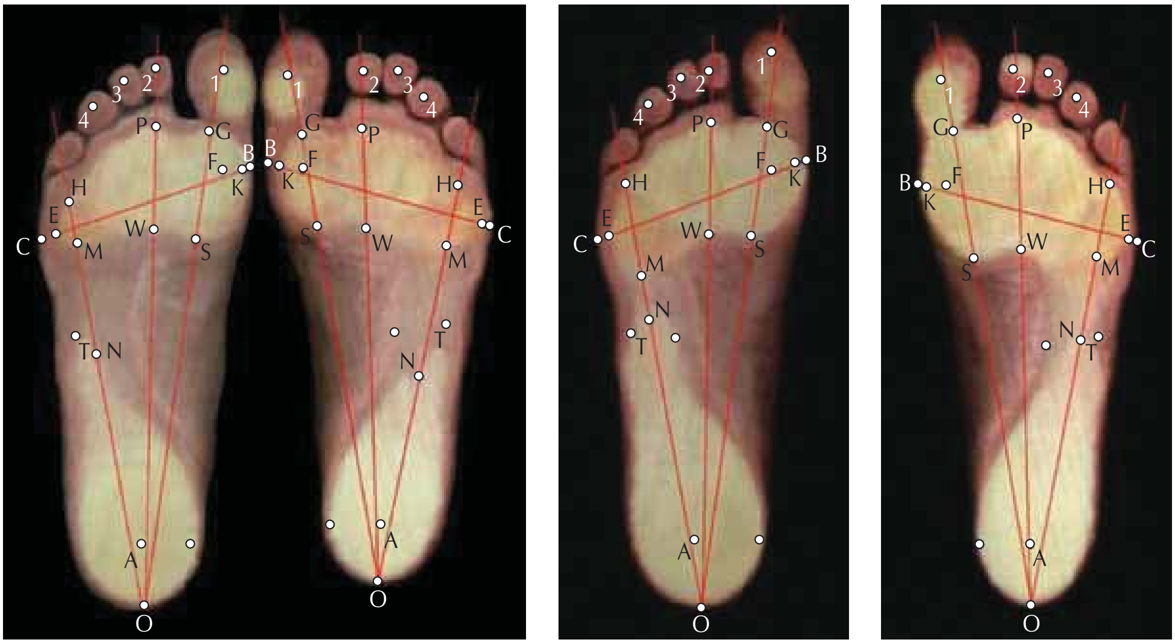
The study included 15 children aged 6 to 16 years (mean age 11.5 ± 0.72) with consequences of acute hematogenous osteomyelitis (CAHO) of the proximal femur, including 1.0 to 6.0 cm shortening of the affected lower limb (Figure 1). The average shortening of the affected lower limb was 3.8 ± 0.53 cm. There was hypoplasia of the foot on the side of the lesion, and its shortening compared with the contralateral foot averaged 2.7 cm ± 0.58% (Figure 2, *a*). Parents of all patients voluntarily signed informed consent to participate in the study.

Stabilometric assessment was performed for all patients using the MBN Biomechanics optical system (MBN, LLC, Moscow, Russia). The assessments were performed according to standard procedure, using optical detectors to show the displacement parameters of the projection of the center of mass (PCM) of the body.



a *b* *c*

Fig. 1. Patient D., 10 years old, with consequences of acute hematogenous osteomyelitis of the proximal part of the left femur: *a* — shortening of the left lower limb by 3 cm; *b* — panoramic radiograph of the lower limbs; *c* — radiograph of the hip joints



a *b* *c*

Fig. 2. Patient D, 14 years old, plantograms of the feet with consequences of acute hematogenous osteomyelitis of the proximal part of the right femur: *a* — double-bearing load; *b* — single-bearing load of the left foot; *c* — single-bearing load of the right foot

The support function of the feet was studied using the Podoskan diagnostic system (MBN, LLC, Russia). This determined plantographic characteristics and evaluated the morphofunctional parameters of the feet [11]. For monitoring, the baseline values of plantographic characteristics were determined for 15 healthy children of the same age as study participants. To assess the dynamic functioning of the feet, biomechanical tests with different weight loads per foot were used, namely, a load of half the body weight per foot (double-bearing plantography) and a load of the whole body weight per foot (single-bearing plantography).

