FEATURE OF BIOELECTRICAL IMPEDANCE ANALYSIS AND ELECTROMYOGRAPHY DATA IN CHILDREN WITH CEREBRAL PALSY

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Assessment of muscle functional state in children with cerebral palsy (CP) is an important aspect of developing personalized rehabilitation programs. The combined use of bioelectrical impedance analysis (BIA) and electromyography (EMG) makes it possible to optimize the diagnosis methods and improve therapy efficacy. The study aimed to compare groups of patients with CP (n = 91) and healthy children (n = 94) using BIA and EM. Based on the BIA data the patient were divided into four categories: A — increased body fat percentage (BFP), reduced skeletal muscle mass (SMM); B — decreased BFP, increased SMM; C — increase in both indicators; D — decrease in both indicators. The analysis considered gender and average age of each group. Patients with CP (M: BFP p = 0.0001, SMM p = 0.0015; F: BFP p = 0.0003, SMM p = 0.0009), regardless of gender, showed similar distribution: the majority belonged to categories C (M — 50%; F — 46.9%) and D (M — 32.5%; F — 28.1%). The group of healthy people (M: BFP p = 0.0005, SMM p = 0.0004; F: p = 0.0013, p = 0.0008) showed the opposite trend: the majority of patients belonged to categories A (34%) and B (34%). In the group of females, the majority of patients belonged to group B (40.4%), group C ranked second based on the number of patients (27.6%), which was considerably lower, than in the group of children with CP. The phase angle values were also traced: there were significant differences ($p < 0.05$) with superiority of categories A and B, regardless of the group and gender. The EMG data also showed superiority of categories A and B when considering turn amplitudes. A conclusion was drawn about the skeletal muscular function differences in the specified categories of patients.

Keywords: children, ICP, muscle activity, bioimpedance, rehabilitation, electromyography

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Compliance with ethical standards: the study was approved by the Ethics Committee of the cientific Research Institute of Children's Balneology, Physiotherapy and Medical Rehabilitation (protocol No. 21 dated 14 December 2022). All the patients submitted the informed consent to participation in the study.

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ОСОБЕННОСТИ ДАННЫХ БИОИМПЕДАНСОМЕТРИИ И ЭЛЕКТРОМИОГРАФИИ У ДЕТЕЙ С ДЕТСКИМ ЦЕРЕБРАЛЬНЫМ ПАРАЛИЧОМ

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Оценка функционального состояния мышц у детей с детским церебральным параличом (ДЦП) является важным аспектом для разработки персонализированных реабилитационных программ. Совместное использование биоимпедансометрии (БИМ) и электромиографии (ЭМГ) позволяет оптимизировать методы диагностики и повысить эффективность терапии. Целью работы было провести сравнение группы пациентов с ДЦП (n = 91) и здоровых детей (n = 94) с помощью БИМ и ЭМГ. Согласно данным БИМ, пациенты были разделены по четырем категориям: A — увеличение доли жировой массы (ДЖМ), уменьшение скелетно-мышечной массы (СММ); B — уменьшение ДЖМ, увеличение СММ; C — увеличение обоих показателей; D — уменьшение обоих показателей. При анализе учитывали половой признак и средний возраст для каждой из групп. Пациенты с ДЦП (М: ДЖМ p = 0,0001, СММ p = 0,0015; Ж: ДЖМ p = 0,0003, СММ p = 0,0009) независимо от пола продемонстрировали схожее распределение — большая часть заняла категории C (М — 50%; Ж — 46,9%) и D (М — 32,5%; Ж — 28,1%). Группа здоровых детей (М: ДЖМ p = 0,0005, СММ p = 0,0004; Ж: p = 0,0013, p = 0,0008) показала диаметрально противоположную тенденцию – количественное преимущество пациентов мужского пола оказалось у категорий A (34%) и B (34%). В группе женского пола большая часть пациентов оказалась в B (40,4%), на втором месте по количеству пациентов — в C (27,6%), что гораздо ниже, чем в группе детей с ДЦП. Отслеживали также значения фазового угла — достоверная разница (p < 0,05) с преимуществом в категориях A и B, независимо от группы и пола. Данные электромиографии также обозначили преимущество категорий A и B при рассмотрении амплитуды турнов. Сделан вывод о наличии функциональных различий скелетной мускулатуры у обозначенных категорий пациентов.

