Physical development as per results produced by bioelectrical impedance analysis (BIA) for estimating body composition depending on sex and age of schoolchildren aged 7–16 years

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Abstract. The research goal was to estimate physical development of schoolchildren as per data of bioelectrical impedance analysis (BIA) of body composition depending on their sex and age. Physical activity (PA) is an important factor in providing physical welfare of schoolchildren and this makes the present research relevant today. We examined 604 schoolchildren. At present a share of schoolchildren who have physical activity with its duration corresponding to the WHO recommendations doesn't exceed 45%. We established an inverse correlation between a share of Skeletal muscle mass (SMM) and age. The determination coefficient which showed a variability a share of SMM and fat mass depending on a combination of PA regularity and duration didn't exceed 0.06. It grew up to 0.19 after we assessed influence exerted by schoolchildren's age on the absolute value of BMM share. A contribution made by age to this parameter was by 8.0 times higher among boys than among girls. We detected an age-specific decline in a probability of lower SMM share which was by up to 11.8 times lower among boys than among girls. These established sex-related differences in probable age-specific decrease in physical development make BIA a more valuable source of information for motivating schoolchildren to have more PA and improve their health.

1 Introduction

Physical activity (PA) is an important factor in securing physical and mental health of schoolchildren. It produces lifelong positive effects [1–5].

Insufficient physical activity of children is among reasons for developing obesity [6–8]. Interventions that only focus on physical activity can reduce the risk of obesity (BMI) in children aged 6 to 12 years, and adolescents aged 13 to 18 years [9]. Public healthcare authorities, medical personnel at schools, and teachers who organize the educational process for pre-pubescent children should remember that this age is critical for obesity manifestation in adolescence [6, 10, 11]. It is possible to estimate physical activity of

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schoolchildren both subjectively by questioning and objectively by applying step-counters, accelerometers, and methods for analyzing body composition, bioelectrical impedance analysis (BIA) included. BIA has several advantages and one of them is a possibility to estimate the phase angle which is used a marker showing nutritional imbalance and functional disorders, as well as improper percentage of fat. It also gives an opportunity to observe certain indicators in dynamics including those characterizing physical and motor activity of a person. These indicators are bone and muscle percentages and the percentage of active body cell mass [12–15]. Other BIA advantages as a method for estimating body composition are its simplicity, safety, portability, relatively low costs, minimal involvement of a patient into analysis, and available reference values which allow correct interpretation of results [16–18].

Our research goal was to estimate physical development of schoolchildren aged 7–16 years using data on body composition obtained by BIA depending on their sex and age.

2 Materials and methods

We performed a retrospective cohort study.

Overall, we examined 604 children aged 7–16 years who attended secondary schools. Children were divided into 5 study groups depending on their age: the 1st one included children aged 7–8 years; the 2nd, 9–10 years. The 3rd, 11–12 years, the 4th, 13–14 years, and the 5th, 15–16 years.

In 2015 we developed a specific questionnaire as a tool for estimating schoolchildren's physical activity, both at school and beyond classes; this questionnaire was applied in the present study as well. We included a block of questions on how often children did any physical exercises or sports during a week and how much time a week they spent doing them. The question "How regularly do you usually do any physical exercises (physical training at school or sports)?" was a multiple choice one and had several answers to choose from: 1) daily; 2) 5-6 times a week; 3) 3-4 times a week; 4) 1-2 times a week; 5) rarer than once a week. Overall, 376 schoolchildren gave their answers (62.3% of all examined children), including 167 (44.4% of the total number of respondents) boys and 209 (55.6%) girls. Another question was "How much time, on average, do you spend on physical activity a day?" and there were also several answers to choose from: 1) less than 30 minutes a day; 2) from 31 to 60 minutes; 3) 61-90 minutes, 4) more than 91 minutes a day. Overall, 362 schoolchildren gave their answers to this question (59.9% of all examined children), including 158 boys (43.7% of the total number of respondents) and 204 girls (56.4%).

