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The Interzonal Distribution of the Load on the Plantar Surface of the Foot During Walking in the Patients with Cerebral Palsy as an Objective Criterion of Functional Impairment Severity

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Abstract

Background. The main direction of rehabilitation of children with cerebral palsy is the preservation and enhancement of the existing level of support and locomotion, as well as compensation of its impairment through various methods of rehabilitation. For an adequate prescription and reliable assessment of these measures effectiveness, it is necessary to use objective indicators of functional impairment characteristic of cerebral palsy. ***The purpose of this study*** was to substantiate objective biomechanical indicators of functional impairment in children with cerebral palsy based on the analysis of the interzonal distribution of the load on the foot during walking, taking into account the level of global motor functions impairment. ***Materials and Methods***. 47 children with cerebral palsy at the GMFCS levels of impairment 1 to 3 were examined. The control group consisted of 14 children without anatomical and functional signs of support and locomotion system impairment. Biomechanical examination was performed on the complex «DiaSled-M-Scan» with matrix plantar pressure meters in the form of insoles. The statistical analysis of the data was carried out by nonparametric methods using the SPSS for Widows software. ***Results***. The analysis of the anatomical and functional impairment of 94 feet of the children with cerebral palsy and 28 feet of the control group revealed differences in the interzonal distribution of the load under the feet in six variables (p from <0.001 to 0.003). The most typical were: an increase in the toe-to-heel load ratio (on average by 80%), an increase in the load on the arch (by 49%), and a decrease in the medio-lateral load ratio on the toe (by 37%). For GMFCS 1 patients, a significant indicator of impairment was an increase in the partial load on the arch, for GMFCS 2 and 3 patients — a decrease in the load on the heel and an increase it under the toe. This leads to an increase in the toe-to-heel load ratio. ***Conclusion***. It is advisable to use the revealed indicators of roll-over-the-foot impairment in the functional diagnosis of the condition and in assessing the effectiveness of rehabilitation of children with cerebral palsy.

Keywords: cerebral palsy, medical rehabilitation, walking, biomechanics.

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Cerebral palsy (CP) is the most common neurological orthopedic disease in the practice of an orthopedist. This situation is determined by both the high prevalence of the disease (2.6 to 3.5 cases per 1000 live births) [1, 2], and the high rate of musculoskeletal system complications [3, 4], primarily the feet [5, 6, 7].

The overwhelming majority of the children with CP have spastic forms of paralysis [4, 8, 9], which are characterized by an early manifestation of the above-mentioned orthopedic complications and pathological changes in the walking stereotype [10, 11, 12].

The main direction of rehabilitation in CP is, at least, the preservation, and preferably, an increase in the existing level of functional capabilities of the child. For almost two hundred years of the CP study, a significant arsenal methods of treatment and rehabilitation was developed: medication, including botulinum therapy, surgery, technical means [1, 13, 14, 15].

For the adequate prescription and reliable assessment of the treatment effectiveness, it is necessary to use justified indicators of functional impairment characteristic of CP. The objectivity of these indicators can be increased by using instrumental diagnostic methods, in particular, biomechanical computer methods for walking study. One of the qualitative criteria of such methods is the rationality of the load distribution under the foot [10, 11].

We believe that this diagnostic aspect in relation to children with CP is insufficiently covered in the literature. In this regard, the search for valid criteria for assessing the distribution of the load on the plantar surface of the foot in walking children with CP expressed various levels of gross motor functions impairment is an urgent task.

The purpose of this study was to substantiate the objective biomechanical indicators of functional disorders in the children with CP based on the analysis of the interzonal distribution of the load on the foot during walking, taking into account the level of gross motor functions impairment.

Materials and Methods

This was one-stage experimental analytical controlled quantitative study "case-control".

The children with CP from 5 to 16 years old were included in this study on the basis of their clinical examination. All of them have had already formed their walking stereotype. The following groups of children for the subsequent biomechanical examination were created.

Group 1 (control) included 14 children without anatomical and functional signs of musculoskeletal system impairment. The children were examined during preventive examinations in general educational institutions. The exclusion criteria for this group were the presence of clinical signs of foot deformity or musculoskeletal function impairment.

Group 2 included 47 patients with spastic forms of CP, divided into 3 subgroups according to the level of gross motor functions impairment by the Gross Motor Function Classification System (GMFCS) [12], reflected the severity of the disease:

– subgroup 2.1 (GMFCS 1) – with the 1st level of impairment (9 people);

– subgroup 2.2 (GMFCS 2) – with the 2nd level (19 people);

– subgroup 2.3 (GMFCS 3) – with the 3rd level (19 people).