Ключевые слова: дети, ДЦП, мышечная деятельность, биоимпедансометрия, реабилитация, электромиография

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Cerebral palsy (CP) is one of the leading causes of childhood disability. According to the epidemiological research data, its prevalence is 1.5–4 cases per 1000 newborns [1–2]. CP is characterized by persistent motor impairment caused by non-progressive central nervous system lesions occurring in perinatal period. Such impairment considerably limits daily activity and reduces the patients' quality of life, which emphasizes the need to develop effective approaches to diagnosis and rehabilitation [3–4].

Metabolic disorders associated with alteration of body composition represent one of the key problems of patients with CP. Such children often show loss of muscle weight against the background of increasing adipose tissue, which negatively affects overall metabolic status and hampers rehabilitation [5–6]. In this regard, developing the methods allowing one to accurately estimate body composition and identify early signs of metabolic disorder is relevant.

In recent years, bioelectrical impedance analysis (BIA) is widely used to assess body composition. This noninvasive method enables quantification of the body fat and muscle mass percentage, along with the hydration level, which is especially important for patients with CP [7–9]. The advantage of BIA is its high accuracy, together with the possibility of multiple use posing no risk for the patient, which enables the dynamic monitoring of changes in body composition during rehabilitation [10–11]. Introduction of BIA into clinical practice contributes to early identification of the groups at risk and the development of personalized approaches to treatment [12–13].

However, the existing methods to assess metabolic status in children with CP often do not consider specifics of their condition [14–16]. Introduction of BIA represents an innovative approach capable of increasing the diagnosis accuracy and contributing to the development of targeted rehabilitation strategies.

Thus, the relevance of the issue of CP, the importance of BIA for the diagnosis of metabolic disorders and the innovative approach to detection of such disorders emphasize the need for further research in this field.

The study aimed to assess the capabilities of BIA in terms of detecting metabolic disorders in children with CP. The hypothesis is that the use of BIA will make it possible to not only quantify changes in body composition, but also reveal the features of metabolic processes, which can contribute to optimization of treatment and rehabilitation measures.

METHODS

A total of 94 patients with CP were included in the study (with spastic monoparesis, spastic diplegia, spastic tetraparesis, and other CP types. The control group was represented by healthy children (n = 94).

Inclusion criteria: age 6–16 years, average age 10.6 (±1.19); no cognitive disorder. All the participants diagnosed with CP were assigned levels I–III according to the Gross Motor Function Classification System (GMFCS), which indicated mild-to-moderate motor disorders and the ability to stand and move without assistance.

Exclusion criteria: patient's refusal of participation in the study; concomitant central nervous system disorder; general contraindications for rehabilitation procedures; GMFCS level IV indicating severe motor disorder and inability to stand or walk without assistance.

Patients were divided into two groups: 1) children with CP; 2) healthy children. The children's gender was taken into account when dividing.

All participants were assessed by multifrequency bioimpedance analysis (BIA) involving the use of tetrapolar electrodes, and flexor and extensor muscles of the forearm were examined by interference electromyography (iEM) using the Neuro-MVP hardware and software complex (Neurosoft, Ivanovo, Russia). The method represents a popular tool to assess functional state of muscles, which allows one to use the method in rehabilitation medicine for more personalized approach to prescription of procedures and assessment of the quality of ongoing treatment [17–18]. BIA is a noninvasive body composition assessment method based on measuring tissue electrical resistance [19–20]. The method becomes more and more topical for medical rehabilitation, especially for children with CP, since it allows one to obtain information on the distribution of fat and muscle mass, as well as on the overall health status [21–22]. The relevance of the method is emphasized by the fact that it is used as an auxiliary tool for planning rehabilitation programs considering the patient's nutritional status, assessing the effectiveness of the procedures prescribed based on BIA indicators, adjusting covert nutritional problems [23–24]. All the above finally enables maximum personalization of rehabilitation approaches, thereby improving the patient's quality of life and outcome. In this study, electromyography was used to objectify the BIA data: it is possible to indirectly judge about the BIA data interpretation correctness by tracing changes in the skeletal muscle functional activity.

Based on the BIA results the patients were assigned to the following subgroups, and membership was preserved based on the fact of diagnosis.