We applied conventional procedures to determine body mass and height of all the examined children (measuring inaccuracy was ±2 mm), measured their waist and thigh circumference as parameters necessary for bioelectrical impedance analysis of body composition.

Bioelectrical impedance analysis was performed with "Medass" ABC-001 analyzer according to conventional procedures using disposable bioadhesive electrodes. We compared absolute values of the phase angle (PhA, degrees), fat mass percentage (FM, %), active cell mass percentage (ACM, %), skeletal muscle mass percentage (SMM, %) and their relative values (PhA, SMM (2), ACM (2), FM (2), %). We also determined whether absolute values of fat, bone and muscle, and active body cell mass percentages corresponded to Z-score values for a given age and sex; to do that, we applied relevant software.

The phase angle, or PhA, is a parameter that allows estimating muscle membranes condition and metabolism rates in the body. Active cell mass percentage shows what share belongs to active cells (or metabolically active tissues) in non-fat body mass and is a correlate of a person's physical capabilities. Skeletal muscle mass percentage characterizes how physically developed and well-trained a person is; fat mass percentage provides the most correct estimation of actual fat contents in the body.

Medical and biological research was approved by the local ethical committee of the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies (protocol No. 3 dated March 01, 2018). The research was conducted in full conformity with the ethical principles stated in the Declaration of Helsinki (1975, with additions made in 1983) and the RF National Standard GOST-R 52379-2005 "Good Clinical Practice" (ICH E6 GCP). Legal representatives of all the examined children gave their written informed voluntary consent to their participation.

Statistical and mathematical analysis, correlations included, was performed with Jamovi 1.6.23.0 statistical software program. We applied Shapiro-Wilk test to check if the variables followed normal distribution. Ages of the examined children in the groups were given as a simple mean and standard deviation (M±SD). The groups were compared using One-Way ANOVA dispersion analysis for qualitative binary variables (sex) with Fischer's test. Absolute and relative values of PhA, proportion of SMM, ACM, and FM, as well as Z-score for absolute SMM, ACM, and FM values were given as median (Me), 25 and 75 percentiles. Qualitative parameters were described with their absolute and percentage values. We determined whether differences in quantitative variables between the samplings were statistically significant using Mann-Whitney test; differences in qualitative parameters were estimated with Pearson's chi-square ($\chi2$); Spearman's rank correlation coefficient was applied to evaluate the relationships between the variables. We determined whether correlations were strong, middle, or weak using the Chaddock scale. Influences exerted by a combination of a sex and age, regularity and duration of physical activity on probable changes in the parameters determined by BIA were established by analyzing linear regression models. The model parameters for the constant (Intercept), predictors (sex, age) and their combination are given in the table as regression coefficient values (Estimate), average squared error (SE), 95% confidence interval, regression coefficient to average squared error ratio (t), and significance (p). We calculated determination coefficient (R2) which showed what percentage of variability in a dependent variable was accounted for by variability in independent ones. Differences were considered statistically significant at $p \leq 0.05$.

3 Results

Table 1 provides data on age and sex profiles of the groups. We didn't detect any sex-specific statistically significant differences between the groups (p=0.758).

Table 1. Profiles of the examined groups

Group	Number of children in the group	Age, M±SD, years	Boys		Girls	
			n	%	n	%
1	142	7.51±0.5	81	57	61	43
2	106	9.92±0.28	53	50	53	50
3	134	11.4±0.49	71	53	63	47
4	130	13.3±0.46	72	55.4	58	44.6
5	92	15.6±0.49	46	50	46	50

The questioning revealed that 70 (41.9%) boys and 94 (45%) girls ($\chi2$=72.8; p=0.553) had physical activity not less than 3 times a week; 31% (49) boys and 37.3% (76) girls of the total number of respondents (χ^2=55.5; p=0.215) spent more than 60 minutes a day on physical activity. Given the determined intensity of the correlation between regularity and duration of physical activity and BIA parameters which can be seen in Table 2 we built multifactorial linear regression models which can be found in Table 3.