The patients underwent rehabilitation at the Federal State Budgetary Institution "Federal Scientific Center for the Rehabilitation of Disabled named after G.A. Albrecht" of the Ministry of Labor and Social Protection of the Russian Federation.

The 2nd group of the patients was formed by the following inclusion criteria: the presence of a confirmed diagnosis: "CP with spastic diplegia" or "CP with spastic tetraparesis".

The exclusion criteria were as follows: the inability to walk without orthoses or devices, even with the use of additional support (crutches, canes, walkers) or with support from other persons; severe cognitive impairment or emotional state of the subject, which does not allow contact with the patient for biomechanical examination; history of botulinum toxin treatment less than 6 months before the examination; a history of surgical treatment less than 1 year before the examination.

The biomechanical examination was performed with registration and analysis of the load under the feet (baroplanthography) distribution during walking with the hardware-software complex "DiaSled-M-Scan", LTD "DiaService", Saint Petersburg, Russia, using matrix plantar pressure meters in the form of insoles. During the examination, the meters were put into special shoes, the design of which had a minimal effect on the foot functionality (flexible sole, soft top, heel 1.0 to 1.5 cm).

The database formed for statistical analysis contained 122 observations: 28 feet of children in the control group (group 1) and 94 feet of the CP patients (group 2).

Statistical analysis. The statistical analysis of the data was performed using the SPSS for Windows program.

The descriptive statistics were used, the Kolmogorov-Smirnov test amended by the Lilliefors or Shapiro-Wilk corrections with a critical level of significance p = 0.05, the non-parametric Kruskal-Wallis and Mann-Whitney tests with a critical level of significance p* = 0.0125, calculated in accordance with the number of groups of variables comparisons.

Results

The conditional division of the foot plantar surface into zones corresponding to the zones of the matrix measuring sensor (insole) in the hardware-software complex "DiaSled-M-Scan" was used to carry out biomechanical examinations (Fig. 1).

The load on the foot area was determined as the sum of the pressure on all sensors of the meter in this area, the partial load on the foot area – as a share of the load on the entire foot. The toe-to-heel load ratio was calculated as the quotient of dividing the heel load by the toe load. The medio-lateral load ratio in the foot area was defined as the ratio of the load on the medial half of the area to the load on the lateral half. The statistical analysis of observations was carried out using 11 selected baroplanthographic dependent variables, which characterize the interzonal distribution of the load under the foot (Table 1).

The results of the data analysis using the Kolmogorov-Smirnov test with the correction of Lilliefors and Shapiro-Wilk showed that the distribution for some dependent variables (in

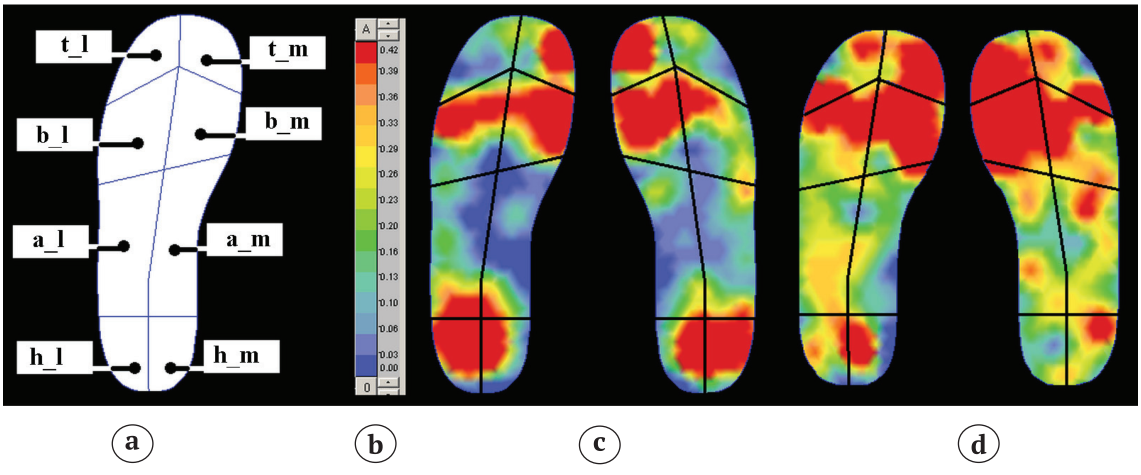

Figure 1. Diagram of dividing the matrix measuring sensor into zones (a); pressure scale (b); baroplantograms of a healthy child from the control group (c) and a child with cerebral palsy (d).

particular, Km/l_b, Km/l and f_h) did not correspond to the law of normal distribution. This was also evidenced by the shape of the histograms and quantile diagrams for above mentioned variables. This was observed both for the control group and, moreover, for the entire set of children with CP. An even larger number of variables did not correspond to the law of normal distribution during their separate evaluation in subgroups with different levels of gross motor functions impairment: GMFCS 1, GMFCS 2, GMFCS 3. In this regard, the nonparametric methods were used for further statistical analysis of the variables.