1.A – Increased BFP and decreased SMM (↑↓)
1.B – Decreased BFP and increased SMM (↓↑)
1.C – Increased BFP and SMM (↑↑)
1.D – Decreased BFP and SMM (↓↓)

Appropriate features were considered in healthy children, among whom there were groups 2.A., 2.B., 2.C., 2.D. with the above specifics.

The decrease and increase in BIA indicators were determined based on median values for the groups: median for group 1 (M) BFP — 10.36; SMM — 14.27; for group 1 (F) BFP — 7.58; SMM — 15.98; group 2 (M) BFP — 20.17; SMM — 22.98; group 2 (F) BFP — 26.95; SMM — 16.59. The phase angle values of each group served as a criterion for estimation of themuscle tissue functional viability [25–27]. BMI was estimated in each group. The resulting percentile values were reconciled with the WHO standard error grids for appropriate age and gender categories [28–30]. BMI deviation was considered significant with z-score > 1.1 and z-score < –1.1.

Statistical processing was conducted using the STATISTICA 10.0 software package (StatSoft Inc., USA).

Quantitative indicators — mean, standard deviation.

Distibution testing — Shapiro–Wilk test, Levene's test for assessment of dispersion homogeneity.

Significance was assessed using factorial analysis of variance, F-distribution estimate; Bonferroni adjustment was used for pairwise comparison.

RESULTS

The analysis of BIA data of male patients with CP (age differences in the comparison group, $p < 0.0001$) (Table 1) revealed predominance of the groups showing both increase and decrease in the studied parameters (A — 8.1%; B — 9.40%; C — 50%; D — 32.5%) (Fig. 2), and the phase angle values (μ = 7.215) of groups A (+0.51; +7%) and B (+1.095; 15.17%) were higher than that of groups C (–1.06; –14.62%)

Table 1. Bioimpedance measurements for male patients with cerebral palsy

Indicator	CP				
	M (*n* = 62)				
	↑↓ (*n* = 5) Average age — 9	↓↑ (*n* = 6) Average age — 11.6	↓↓ (*n* = 31) Average age — 8.4	↑↑ (*n* = 20) Average age — 11.8	*p*-value
BFP	17.51 (±1.58)	9.55 (±0.77)	4.6 (±1.83)	17.79 (±2.85)	0.0001
SMM	11.87 (±0.37)	15.94 (±0.99)	8.37 (±2.31)	22.92 (±4.94)	0.0015
PA	7.72 (±0.05)	8.31 (±0.12)	6.16 (±0.09)	6.67 (±0.11)	0.012
BMI	22	17.95	15.73	23.8	
Z-score (BMI)	0.86	–0.29	–0.93	1.38	

Note: CP — cerebral palsy; BMI — body mass index; BFP — body fat percentage; SMM — skeletal muscle mass; PA — phase angle.

and D (–0.55; –7.55%), which could indicate skeletal muscle failure and body's overall untrained state in the latter groups, regardless of higher SMM (μ = 14.76) in group D (+8.145; +55.23%).

Significant BMI deviation based on z-score was reported for the category of patients with both BFP and SMM increase; other groups remain commonly distributed, which reflects low analytic function of BMI when used to assess the patients' nutritional status.

In the group of females (age differences in the comparison groups, $p < 0.001$) (Table 2), a general trend towards distribution of the majority of patients across groups C and D (A — 18.75%; B — 6.25%; C — 46.9%; D — 28.1%) can be traced and determined in patients with CP, with predominance of better phase angle estimates (μ = 7.89) in groups A (+0.5; +6.1%) and B (+1.14; 14.5%). BMI assessment also showed a trend towards significant deviation in group D, while other groups were within the ranges corresponding to reference percentile values.

BIA indicators of the group of male patients without CP (differences in the groups, $p < 0.001$) (Table 3) make it possible to reveal an opposite distribution pattern: the number of patients in groups A and B predominates (A — 34%; B — 34%; C — 19.2%; D — 12.8%), which represents indirect evidence of the relationship between better tissue quality and non-homogeneous distribution, since such feature is specific for healthy children. Furthermore, better phase angle measurement results (μ = 6.215) also persist in groups A (+0.47; +7.48%) and B (+0.71; +11.34%). BMI assessment does not allow one to speak about significant differences between groups, since all the values remain within the reference percentiles.