Table 2. Correlations between regularity and duration of physical activity, age of schoolchildren and BIA parameters in school children

Parameter	How regularly do you usually do any physical exercises (physical training at school or sports)?		How much time, on average, do you spend on physical activity a day?		Age of schoolchildren	
	r	p	r	p	r	p
PhA, degrees	0.000	1.000	0.090	0.087	0.31	< 0.001
PhA, %	0.068	0.190	0.136	0.009	-0.01	0.891
SMM, %	0.002	0.971	0.055	0.294	0.46	<0.001
SMM (2), %	0.217	< .001	0.190	< 0.001	-0.75	<0.001
Z-score for SMM	0.209	< 0.001	0.190	<0 .001	-0.50	< 0.001
ACM, %	0.001	0.989	0.090	0.086	0.31	<0.001
ACM (2), %	0.021	0.684	0.114	0.030	0.001	0.985
Z-score for ACM	0.066	0.203	0.135	0.010	-0.01	0.850
FM, %	-0.22	<0.001	0,23	< 0.001	0.24	<0.001
FM (2), %	-0.23	<0.001	0,25	<0 .001	0.13	0.001
Z-score for FM	-0.23	<0.001	0,25	<0.001	0.10	0.012

Table 3. Parameters of the linear regression models "Physical activity – a probability of qualitative changes in body composition"

Predictor	Estimate	SE	95% Confidence Interval		t	p
			Lower	Upper		
Model parameters for a probability that relative SMM value would grow depending on regularity and duration of physical activity (physical training at school or sports)						
Intercept	124	5.95	113	136	20.9	<0.001
Regularity, times a week	2.74	1.42	5.53	0.05	-1.93	0.055
Duration, minutes a day	0.58	1.32	-2.02	3.17	0.44	0.662
Model parameters for a probability that Z-score for SMM would grow depending on regularity and duration of physical activity (physical training at school or sports)						
Intercept	1.87	0.47	0.94	2.80	3.94	<0.001
Regularity, times a week	0.13	0.11	0.35	-0.09	-1.14	0.256
Duration, minutes a day	0.19	0.11	-0.02	0.39	1.76	0.079
Model parameters for a probability that absolute FM would grow depending on regularity and duration of physical activity (physical training at school or sports)						
Intercept	22.8	2.49	17.9	27.7	9.16	< 0.001
Regularity, times a week	-0.44	0.59	-1.60	0,73	0.74	0.460
Duration, minutes a day	-1.62	0.55	-2.70	-0.53	-2.94	0.004
Model parameters for a probability that relative FM would grow depending on regularity and duration of physical activity (physical training at school or sports)						
Intercept	125	12.4	100	149	10,0	< 0.001
Regularity, times a week	-1.37	2.97	-4.47	7.22	-0.46	0.644
Duration, minutes a day	-9.24	2.76	-14.66	-3.82	-3.35	<0 .001
Model parameters for a probability that Z-score for FM would grow depending on regularity and duration of physical activity (physical training at school or sports)						
Intercept	0.60	0.30	0.01	1.18	2.0	0.046

Regularity, times a week	-0.04	0.07	-0.18	0,11	-0.50	0.620
Duration, minutes a day	-0.22	0.07	-0.36	-0.1	-3.36	<0.001

The statistically significant models showing a probable rise in SMM and fall in FM depending on regularity and duration of physical activity turned out to have insufficient value of the determination coefficient (0.02–0.06).

Sex-specific median values of body composition parameters determined for children and teenagers in the examined groups are given in Table 4.

Table 4. Body composition parameters in boys and girls form the examined groups, Me (25;75)