To identify the characteristic differences in the zonal distribution of the load under the feet of children with CP compared with the control group, the nonparametric Mann-Whitney test was used, the results are presented in Table 2.

Table 1

The studying dependent variables

No	Designation	Denomination
1	f_h	Partial load on the heel area
2	f_ a	Partial load on the arch area
3	f_ b	Partial load on the area metatarsal phalangeal joints (MT-PH j)
4	f_l	Partial load on the toe area
5	Kt/h	Toe-to-heel load ratio
6	Kff/re	The ratio of loads on the forefoot (the zone of the bundles metatarsal phalangeal joints area together with the toe) and the rear (heel together with the arch space)
7	Km/l_h	Medio-lateral heel load ratio
8	Km/l_a	Medio-lateral arch load ratio
9	Km/l_b	Medio-lateral bundle load ratio
10	Km/l_t	Medio-lateral toe load ratio
11	Km/l	Medio-lateral foot load ratio

Table 2

The results of the analysis of variables using the Mann-Whitney test: the statistical significance of differences between the control group and the group of children with cerebral palsy

No	Variables	Mann-Whitney test values	Difference significance level (Asymp. Sig. (2-tailed))
1	f_h	481	0.000
2	f_ a	348	0.000
3	f_b	819	0.003
4	f_t	834	0.003
5	Kt/h	544	0.000
6	Kff/re	1185	0.427
7	Km/l_h	1276	0.808
8	Km/l_a	1138	0.278
9	Km/l_b	1048	0.103
10	Km/l_t	779	0.001
11	Km/l	1200	0.480

Table 2 shows that the walking of children with CP differs from the walking of children in the control group in six variables which are the indicators of the interzonal distribution of the load under the foot: f_h, f_a, f_b, f_t, Kt/h, Km/l_t. To clarify these differences, Table 3 indicates the values of the median and percentile of these variables in the compared groups.

In addition, the difference between the median values ΔMei of these variables for the group of patients with CP was calculated as compared with the control group (Table 4):

$\Delta Me_i = 100\% (Me_{i\_п} - Me_{i\_к})/(Me_{i\_к})$,

where $Me_{i\_п}$ is the median of the i-th variable of the CP patients, $Me_{i\_к}$ – in the control group.

A visual representation of the differences between the surveyed groups is provided by a visual comparison of the medians and quartiles of the variables on quantile diagrams (Fig. 2).

The plane valgus deformity of the foot was observed in the overwhelming number of patients with CP. Although varus or equinovarus deformities of the feet were also observed in 9% of the CP patients (8 feet). The statistical calculation was carried out after the removal

Table 3

The main characteristics of the variables for which a statistically significant difference was found between the control group and the group of children with cerebral palsy

No	Variables	Groups	Percentiles			Median	Percentiles		
			5	10	25		75	90	95
1	f_h	Control	17.67	19.19	22.54	28.02	31.80	34.58	35.63
		Cerebral palsy	5.67	7.64	12.69	17.92	25.26	28.76	31.98
2	f_ a	Control	11.08	12.90	16.68	19.71	22.85	26.81	30.70
		Cerebral palsy	17.84	20.41	24.87	29.34	34.44	41.13	44.04
3	f_b	Control	27.53	30.65	34.93	38.47	43.10	47.59	48.08
		Cerebral palsy	20.86	23.29	26.13	34.15	38.93	42.91	47.78
4	f_t	Control	4.68	5.26	9.81	14.11	18.08	23.34	24.17
		Cerebral palsy	6.86	10.33	13.04	18.23	23.28	26.72	28.51
5	Kt/h	Control	0.16	0.19	0.33	0.55	0.67	0.94	1.26
		Cerebral palsy	0.27	0.39	0.62	0.99	1.73	3.20	4.70
6	Km/l_t	Control	0.99	1.47	1.96	2.92	3.93	4.24	5.36
		Cerebral palsy	0.78	0.99	1.31	1.83	2.66	4.55	5.67

Table 4

Difference in median values of variables in the group of children with cerebral palsy compared with the control group

No	Variables with statistically significant differences		ΔMe, %
	Designation	Denomination	
1	f_h	Partial load on the heel area	– 36
2	f_ a	Partial load on the arch area	49
3	f_b	Partial load on the bundle area	11
4	f_t	Partial load on the toe area	29
5	K t/h	Toe-to-heel load ratio	80
6	Km/l_t	The medio-lateral load ratio in the toe area	37

of 8 these cases. However, the results of the statistical analysis of this truncated base practically did not change in comparison with the whole one, and therefore were not presented in the article. In particular, the list of variables for which the statistically significant differences from the control group were revealed remained the same.