Assessment of BIA parameters in the group of healthy female patients (differences in the comparison groups, $p < 0.001$) (Table 4) demonstrates a modest advantage of groups B and C (A — 19.2%; B — 40.4%; C — 27.6%; D — 12.8%) with persistent trend towards better phase angle values (μ = 6.57) in the first two groups (A = +0.25; +3.8%; B = +0.52; +7.91%) and, according to percentile tables, towards significant BMI deviation in group D only.

The interference electromyography (iEM) method allows us to note that the turn amplitude (Atur) is symmetrically larger in groups A and B of both genders (Table 5). This makes it possible to directly judge about the functional characteristics of the upper limb muscles and indirectly judge about the state of other muscle groups. Despite higher muscle mass values in group D, the Atur values here are lower, than in the first two groups. This can be indicative of the fact that the muscle mass increase is not always correlated to functional activity of muscles, which emphasizes the importance of comprehensive approach to assessment of the skeletal muscle state. Moreover, the SMM quantity is similar in groups A and C, and the skeletal muscle activity is higher in the group with mixed alterations. This can indicate differences in neuromuscular function and adaptation between these two groups.

Taking into account the iEM and BIA data obtained, it can be concluded that there are some functional differences in the skeletal muscle tissue in groups A and B.

DISCUSSION

The study has revealed significant differences in body composition and the skeletal muscle functional state between patients with CP and healthy children. The findings are consisted with the data of other studies, in which specific body composition alterations were also reported for children with CP, such as decreased muscle mass and increased body fat percentage [8, 10, 12]. However, our results complement the existing knowledge showing that these alterations are heterogeneous.

Table 2. Bioimpedance measurements for female patients with cerebral palsy

Indicator	CP				
	F (*n* = 32)				
	↑↓ (*n* = 6) 1 Average age — 11	↓↑ (*n* = 2) 12 Average age — 12	↓↓ (*n* = 15) 8 Average age — 8.4	↑↑ (*n* = 9) Average age — 11.55	*p*-value
BFP	11.51 (±1.47)	3.4 (±0.77)	4.52 (±1.47)	13.03 (±2.47)	0.0003
SMM	13.52 (±0.44)	24.8 (±3.05)	8.89 (±2.71)	19.76 (±3.56)	0.0009
PA	8.40 (±0.28)	9.03 (±1.01)	7.36 (±0.98)	6.80 (±0.35)	0.023
BMI	18.15	15.2	15.06	19.27	
Z-score (BMI)	0.63	–0.97	–1.05	1.23	

Note: CP — cerebral palsy; BMI — body mass index; BFP — body fat percentage; SMM — skeletal muscle mass; PA — phase angle.

Table 3. Bioimpedance measurements for male patients without cerebral palsy

Indicator	Patients without CP				
	M (*n* = 47)				
	↑↓ (*n* = 16) Average age — 11.2	↓↑ (*n* = 16) Average age — 11.4	↓↓ (*n* = 9) Average age — 10	↑↑ (*n* = 6) Average age — 9.4	*p*-value
BFP	27.04 (±2.44)	15.69 (±1.39)	16.14 (±1.29)	22.13 (±0.90)	0.0005
SMM	17.61 (±1.81)	28.38 (±2.18)	19.25 (±2.07)	26.05 (±0.57)	0.0004
PA	6.68 (±0.64)	6.92 (±0.47)	5.45 (±0.83)	5.81 (±0.21)	0.021
BMI	18.46	19.54	17.27	18.1	
Z-score (BMI)	–0.05	0.75	–0.94	–0.32	

Note: CP — cerebral palsy; BMI — body mass index; BFP — body fat percentage; SMM — skeletal muscle mass; PA — phase angle.

Phase angle reduction reported for groups C and D of males with CP is correlated to the iEM data showing low Atur in these groups, despite the increased SMM. This confirms the hypothesis about the structural and functional dissociation of muscles in CP reported in the studies [11]. In girls with CP, the phase angle values were higher, which could be due to hormonal features and adaptive capacity of metabolism.

In healthy children, the distribution across groups (A — 34%, B — 34% in males; B — 40.4% in females) and high Atur values confirm the relationship between multidirectional BFP/SMM alterations and better quality of muscles. This is in line with the concept of physiological heterogeneity of normal body composition [26, 29].