The line of the transverse arch of the foot and the force rays were displayed as identification points on plantograms (Fig. 2), showing that the force load was directed to the first, second, and fifth toes (Dukendzhiev line) when walking.

The following planographic indices were calculated:

$t = KE/BC$ — front index of support, reflecting the state of the transverse arch of the foot;

$m = GS/GO$ — medial index of support, reflecting the state of the internal longitudinal arch of the foot;

$s = PW/PO$ — median index of support, reflecting the state of the median longitudinal arches of the foot;

$l = MN/HO$ — lateral index of support, reflecting the state of the external longitudinal arch of the foot.

A descriptive statistical analysis of the data was performed using Microsoft Excel. To investigate the relationship between the two signs, a correlation analysis was applied using the Spearman nonparametric coefficient rs. The correlation was considered strong at $r_s \geq 0.7$; average at $0.3 < r_s < 0.7$; and weak at $r_s < 0.3$ [12]. To search for a function describing the relationship between the signs, regression analysis was applied using Statgraphics Centurion 16.2 software.

Results and discussion

Stabilometric data analysis showed that in patients with CAHO with a unilateral lesion, the most common and pronounced stability disorders were in the frontal plane. The clear pattern of displacement of the real PCM from absolute by 13.8 ± 2.71 cm towards the healthy limb was statistically significantly. This type of asymmetric distribution of body weight on the lower limbs may indicate a compensatory redistribution of the static load when standing in favor of a healthy lower limb, because of a decrease in the support function of the affected lower limb.

In tests with a double-bearing load on the feet, patients with CAHO, in comparison with healthy children, had a significant decrease in the value of the anterior index of the support *t*, both on the affected and on the intact sides (Table 1).

In the feet of the affected lower limbs, the decrease in the index *t* was significantly more pronounced than in the feet of the intact lower limbs. On the one hand, this demonstrated the rigidity of the transverse arch of the feet of both the affected and intact lower limbs. However, in the load tests with single-bearing plantography, this assumption was not confirmed, because the indices of the anterior support were restored to normal values. It should be noted that these changes in the index *t* were observed more often on the affected side. The preserved spring function of the transverse arch of the foot of the affected lower limb was confirmed by data indicating its high mobility with a double increase in the axial load (Table 2).

The parameters of *m*, *s*, and *l* support indices were within normal limits for contralateral feet of patients with CAHO, which indicated the functional consistency of the corresponding arches of the feet in the ability to provide static and dynamic limb support.

Table 1

Comparative evaluation of the plantographic indices of the feet of healthy children and children with CAHO of the proximal femur

Category of children (feet)	Plantographic indices ($\times 10^{-2}$)							
	Double-bearing plantography ($M \pm m$)				Single-bearing plantography ($M \pm m$)			
	t	*m*	*s*	*l*	*t*	*m*	*s*	*l*
Healthy ($n = 30$)	93.6 ± 0.5	21.8 ± 0.32	24.0 ± 0.38	13.3 ± 2.45	96.2 ± 0.34*	25.2 ± 0.3*	26.3 ± 0.39*	1.7 ± 1.19*
With CAHO, intact side ($n = 15$)	90.3 ± 0.93**	21.1 ± 0.89	22.4 ± 0.91	18.1 ± 4.77	93.6 ± 1.08*	23.3 ± 0.72	24.4 ± 0.76	8.4 ± 2.75
With CAHO, affected side ($n = 15$)	87.6 ± 0.66**	22.1 ± 0.73	23.2 ± 0.99	22.1 ± 3.81	95.9 ± 3.24*	24.5 ± 1.18	26.3 ± 1.28*	8.4 ± 2.84*

Note. * Significantly changing indices of single-bearing plantography in comparison with similar parameters of double-bearing plantography, with a confidence of at least $p < 0.05$; ** indicators that differ from similar in the norm with a confidence not less than $p < 0.05$; CAHO — consequences of acute hematogenous osteomyelitis.