Noteworthy is the significantly greater spread of variables values in the patient group as compared with the control. This situation has given relevance to the search for group differences in these variables, depending on the severity of impairment of gross motor functions. This led to a search for the group differences of these variables depending on the severity the gross motor functions impairment.

For that purpose the nonparametric Kruskal-Wallis test with the GMFCS group of variable was preliminary applied (Table 5).

The Kruskal-Wallis test showed that many dependent variables were significantly different in subgroups of the patients with CP characterized by disease severity. So it was decided to conduct the further a posteriori pairwise comparisons of subgroups for these variables using the Mann-Whitney test with a new critical the level of significance p*, taking into account the number of comparisons made. The latter was made in order to avoid the problem of multiple comparisons and not to make a decision about the differences where they were absent:

$$p^* = 1 - 0{,}95^{1/n},$$

where n is the number of comparisons made.

For 4 groups, this critical level was $p^* = 1 - 0.95^{0.17} = 0.0085$.

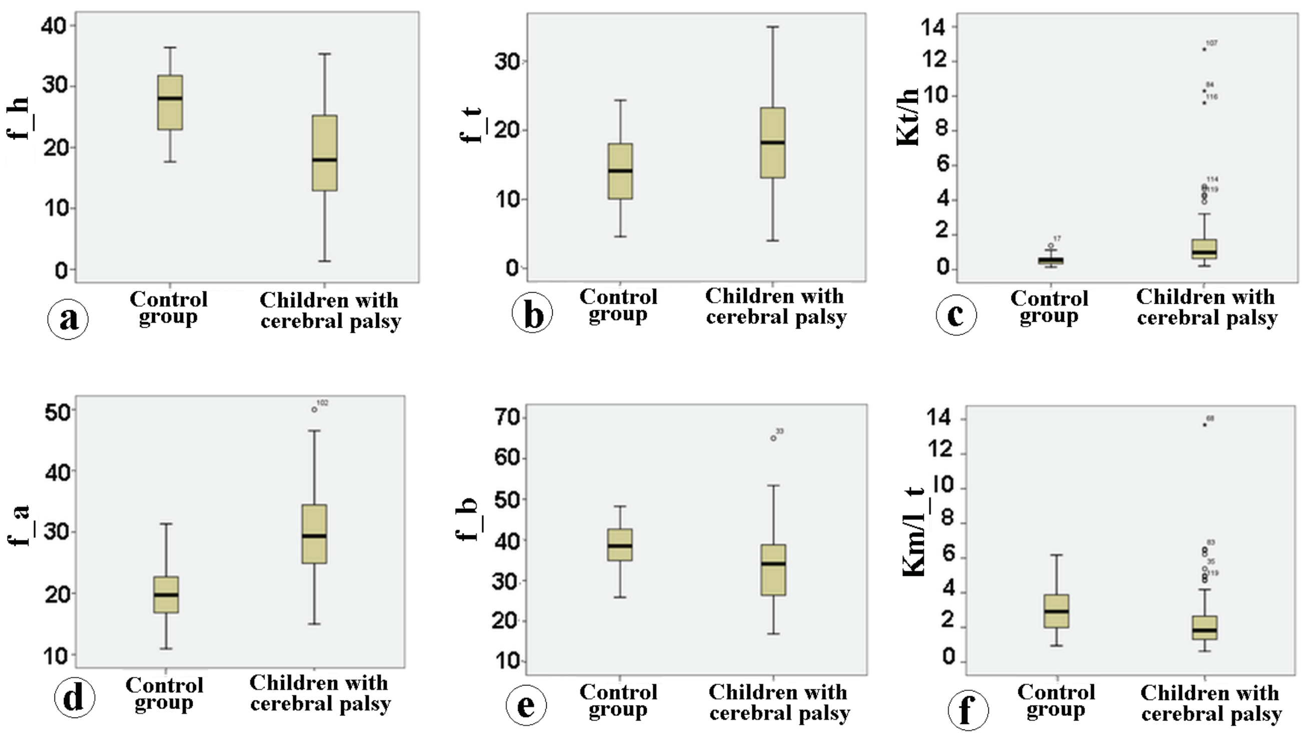

Figure 2. The quantile diagrams of the variables, which revealed a statistically significant difference in the rolling-over-the-foot of children with cerebral palsy compared with the control group: a – partial load on the heel area (f_h); b – partial load on the toe area (f_t); c – toe-to-heel load ratio (Kt/h); d – partial load on the arch area (f_a); e – partial load on the bundles area (f_b); f – medio-lateral load ratio in the toe area (Km/l_t). The bold line is the median; the lower and upper bounds of the box are the 25th and 75th percentiles; whisker tips – 10th and 90th percentiles.

The statistical significance of the differences revealed by above method is presented in Table 6.

Comparison of medians and quartiles of variables on quantile diagrams provides a visual representation of the differences between the surveyed groups (Fig. 3).

It should be noted that the exclusion from the database of those observations that correspond to the equinovarus feet led to significant changes in only one of the baroplanthographic indicators, namely the partial load on the region of the longitudinal arch f_a (Fig. 4).