In female patients with CP, a similar trend towards distribution across groups C and D was observed, which confirmed the common nature of metabolic disorders in children with CP, regardless of their gender. However, girls had higher phase angle values, than boys, which could be due to differences in the endocrine profile and the features of fat and muscle mass distribution.

The differences in body composition and functional state of muscles found in patients with CP can be explained by several mechanisms. First, limited physical activity and decreased motor functions in children with CP lead to muscle mass reduction and increased body fat percentage [14]. Second, neuromuscular disorders typical for CP can cause reduction of muscle functional activity, even when muscle mass is preserved or increased, which is confirmed by the iEM data [24]. Third, the differences in endocrine profile and metabolic processes between boys and girls can affect fat and muscle mass distribution, as well as functional characteristics of muscles [12].

Study limitations. The lack of data on the participants' hormonal status is a limitation of the study. To refine the results obtained it is necessary to conduct further research involving a larger number of participants and considering additional factors, such as physical activity level, hormonal status, and nutritional specifics.

Table 4. Bioimpedance measurements for female patients without cerebral palsy

Indicator	Patients without CP				
	F (*n* = 47)				
	↑↓ (*n* = 9) Average age — 10.6	↓↑ (*n* = 19) Average age — 10.8	↓↓ (*n* = 13) Average age — 11.5	↑↑ (*n* = 6) Average age — 10.2	*p*-value
BFP	37.05 (±4.61)	23.01 (±1.31)	16.76 (±4.56)	32.17 (±3.17)	0.0013
SMM	13.30 (±0.30)	18.39 (±0.59)	13.87 (±1.29)	18.60 (±0.61)	0.0008
PA	6.82 (±0.20)	7.09 (±0.69)	6.02 (±1.05)	6.36 (±0.88)	0.019
BMI	20.73	18.4	16.1	20.55	
Z-score (BMI)	0.83	–0.38	0.73	–1.57	

Note: CP — cerebral palsy; BMI — body mass index; BFP — body fat percentage; SMM — skeletal muscle mass; PA — phase angle.

Table 5. Indicators of interference EM of the groups compared

CP (gender)	Groups	Tested muscles (Turns amplitude (mkV)			
		m. flexor carpi ulnaris		*m. extensor digitorum*	
		Right	Left	Right	Left
Males	A	223.05 (±12.20)	242.44 (±6.84)	256.32 (±12.51)	274.04 (±14.65)
	B	270.75 (±22.04)	255.20 (±5.21)	313.74 (±11.27)	301.36 (±13.58)
	C	172.59 (±14.50)	166.07 (±11.98)	212.15 (±10.17)	204.33 (±10.03)
	D	200.65 (±8.98)	198.84 (±6.39)	221.24 (±6.03)	218.48 (±12.98)
Females	A	180.38 (±14.80)	188.96 (±9.20)	201.98 (±9.10)	203.55 (±6.52)
	B	233.26 (±9.45)	240.02 (±8.32)	247.05 (±9.10)	250.24 (±8.07)
	C	139.65 (±5.23)	142.33 (±6.39)	155.03 (±6.71)	159.90 (±11.63)
	D	128.48 (±7.68)	137.94 (±8.25)	134.35 (±8.99)	148.10 (±10.29)

CONCLUSIONS

The study has revealed significant differences in the structural and functional muscle tissue characteristics of children with CP. This is confirmed by the BIA data showing that the groups that are heterogeneous based on the muscle and adipose tissue composition predominate in healthy patients, while homogeneous groups predominate in children with CP. The phase angle specifics reported for members of the studied groups suggest qualitative differences in muscle state between groups A/B and C/D, which is confirmed by the lack of positive correlation between the SMM quantity and the maximum phase angle values. The iEM data reported for groups A and B demonstrate higher amplitude activity. This makes it possible to confirm the importance of body's physiological heterogeneity and disproves the linear "volume – power" relationship. The findings emphasize the need to include the muscle structural and metabolic status estimates in the rehabilitation algorithms for CP in order to improve their effectiveness. The study of molecular mechanisms underlying the reported imbalance between bioelectric parameters (phase angle, iEM) and muscle tissue metabolism is a promising area. This will enable the development of targeted methods to adjust muscle dysfunction associated with CP.

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