Table 2

Changes in the plantographic indices of the feet. Δ in healthy children and children with CAHO in the transition from double-bearing to single-bearing plantography

Group of children (feet)	Plantographic indices ($\times 10^{-2}$) ($M \pm m$)			
	Δt	Δm	Δs	Δl
Healthy ($n = 30$)	2.6 ± 0.41	3.5 ± 0.48	3.5 ± 0.48	–11.5 ± 1.58
With CAHO, intact side ($n = 15$)	3.3 ± 1.14	2.3 ± 1.03	2.8 ± 0.72	–9.8 ± 4.46
With CAHO, affected side ($n = 15$)	8.2 ± 2.4*	2.4 ± 1.23	3.1 ± 1.16	–13.7 ± 5.52

Note. * Indicators that differ from similar indicators in the norm with a confidence of at least $p < 0.05$; CAHO — consequences of acute hematogenous osteomyelitis.

Table 3

Correlation-regression analysis of interdependence between indices of support of healthy children and children with consequences of acute hematogenous osteomyelitis

Group of children (feet)	Correlation coefficient r_s					
	Double-bearing plantography ($M \pm m$)			Single-bearing plantography ($M \pm m$)		
	$m \sim t$	$s \sim t$	$m \sim s$	$m \sim t$	$s \sim t$	$m \sim s$
Healthy ($n = 30$)	0.10	0.02	0.29	0.22	0.33	0.61
With CAHO, intact side ($n = 15$)	0.23	0.25	0.68	–0.03	–0.02	0.90
With CAHO, affected side ($n = 15$)	0.36	0.22	0.73	–0.68	–0.42	0.77

Note. CAHO — consequences of acute hematogenous osteomyelitis.

The correlation-regression analysis of plantographic indices showed the linear interdependence of the medial and median indices of the support *m* and *s*, as well as their relationship to the anterior index of the support *t* in healthy and affected children (Table 3).

For graphical expression of the relationship between the support indices, regression lines were constructed (Fig. 3).

With the help of correlation analysis, it was revealed that in the healthy children with a double-bearing load on the feet, the connection between the various indexes of support was weak or absent. Consequently, the transverse and longitudinal arches in healthy children were loaded independently of each other in a static position with support on both feet. This was consistent with a multidirectional change in the linear dimensions of the feet, when the feet spread along both the frontal and sagittal axes with the weight load of the human body [13]. Thus, with the natural support of both limbs, the load distribution between the arches of the feet was arbitrary, which was adequate for the consistent spring function of the transverse and longitudinal arches.

Tests in healthy children to determine the dynamic support ability when body weight is transferred to one foot show minor unidirectional changes in the relationship between the plantographic indices. The relationship between the longitudinal arches becomes more prominent, reaching a moderate value (Figure 3, *b*), which may be caused by an increase in energy consumption. This maintains balance when there is a reduction in total area of the support when standing on one lower limb. At the same time, the connection between the transverse and longitudinal arches of the foot remains weak, despite a slight increase (Figure 3, *a*).

In the patients with CAHO, a correlation between the indices of support was found with a double-bearing load, which was analogous to a single-bearing load in healthy children. In this case, the ratio of the indices of the contralateral feet was quite symmetrical, because of the preservation of the adaptive processes in the locomotor apparatus,