This result indicates the need of accumulating and processing a larger database with a sufficient number of observations with varus and equinovarus deformities of the foot for making it possible the statistical analysis of their characteristic distribution of the load on the foot.

Table 5

The analysis of the variables with the Kruskal–Wallis test. The statistical significance of the differences among the subgroups of the children with cerebral palsy characterized by various degrees of gross motor functions impairment in terms of GMFCS

Statistical criteria	Variables										
	f_h	f_ a	f_b	f_t	Kt/ h	Kff/re	Km/l_h	Km/l_a	Km/l_b	Km/l_t	Km/l
Chi-Square	32.821	37.317	11.023	25.306	34.358	4.469	1.165	22.311	8.892	11.223	13.412
Degree of freedom	3	3	3	3	3	3	3	3	3	3	3
Statically significance level Asymp. Sig.	0.000	0.000	0.012	0.000	0.000	0.215	0.761	0.000	0.031	0.011	0.004

Table 6

The analysis of the variables with the Mann-Whitney test (U). The statistical significance of differences among the control group and the subgroups of children with cerebral palsy characterized by various degrees of gross motor functions impairment in terms of GMFCS

Groups of comparison	Statistics	Variables							
		f_h	f_a	f_b	f_t	Kt/h	Km/l_a	Km/l_b	Km/l_t	Km/l
Control vs GMFCS 1	U	152	66	145	230	184	137	233	180	152
	Asymp. Sig.	0.024	**0.000**	0.016	0.620	0.129	0.010	0.669	0.108	0.024
Control vs GMFCS 2	U	185	159	323	318	205	429	410	279	444
	Asymp. Sig.	**0.000**	**0.000**	0.010	**0.008**	**0.000**	0.238	0.152	**0.002**	0.330
Control vs GMFCS 3	U	144	123	351	242	154	342	367	319	403
	Asymp. Sig.	**0.000**	**0.000**	0.013	**0.000**	**0.000**	0.009	0.023	**0.004**	0.070
GMFCS 1 vs GMFCS 2	U	233	291	329	161	185	124	226	324	155
	Asymp. Sig.	0.074	0.451	0.943	**0.002**	**0.008**	**0.000**	0.056	0.872	**0.001**
GMFCS 1 vs GMFCS 3	U	180	301	315	113	135	108	199	350	161
	Asymp. Sig.	**0.003**	0.391	0.537	**0.000**	**0.000**	**0.000**	0.009	0.986	**0.001**
GMFCS 2 vs GMFCS 3	U	553	570	650	574	531	561	603	684	632
	Asymp. Sig.	0.080	0.080	0.457	0.125	0.048	0.095	0.218	0.701	0.355

Variables for which statistically significant differences were noted are in bold.