Parameter	Group	Boys	Girls	p
PhA, degrees	1	5.84 (5,49;6,16)	5.92 (5,52; 6,22)	0,114
	2	6.06 (5.60;6.38)	6.00 (5.58; 6.37)	0.390
	3	6.02 (5.72; 6.54)	6.02 (5.69; 6.50)	0.565
	4	6.19 (5.78; 6.80)	6.21 (5.81; 6.82)	0.554
	5	6.99 (6.62; 7.77)	6.62 (6.11; 7.18)	<0.001
PhA, %	1	101 (96.0; 106)	102 (96.0; 108)	0.176
	2	102 (93.0; 107)	100 (93.3; 107)	0.606
	3	99.0 (93.5; 108)	99.0 (93.0; 107)	0.774
	4	100 (92.8; 109)	100 (93.0; 110)	0.745
	5	107 (100;119)	103 (94.0; 111)	<0.001
SMM, %	1	49.0 (47.9; 50.5)	48.3 (46.7; 49.7)	<0.001
	2	53.8 (52.1; 56.3)	52.2 (50.0; 54.7)	<0.001
	3	55.9 (53.3; 59.6)	53.3 (51.0; 56.4)	<0.001
	4	60.1 (57.2; 61.8)	55.4 (51.4; 60.4)	<0.001
	5	58.3 (55.9; 60.0)	52.9 (49.7; 58.3)	<0.001
SMM (2), %	1	125 (117; 133)	136 (123; 154)	<0.001
	2	113 (109; 118)	123 (113; 134)	<0.001
	3	109 (104; 114)	116 (108; 124)	<0.001
	4	110 (104; 111)	110 (105; 113)	0.004
	5	104 (100; 107)	104 (99.0; 107)	0.910
Z-score for SMM	1	2.09 (1.56; 2.64)	2.80 (1.91; 3.93)	<0.001
	2	1.64 (1.14; 2.47)	2.47 (1.65; 3.09)	<0.001
	3	1.28 (0.46; 2.24)	2.14 (1.23; 2.71)	<0.001
	4	1.87 (0.74; 2.57)	1.63 (0.81; 2.15)	0.141
	5	1.22 (-0.03; 2.13)	0.78 (-0.12; 1.60)	0.069
ACM, %	1	52.9 (51.1; 54.6)	53.3 (51.3; 54.8)	0.113
	2	54.1 (51.7; 55.6)	53.8 (51.5; 55.5)	0.394
	3	53.9 (52.3; 56.3)	53.8 (52.2; 56.2)	0.556
	4	54.7 (52.6; 57.5)	54.8 (52.8; 57.7)	0.558
	5	58.3 (56.7; 61.5)	56.7 (54.3; 59.1)	<0.001
ACM (2), %	1	101 (98.0; 104)	101 (98.0; 105)	0.182
	2	101 (96.0; 104)	101 (96.3; 104)	0.626
	3	100 (97.0; 104)	100 (97.0; 104)	0.714
	4	100 (96.0; 105)	100 (96.0; 106)	0.820
	5	104 (100; 110)	102 (97.0; 106)	<0.001
Z-score for ACM	1	0.23 (-0.41; 0.74)	0.26 (-.0.40; 0.86)	0.166
	2	0.26 (-0.65; 0.76)	0.14 (-0.61; 0.72)	0.709
	3	-0.03 (-0.57; 0.76)	0.01 (-0.58; 0.68)	0.890
	4	0.08 (-0.62; 0.87)	0.08 (-0.57; 0.92)	0.684
	5	0.66 (0.07; 1.47)	0.32 (-0.41; 0.97)	<0.001
FM, %	1	13.8 (9.00; 18.9)	16.2 (11.2; 20.7)	<0.001
	2	18.0 (15.5; 28.2)	19.7 (15.8; 27.3)	0.394

	3	20.9 (13.9; 26.4)	20.0 (15.2; 26.6)	0.857
	4	14.9 (11.1; 22.3)	20.7 (14.1; 26.5)	<.0.001
	5	18.6 (13.1; 24.2)	23.1 (17.6; 31.30)	<0.001
FM (2), %	1	88.0 (58.0; 120)	95.5 (69.0; 120)	0.071
	2	110 (94.0; 171)	109 (88.3; 143)	0.206
	3	124 (82.5; 157)	109 (79.0; 149)	0.019
	4	86.5 (65.0; 129)	104 (79.3; 137)	0.002
	5	105 (73.5; 136)	121 (90.8; 147)	0.018
Z-score for FM	1	-0.55 (-1.29; 0.24)	-0.36 (-1.02; 0.26)	0.027
	2	-0.32 (-0.66; 0.93)	-0.21 (-0.77; 0.70)	0.818
	3	-0.07 (-0.93; 0.58)	-0.29 (-1.04; 0.48)	0.141
	4	-0.58 (-1.06; 0.22)	-0.37 (-0.92; 0.45)	0.017
	5	-0.01 (-0.70; 0.66)	0.21 (-0.61; 0.79)	0.274

These results indicate that the greatest number of significant sex-specific differences were determined for SMM and FM.