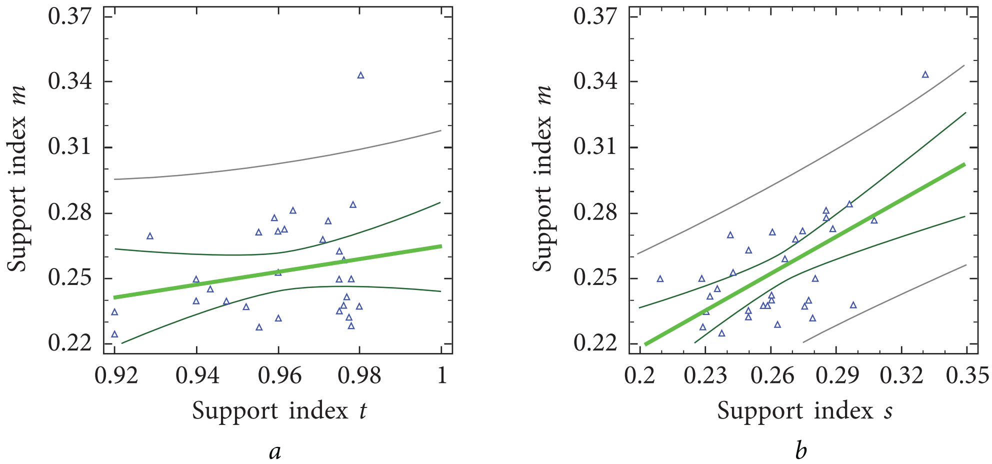


Fig. 3. The regression line (*heavy line*) and confidence intervals (*fine lines*) for the dependence of the medial index of the support *m*: *a* — front support index *t*; *b* — median support index of feet *s* under single-bearing load in healthy children

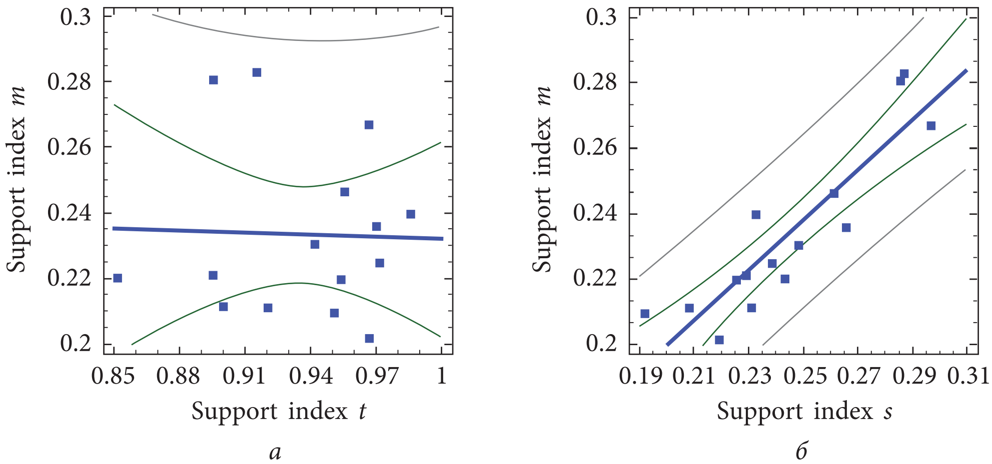


Fig. 4. The regression line (*heavy line*) and confidence intervals (*fine lines*) for the dependence of the medial index of the support *m*: *a* — front support index *t*; *b* — median support index of feet *s* of the intact limb with single-bearing load in children with CAHO

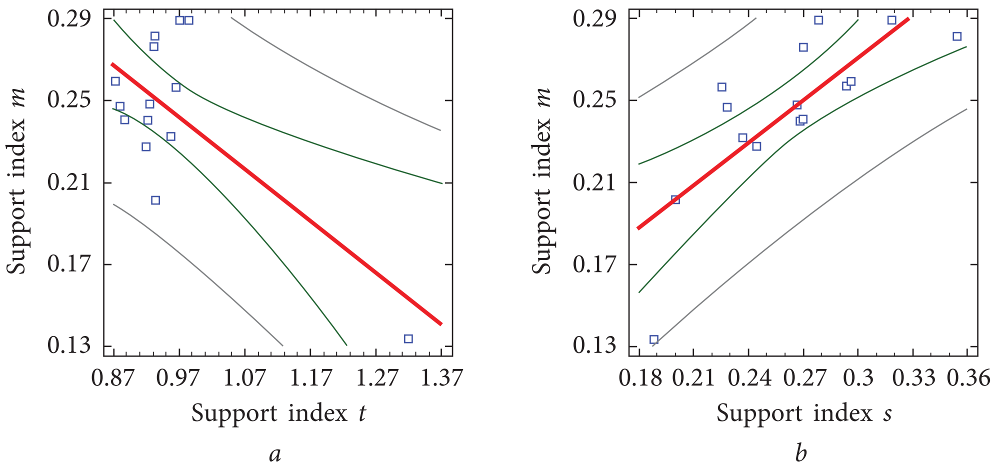


Fig. 5. The regression line (*heavy line*) and confidence intervals (*fine lines*) for the dependence of the medial index of the support *m*: *a* — front support index *t*; *b* — median support index of feet *s* of the affected limb with a single-bearing load in children with CAHO