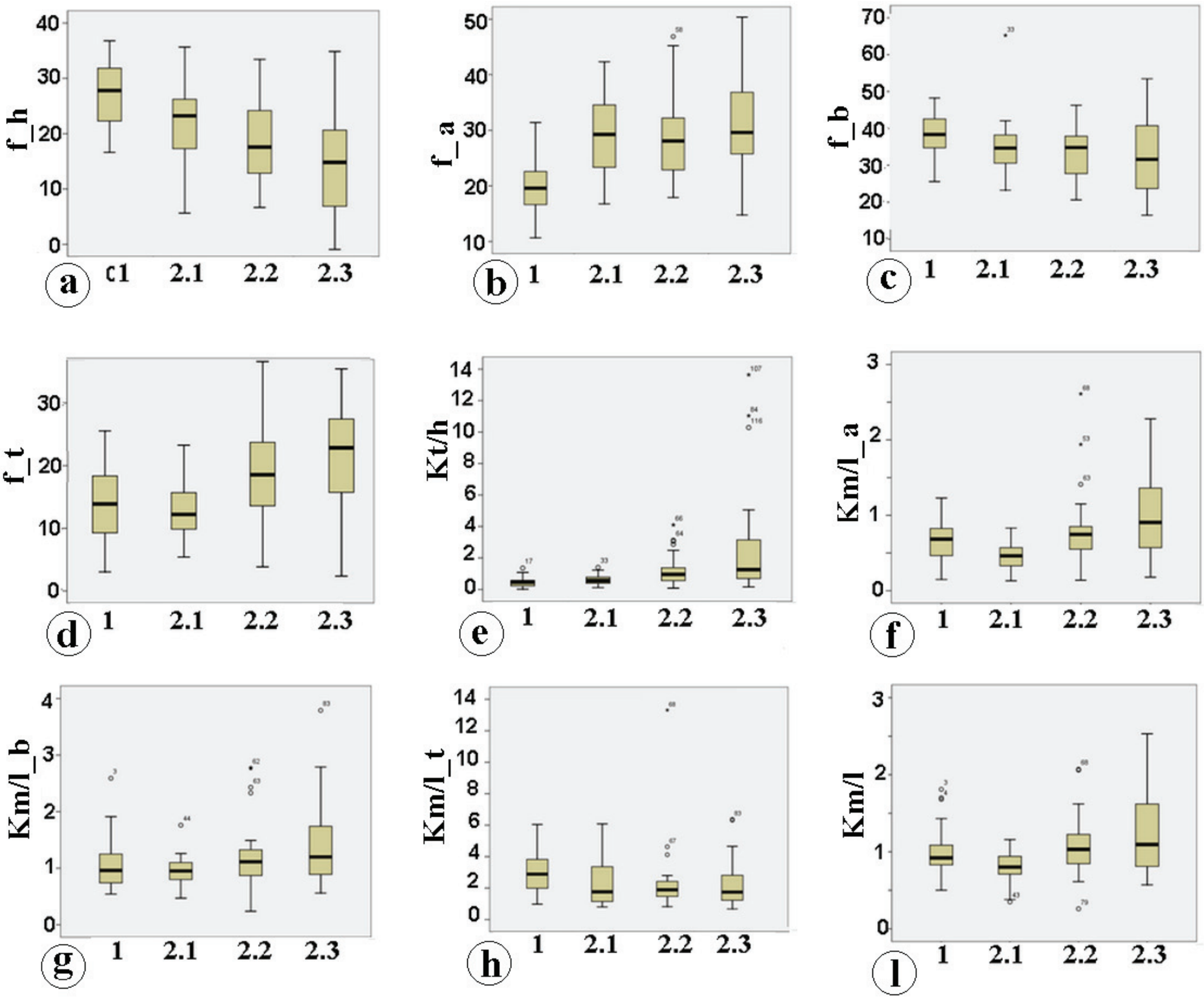

Figure 3. The quantile diagrams of variables for the control group (“2”) and for the GMFCS 1–3 cerebral palsy group (subgroups 1.1, 1.2, 1.3): a – partial load on the heel area (f_h); b – partial load on the arch area (f_a); c – partial load on the bundles area (f_b); d – partial load on the toe area (f_t); e – toe-to-heel load ratio (Kt/h); f – medio-lateral load ratio in the arch area (Km/l_a); g – medio-lateral load ratio in the bundles area (Km/l_b); h – medio-lateral load ratio in the toe area (Km/l_t); i – (Km/l) medio-lateral load ratio on the foot. The bold line is the median; the lower and upper bounds of the box are the 25th and 75th percentiles; whisker tips – 10th and 90th percentiles.