The correlation analysis established statistically significant direct correlations between an age and absolute PhA value (moderate correlation); SMM (moderate); ACM (moderate); FM (weak); relative FM value (weak); Z-score for FM (weak). There were inverse correlations between an age and relative SMM value (strong correlation) and Z-score for SMM (substantial correlation) (Table 2). Spearman's correlation coefficient corresponded to significant strength in this research (r=0.87).

Table 5 provides data on influences exerted by a combination of a sex and age on probable changes in body composition; the data are given as parameters of multifactorial linear regression models.

Table 5. Parameters of multifactorial linear regression models "factor (age and sex) – a probability of qualitative changes in body composition"

Predictor	Estimate	SE	95% Confidence Interval		t	p
			Lower	Upper		
Model parameters showing a probable rise in absolute PhA value depending on age and sex						
Intercept	5.14	0.13	4.87	5.4	38.2	< 0.001
Age	0.09	0.01	0.07	0.11	8.30	<0.001
Sex	0.08	0.06	-0.04	0.20	1.29	0.196
Model parameters showing a probable rise in absolute SMM value depending on age and sex						
Intercept	40.6	0.65	39.3	41.9	61.6	<0.001
Age	0.81	0.05	0.71	0.92	14.9	<0.001
Sex	5.11	0.30	4.51	5.70	16.9	<0.001
Model parameters showing a probable rise in relative SMM value depending on age and sex						
Intercept	178	1.7	175	181.7	105	<0.001
Age	-4.59	0.14	-4.87	-4.32	-32.7	<0.001
Sex	-14.4	0.78	-15.9	-12.8	-18.4	<0.001
Model parameters showing a probable rise in Z-score value for SMM value depending on age and sex						
Intercept	5.34	0.21	4.94	5.76	25.8	<0.001
Age	-0.27	0.017	-0.30	-0.23	-15.6	<0.001
Sex	-0.75	0.09	-0.94	-0.57	-7.9	<0.001
Model parameters showing a probable rise in absolute ACM value depending on age and sex						
Intercept	49.6	0.64	48.4	50.8	80.3	<0.001
Age	0.43	0.36	0.33	0.53	8.33	<0.001
Sex	0.39	0.62	-0.16	0.950	1.38	0.167
Model parameters showing a probable rise in absolute FM value depending on age and sex						
Intercept	14.2	1.40	11.4	17.0	10.1	<0.001

Age	0.75	0.12	0.53	0.98	6.49	<0.001
Sex	-4.56	0.64	-5.82	-3.29	-7.08	<0.001
Model parameters showing a probable rise in relative FM value depending on age and sex						
Intercept	87.8	7.80	72.4	103	11.2	<0.001
Age	2.16	0.66	0.89	3.43	3.33	<0.001
Sex	-3.83	3.60	-10.9	3.23	-1.07	0.287
Model parameters showing a probable rise in Z-score for FM depending on age and sex						
Intercept	-0.61	0.18	-0.97	-0.25	-3.31	<0.001
Age	0.05	0.01	0.02	0.08	3.15	0.002
Sex	-0.19	0.08	-0.35	-0.02	-2.21	0.027