despite some of their tension. The need to maintain the relative symmetry of the functions of healthy and affected limbs with small loads is beneficial to the body in terms of energy and biomechanics. At the same time, the intact limb has a greater functional reserve than the affected one, which tends to reduce asymmetry by approximating the pattern of its movements to the kinematics of the limb on the affected side [14]. Functional copying begins, in which an intact limb copies the function of the affected one to reduce the functional asymmetry.

In a single-bearing load in the feet of the intact side, a strongly pronounced correlation was observed between the medial *m* and median *s* indices of support (Fig. 4, *b*). There was a total absence of linear interdependence of these indices on the anterior index of the support *t* (Fig. 4, *a*).

In the feet of the affected lower limbs, an inverse correlation was revealed between the medial and median indices of the support *m* and *s* from the front index of the support *t* (Figure 5, *a*), with the normal relationship between the longitudinal arches (Fig. 5, *b*). Such pronounced differences between the feet of the affected and the healthy limbs may be explained by a decrease in the functional capacity of the affected limb. The axial load increases with alternating support on each of the contralateral limbs, which is analogous to walking. This initiates a normal compensation mechanism that allows partial unloading of the affected limb by increasing the load on the intact one [15]. The adequate response of the musculoskeletal system to the pathological process is that the healthy limb performs the function of support and the affected limb performs a transfer function [16].

In the process of evolution, the complex locomotor system has reached an optimal structural organization that allows long and reliable functioning under physiological conditions. One of the most important factors affecting the functioning of bones is the load on the skeleton. The limb bones of the body are the most vulnerable to constantly changing static and dynamic loads. The foot is one of the main structural segments of the human musculoskeletal system, providing its static and locomotor function. It is an integral morphofunctional object on which human motor function depends [17]. One of the evolutionarily formed adaptive reactions to pathological process in the lower limb is its unloading reflex, partially increasing the load on the intact limb.

In children with a shortening of the lower extremity after hematogenous osteomyelitis, this study showed the modified adaptability of the arches of the feet to the perception of the load. The anatomical imbalance of the limbs is complicated by changes in the corticospinal mechanism of the act of foot support, which is affected by pathological sensory input from the proximal part of the affected thigh. In such conditions, the altered central regulation of locomotor functions in children with CAHO triggers additional compensatory mechanisms to maintain body balance. It is very likely that these compensatory mechanisms are implemented by selective changes in the activity and synchronization of the muscles of the lower legs, which leads to a change in the strategy of the arch apparatus of the feet [18]. This compensation emerges as a close functional relationship between the inner and median longitudinal arches of the foot of the intact lower limb and the inversion of the interaction of similar foot indices of the affected limb. This strategy ensures the maintenance of the vertical posture and the possibility of movement under adverse functional conditions.

At the same time, it must be considered that compensatory mechanisms are not designed for long-term functioning. In the persistence or progression of triggers such as disorders in the proximal femur and hip joint of the affected lower limb, decompensation is possible over time. This leads to the progression of the pathological process on the side of the lesion and the involvement of the contralateral limb.

Conclusions

In children with CAHO, the parameters of the planographic characteristics indicate a change in the activity and consistency of the muscles that form the arches of the feet of both the affected and intact lower limb. Studies of the support function of the feet in children with CAHO indicate deviations in motor functioning of their anatomical structures. Compared with healthy children, the foot support ability in patients with CAHO is different. It is implemented by enhancing the functional interrelation between the inner and median longitudinal arches of the foot of the intact side and inversion of the interaction of the longitudinal arches with the transverse one on the side of the lesion. Comprehensive diagnosis and medical rehabilitation of children with CAHO should include the support function of the feet. When the support function of the feet is damaged or existing damage worsens, the necessary corrective orthopedic treatment must be implemented.