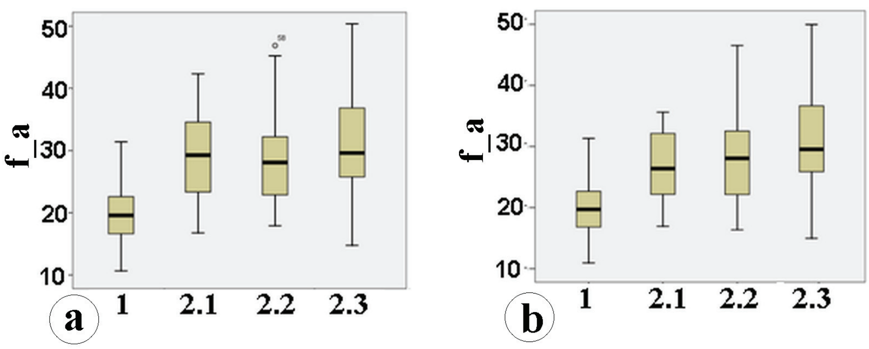

Figure 4. The quantile diagrams of the variable “partial load on the arch area” (f_ a) for the control group ("2") and for the GMFCS 1–3 cerebral palsy group (subgroups 1.1, 1.2, 1.3): a – before deleting the cases with varus and equinovarus feet from the database; b – after deleting.

Discussion

There exist the clinical studies of pathological changes of anatomical and functional characteristics of the feet due to CP. These pathological changes comprise the decrease of the foot longitudinal arch height, the pronation of the middle section and valgus of the posterior section of the foot, and hallux valgus [16]. However, we did not find scientific sources with a detailed evidence-based analysis of the relationship between the CP severity, on the one hand, and the impairment of the interzonal distribution of the load on the plantar surface of the foot during walking, on the other hand.

The comparative analysis of the walking pattern of the children with CP and the control group showed statistically significant differences in 6 variables: f_h, f_a, f_b, f_t, Kt/h (dependent on f_h и f_t), as well as the Km/l_t (see Table 2). The patients with statistically significant differences revealed a pronounced increase in the toe-to-heel ratio of the foot load, Kt/h (see Tables 2 and 3). According to W. Chen et al. [17], this parameter is a useful objective quantitative criterion for assessing the severity of the foot equinus deformity. The excess of the median value for this variable in our study was 80% over the control group (see Table 4, Fig. 2 c). This was a consequence of a decrease in the load on the heel, f_h by 36% (see Table 4 and Fig. 2 a) and its increase in the load on the toe, f_t by 29% (see Table 4, Fig. 2 b). Our results do not contradict the data of the world literature, according to which the equinus deformity of the feet in the children with CP is the most common [17, 18, 19, 20]. The parents often describe this condition as "walking on the toes." A similar name can often be found in foreign scientific literature (tip-toeing gait, in-toeing gait) [21, 22, 23]. In our opinion, the above terms most successfully describe the distribution of the load on the plantar surface of the foot in the sagittal plane. At the same time, no significant difference in the ratio of loads on the anterior part of the foot (bundles with the toe) and the rear (the heel together with under-arch space, Kff/re, was not revealed (see Table 2). This can be explained by the simultaneous anti-phase load on the arch area, f_a (see Fig. 2 c) and its decrease on the bundles of the foot, f_b (see Fig. 2 e) in the children with CP.

Also, the patients with CP revealed a significant increase in the load on the arch, f_a, almost 1.5 times (by 49%). We believe that the reasons for such a phenomenon was an increase in the foot contact area with the support in this area due to a combination of factors. These factors are as follows: a decrease in the height of the arch associated with the development of the longitudinal flat feet, valgus posture of the foot, the reduction of the heel participation in the perception of the load on the foot. Our assumptions about the reasons for the increased load on the arch are consistent with the clinical observations of a number of authors. For example, J.P. Sees et al. [11] described plano-valgus deformity as one of the most common foot pathologies in the patients with spastic diplegia. Clinically, this deformity ranges from mild, when there is a slight decrease in the longitudinal arch, to severe, when the load in the midfoot is applied practically to the talus head. W. Chen et al. [17] argued that retraction of the triceps muscle of the leg leads to a shift in the load in the direction from the hindfoot to the forefoot.

We also found a 37% decrease in the medio-lateral ratio of the load on the toe, f_t (see Table 4, Fig. 2 f), i.e. more pronounced loading of the lateral half of the anterior part of the foot. At the same time, we observed a slight decrease in the load on the region of bundles, f_b, by only 11% (see Table 4, Fig. 2 e).

A similar complex of impairments can be observed in clubfoot, but this type of foot deformity is less typical for children with CP. Another reason, in our opinion, is such a common pathological pattern for the patients with CP as internal rotation of the lower limb during movement, which is observed both in the swing and stance phases. This position of the limb and foot, in particular, in the phase of the heel-off, leads to an increased load on the lateral part of the toe. Clinical observations showed that this stereotype of rolling over the foot was typical for a significant number of patients with CP. According to the world literature, this condition was one of the most frequent components of the pathological walking pattern and was known in the English-language literature as the "foot progression angle (FPA)" [22, 23, 24].