We obtained a statistically significant model for a probable rise in the absolute PhA value depending on an age and sex with the determination coefficient being 0.11 and "sex" variable having no influence on a probability of the rise in PhA value. R2 coefficient was equal to 0.19 for the estimation of influence exerted by an age on the absolute SMM value; sex-adjusted values were 0.48 for boys and 0.06 for girls, the regression coefficient value being positive. R2 coefficient value determined for the estimation of influence exerted by a combination of an age and sex on the relative SMM value and Z-score for SMM reached 0.52 and 0.26 respectively; sex-adjusted values were 0.49 and 0.06 for boys and 0.84 and 0.71 for girls respectively, the regression coefficient value being negative. R2 coefficient value determined for the estimation of influence exerted by an age on the absolute ACM value amounted to 0.10 without any effects produced by "sex" variable. R2 coefficient values were insignificant both in estimating influences exerted by an age on absolute and relative FM values and Z-score for FM (0.02–0.07), the regression coefficient being positive, and in estimating influence exerted by "sex" variable, the regression coefficient being negative (0.002–0.08).

Our further analysis revealed an inverse correlation between relative FM and SMM values ($r=-0.41$; $p<0.001$); the determination coefficient calculated by analyzing a probable rise in the relative SMM value given the growing FM reached 0.13, the regression coefficient being negative.

4 Discussion

We examined 604 schoolchildren aged 7–16 years aiming to estimate their physical development as per results produced by bioelectrical impedance analysis of body composition depending on their age and sex.

The primary limitation of the present study is that it is not a longitudinal one.

The questioning revealed that only 31-45% of schoolchildren had physical activity which corresponded to the WHO recommendations on physical activity and sedentary lifestyle. These results indicate that at present most schoolchildren are not committed to being physically active and this is in line with results produced by other research works. Having analyzed available literature data on a correlation between physical activity among schoolchildren and their sex, we established that different authors described rather controversial results [1, 2, 7, 19]. We didn't reveal any differences between regularity and duration of physical activity and body composition depending on sex in this research ($p=0.215$–0.553) and these results are similar to those obtained by other authors. Malinin A.V. with colleagues also examined physical activity among schoolchildren and established that percentages of boys and girls were quite similar in sub-groups with different PA levels [19]. In our opinion, these controversial results produced by studies based on questionings might be due to respondents not always giving truthful answers [12, 20]. Insufficient values of the determination coefficient in establishing contributions made by regularity and duration of physical activity to body composition parameters (0.02–0.06) can also be due to respondents not being sincere when giving their answers.

If we compare average values calculated for boys and girls in the same age group, we should pay attention to high relative SMM values in girls in all the examined age groups, excluding those aged 15–16 years. Having analyzed relevant literature in the issue, we found that Larsen M N with colleagues also mentioned that BIA procedure tended to underestimate SMM in boys. But still, the authors concluded that the procedure was quite relevantly used for comparative analysis in longitudinal and dynamic examinations within a group [13].

We performed the mathematical analysis that involved building linear regressions based on comparing the determination coefficient values. The analysis revealed that a contribution made by an age into the absolute SMM value was by up to 8.0 times higher among boys than among girls. This is probably due to physiological peculiarities related to a male body maturing under influence exerted by male hormones [21, 22]. A probability that a relative SMM value would decrease is by 1.7 times lower among boys as per the relative value and by 11.8 times lower among them as per Z-score than among girls. Bearing in mind, that schoolchildren spend a lot of their time at school, experts try to draw public attention to a role which school plays in satisfying schoolchildren's needs in proper levels of physical activity, with its primary focus being on physical development of girls [6–9, 23].

The moderate inverse correlation between relative FM and SMM values and the negative regression coefficient obtained by building up the one-factor linear regression indicate that SMM makes a contribution to preventing obesity in schoolchildren. This allows using relative FM values as an indicator of obesity and SMM values determined by BIA in monitoring over fat metabolism and physical development [24, 25].

5 Conclusion

According to the performed questioning, at present less than 45% of schoolchildren do physical training and sports with regularity and duration that correspond to the levels recommended by the WHO. We have established the inverse correlation between the relative SMM value and Z-score for SMM among children aged 7-16 years. Bioelectrical impedance analysis of body composition can be used to estimate relative SMM values in children in dynamics and their conformity with Z-scores in order to determine risk groups prone to obesity. When organizing the educational process, teachers and medical personnel at schools have to pay greater attention to physical development of girls.

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