Funding and conflict of interest

The work was performed on the basis of and with the support of the Turner Scientific and Research Institute for Children's Orthopedics of the Ministry of Health of Russia.

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

References

1. Гаркавенко Ю.Е. Поражение тазобедренных суставов при последствиях гематогенного остеомиелита у детей // Новые технологии в травматологии и ортопедии детского возраста: сборник научных статей, посвященный 125-летию Научно-исследовательского детского ортопедического института имени Г.И. Турнера / Под ред. А.Г. Баиндурашвили. – СПб.: Эко-Вектор, 2017. – С. 96–100. [Garkavenko YE. Lesion of hip joints with consequences of hematogenous osteomyelitis in children. In: Baindurashvili AG, editor. *New technologies in traumatology and orthopedics of childhood: a collection of scientific articles dedicated to the 125th anniversary of the Research Children's Orthopedic Institute named after GI. Turner*. Saint Petersburg: Eko-Vektor; 2017. P. 96-100. (In Russ.)]
2. Bakirhan S, Angin S, Karatosun V, et al. Physical performance parameters during standing up in patients with unilateral and bilateral total knee arthroplasty. *Acta Orthop Traumatol Turc*. 2012;46(5):367-372. doi: 10.3944/AOTT.2012.2684.
3. Adegoke BO, Olaniyi O, Akosile CO. Weight bearing asymmetry and functional ambulation performance in stroke survivors. *Glob J Health Sci*. 2012;4(2):87-94. doi: 10.5539/gjhs.v4n2p87.
4. Paulus DC, Settlage DM. Bilateral symmetry of ground reaction force with a motor-controlled resistance exercise system using a mechanical advantage barbell for spaceflight. *Biomed Sci Instrum*. 2012;48:340-344.
5. Щуров В.А., Новиков К.И., Мурадисинов С.О. Влияние разновысокости нижних конечностей на биомеханические параметры ходьбы // Российский журнал биомеханики. – 2011. – Т. 15. – № 4. – С. 102–107. [Shchurov VA, Novikov KI, Muradisinov SO. Effect of uneven legs on biomechanical parameters of walking. *Rossiyskiy zhurnal biomekhaniki*. 2011;15(4):102-107. (In Russ.)]
6. Скворцов Д.В. Диагностика двигательной патологии инструментальными методами: анализ походки, стабилометрия. – М., 2007. [Skvortsov DV. *Diagnostics of motor pathology by instrumental methods: gait analysis, stabilometry*. Moscow; 2007. (In Russ.)]
7. Hurkmans HL, Bussmann JB, Benda E, et al. Techniques for measuring weight bearing during standing and walking. *Clin Biomech (Bristol, Avon)*. 2003;18(7):576-589. doi: 10.1016/S0268-0033(03)00116-5.
8. Kumar SN, Omar B, Joseph LH, et al. Evaluation of limb load asymmetry using two new mathematical models. *Glob J Health Sci*. 2014;7(2):1-7. doi: 10.5539/gjhs.v7n2p1.
9. Cousins SD, Morrison SC, Drechsler WI. The reliability of plantar pressure assessment during barefoot level walking in children aged 7-11 years. *J Foot Ankle Res*. 2012;5(1):8. doi: 10.1186/1757-1146-5-8.
10. Xu C, Wen XX, Huang LY, et al. Normal foot loading parameters and repeatability of the Footscan(R) platform system. *J Foot Ankle Res*. 2017;10:30. doi: 10.1186/s13047-017-0209-2.
11. Наумочкина Н.А., Никитюк И.Е. Вовлечение спинного мозга в патологический процесс при родовых повреждениях плечевого сплетения (биомеханическое исследование) // Врач-аспирант. – 2013. – Т. 56. – № 1.3. – С. 388–396. [Naumochkina NA, Nikityuk IE. Involvement of spinal cord into pathological process in childbirth brachial plexus injury (biomechanical study). *Vrach-aspirant*. 2013;56(1.3):388-396. (In Russ.)]
12. Зайцев В.М., Лифляндский В.Г., Маринкин В.И. Прикладная медицинская статистика. – СПб.: Фолиант, 2006. [Zaytsev VM, Liflyandskiy VG, Marinkin VI. *Applied medical statistics*. Saint Petersburg: Foliant; 2003. (In Russ.)]
13. Перепелкин А.И., Калужский С.И., Мандриков В.Б., и др. Исследование упругих свойств стопы человека // Российский журнал биомеханики. – 2014. – Т. 18. – № 3. – С. 381–388. [Perepelkin AI, Kaluzhskiy SI, Mandrikov VB, et al. Research of resilient properties of the human foot. *Rossiyskiy zhurnal biomekhaniki*. 2014;18(3):381-388. (In Russ.)]
14. Skvortsov DV, Larina VN. Gait and posture in patients with low back pain compare with clinical form. *Gait Posture*. 1995;3(2):85. doi: 10.1016/0966-6362(95)93463-m.
15. Дашевский И.Н., Никитин С.Е. Биомеханика разгрузки нижних конечностей при ортезировании // Российский журнал биомеханики. – 2016. – Т. 20. – № 2. – С. 134–149. [Dashevskiy IN, Nikitin SE. Biomechanics of unloading of the lower extremities at prosthetics. *Rossiyskiy zhurnal biomekhaniki*. 2016;20(2):134-149. (In Russ.)]
16. Кравцова Г.В., Хоменко Б.Ф. Особенности ходьбы по данным подографии у больных с последствиями переломов бедренной кости и костей голени. – Рига: Медицинская биомеханика, 1975. [Kravtsova GV, Khomenko BF. *Features of walking according to the data of subgraphy in patients with consequences of fractures of the femur and bones of the lower leg*. Riga: Meditsinskaya biomekhanika; 1975. [(In Russ.)]
17. Ефимов А.П. Информативность биомеханических параметров походки для оценки патологии нижних конечностей // Российский журнал биомеханики. – 2012. – Т. 16. – № 1. – С. 80–88. [Efimov AP.