At present, there is no consensus on the factors that cause internal rotation of the foot during walking in the children with CP. For example, some authors pointed to "static" causes: anteversion of the femoral head and torsion of the leg bones [23, 24, 25]. Other researchers believed that a more significant effect was exerted by "dynamic" causes, such as muscle tone disorders (spasticity, dystonia, weakness), pathology of selective motor control and associated impairment of coordinated muscle work (parakinesia, discoordination of agonists and antagonists muscles action) [24, 26, 27, 28]. There is also a different opinion about possible factors in the development of internal rotation of the foot. It is based on the fact that the Achilles tendon is attached 2.0 cm medially from the midline, and as a result of its contraction, the heel is displaced internally [21]. At the same time, the spastic tibialis posterior adducts the anterior part of the foot which resulted in "functional clubfoot" development.

The sequence of the disturbances formation of the interzonal distribution of the load on the feet, characteristic of CP, becomes clearer when we consider the differences intrinsic for the groups of patients with different degrees of gross motor functions impairment. These differences reflect the severity of the disease.

The analysis of group differences (see Table 4) showed that the statistically significant difference of the GMFCS 1 group of the patients with CP from the control group was observed in only 1 variable: f_a, an increase in the partial load on the arch area (see Fig. 2 b). We regard this result as the simultaneous action of 2 factors affecting the distribution of the load on the foot: a decrease in the height of the longitudinal arch, which causes an increase in the load on the underarch area, and a decrease in the load on the heel due to the equinus position of the foot.

The patients of GMFCS 2 and GMFCS 3 groups demonstrated a statistically significant difference from the control group in 5 variables. The patients in these groups retained an increased load on the arch. But an even more characteristic sign was an impairment of the load distribution in the longitudinal direction of the foot: a decrease in the load on the heel, f_h (see Fig. 2 a), and its increase under the toe, f_t (see Fig. 2 d), resulted in an increase in the index of the toe-to-heel load ratio, Kt/h (see Fig. 2 e). In addition, there was an increase in the load on the lateral part of the toe area, i.e. an increase in Km/l_t. This we associate with pathological internal rotation of the foot in the phase of the rear push.

From the quantile diagrams (see Fig. 2) it can be seen that as the severity of CP increases, there is a systematic decrease in the load on the heel, f_h (see Fig. 2 a), and, as a result, an increase in the toe-to-heel load ratio, Kt/h (see Fig. 2 e). For the rest of the indicators, there was no such pronounced tendency to change as the patient's gross motor functions impairment increased. Our results are consistent with the literature data, according to which, with the aggravation of movement disorders, there is an increase in the number of deformities from the musculoskeletal system [20, 28, 29, 30] and, as a consequence, an impairment of the interzonal distribution of the load on the plantar surface of the foot.

An increase in the toe-to heel load ratio, an increase in the load on the arch, and a decrease in the medio-lateral ratio of the load on the toe, characteristic of children with CP, are also seen in the baroplanthograms shown in Figure 1.

An objective method revealed the statistically significant differences of the interzonal load distribution indicators in the walking children with CP of various levels of gross motor functions impairment. As this impairment worsened, an increase in these differences was noted both in the number of indicators and in their values.

The most sensitive indicator of the interzonal distribution of the load on the feet impairment, reflected the severity of functional disorders, is an increase in the toe-to-heel load ratio due to a decrease the load on the heel and an increase it on the toe.

It is advisable to use the identified indicators of impaired roll over the foot as additional measures in diagnosing the condition of the patients with CP and assessing the effectiveness of their rehabilitation.

The presented conclusions are based on the analysis of data obtained during the examination of the most common foot deformities in the children with spastic CP, namely valgus, planovalgus and equino-plano-valgus. Therefore, the conclusions of this article should be used with caution in varus and heel variants of foot deformities

Ethics approval

This study was approved by the ethics committee of the Federal Scientific Centre of Rehabilitation of the Disabled named after G.A. Albrecht and was conducted in accordance with the ethical standards of the Declaration of Helsinki. An informed consent was obtained from all subjects participated in this study.

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Authors' contributions

L.M. Smirnova – consulting assistance in carrying out instrumental biomechanical examinations, data statistical processing, text preparation, stage and final editing of the article.

E.I. Dzhomardly – literature analysis, clinical and biomechanical examinations, statistical forms creation, collection and processing of the material, text preparation, stage and final editing of the article.

A.A. Koltsov – research concept and design, stage and final editing of the article.

All authors made a significant contribution to the research and preparation of the article and read and approved the final version before its publication. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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