Informativity of biomechanical parameters of gait for the estimation of the lower extremities pathology. *Rossiyskiy zhurnal biomekhaniki*. 2012:16(1):80-88. (In Russ.)]

18. Аничков Н.М., Кудрявцев В.А., Минченко Н.Л. Клинико-морфологические параллели при распластанности переднего отдела стопы // Травматология и ортопедия России. – 1995. – № 1. – С. 15–18. [Anichkov NM, Kudryavtsev VA, Minchenko NL. Clinical and morphological parallels in the spreading of the forefoot. *Travmatologiia i ortopediia Rossii*. 1995;(1):15-18. (In Russ.)]

Information about the authors

Igor E. Nikityuk — MD, PhD, Leading Research Associate of the Laboratory of Physiological and Biomechanical Research. The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia. E-mail: femtotech@ mail.ru.

Yuriy E. Garkavenko — MD, PhD, Professor of the Chair of Pediatric Traumatology and Orthopedics. North-Western State Medical University n.a. I.I. Mechnikov; Leading Research Associate of the Department of Bone Pathology of The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia. E-mail: yurijgarkavenko@mail.ru

Elizaveta L. Kononova — MD, PhD, Head of the Laboratory of Physiological and Biomechanical Research. The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia. E-mail: Yelisaveta@ yandex.ru.

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

Юрий Евгеньевич Гаркавенко — д-р мед. наук, профессор кафедры детской травматологии и ортопедии ФГБОУ ВО «СЗГМУ им. И.И. Мечникова» Минздрава России, ведущий научный сотрудник отделения костной патологии ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России, Санкт-Петербург. E-mail: yurijgarkavenko@mail.ru.

Елизавета Леонидовна Кононова — канд. мед. наук, руководитель лаборатории физиологических и биомеханических исследований ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России, Санкт-Петербург. E-mail: Yelisaveta@yandex.ru.