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Anthropometric, body composition and behavioural predictors of bioelectrical impedance phase angle in Polish young adults – preliminary results

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Abstract

Introduction and objective. Bioimpedance analysis (BIA) phase angle (PhA) is an index of the integrity of cells and cellular membranes. The aim of the study was identification of behavioural and anthropometric predictors of PhA in a group of young adults.

Materials and method. A cross-sectional observational study of health behaviours, anthropometric indicators and body composition assessed by the BIA method was conducted in a group of Polish young adults (n=92) aged 18 – 24 (mean – 19.33, STD – 0.915). Behavioural variables included: level of physical activity, eating behaviours and nutritional knowledge. Body composition was analysed by means of BIA phase-sensitive 8-electrode medical SECA mBCA 525 device.

Results. The mean PhA value in the examined cohort was 6.38±0.75 (males – 7.22±0.72; females – 6.13±0.57). Males also showed higher statistically significant other body composition indices, excluding fat mass. The multiple regression model, including anthropometric variables and gender, which explained the effect of these variables on PhA, occurred to be significant (p<0.0000) and allowed explanation of the 82.49% of PhA variability. PhA was significantly predicted from body mass index (BMI), absolute fat mass, visceral adipose tissue value, skeletal muscle mass value and gender. The regression model, including behavioural predictors and gender, allowed explanation of the lower percentage of PhA variability (42.75%; p<0.0000) and included general intensity of health behaviours, level of nutritional knowledge, and gender. A regression model which would consider simultaneously anthropometric and behavioural variables could not be constructed.

Conclusions. In the examined cohort, anthropometric and body composition variables showed a stronger predictive value with respect to PhA, compared to behavioural variables.

Key words

young adults, bioelectrical impedance, phase angle, body composition analyzer, phase angle predictors

Abbreviations used

(in the order in which they appear in the text): BIA – bioelectrical impedance analysis; Z – impedance; R – resistance; X_c – reactance; PhA – phase angle; BIVA – bioelectrical impedance vector analysis; ECW – extracellular body water; TBW – total body water; FFM – fat free mass; FM – fat mass; BCM – body cell mass; ECM – extracellular matrix; PA – physical activity; BMI – body mass index; SMM – skeletal muscle mass; IPAQ – International Physical Activity Questionnaire; MET – metabolic equivalent; KomPAN – questionnaire for investigating nutritional attitudes and habits; pHDI-10 – pro-Healthy Diet Index-10; nHDI-14 non-Healthy Diet Index-14; HBI – Healthy Behaviour Inventory; VAT – visceral adipose tissue; ICW – intercellular body water; FFQ – food frequency questionnaire

INTRODUCTION

Bioelectrical impedance analysis (BIA) allows quick, non-invasive and repeatable assessment of the body compartments, and is commonly applied for evaluation of the nutritional status in many clinical situations [1, 2, 3], as well as in healthy individuals [4, 5, 6, 7]. BIA is based on the measurement of impedance (Z), i.e. electrical resistance of body tissues in the situation of the flow of electric current of low intensity through the body. Impedance is the function of resistance (R), conditioned by an active electrical resistance of tissues, and reactance (X_c), i.e. capacitive resistance resulting from the electrical capacity of cell membranes which have the physical properties of capacitors [2, 8]. R depends primarily on water content and concentrations of electrolytes in tissues, it causes voltage drop and is the dominant component of impedance. In turn, X_c, generated when current passes through the cell membrane, is responsible for approximately 10% of impedance and causes a phase shift of the flowing alternating current, expressed by the phase angle (PhA; φ) [2]. X_c also referred

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to as capacitive resistance, depends on potential differences accross the cell membrane. X_c is a derivative of the state of cell membranes, their integrity, functions, and biochemical structure [5]. PhA is calculated from the formula: arc tangent = $(X_c / R) \times 180°/\pi$ [1, 9]. The PhA value and resistance increase as the current frequency increases [2, 8]. Figure 1 demonstrates geometrical relationships between PhA (φ) and R, Xc, Z, and the frequency of the current [2, 7]. In the presented study, PhA was measured at the frequency of 50 kHz.

R and X_c, which belong to the direct bioimpedance measures/raw bioimpedance data and their derivatives, i.e. PhA and bioelectrical impedance vector analysis (BIVA), are increasingly more often used for the nutritional status assessment in healthy individuals and in many clinical situations [1, 2, 10, 11]. Based on the direct BIA measurments, using special equations, the remaining, indirect measurement parameters of body composition are calculated. The calculation of the content of extracellular body water (ECW) in relation to the total body water (TBW) enables further mathematical calculations of the content of fat-free mass (FFM) and fat mass (FM) [2, 8]. The starting point for calculations of the individual elements of body composition associated with the state of hydration of the body, imposes the need to maintain standardized measurement conditions by the BIA method, with particular consideration of the circumstances exerting an effect on the body water homeostasis [1, 3, 9, 11]. The advantage of raw bioimpedance measures is that they provide data concerning the state of hydration, body cell mass (BCM) and cell integrity, without the necessity to use computational algorithms, and without the necessity for meeting the conditions for constant tissue hydration [9].

The PhA value is associated with the number of skeletal muscle cell membranes and BCM. Therefore, PhA is used in BIA equations for the prediction of BCM [7]. Małecka-Massalska et al. pay attention to the fact that well-nourished cells are characterized by high reactance and high PhA, whereas the deterioration of the state of cells results in the loss of integrity of cellular membranes and a decrease in PhA [12]. PhA reflects the ratio of extracellular mass (ECM) to body cell mass (BCM). The prognostic importance of PhA seems to be a derivative of changes in the ECM/BCM ratio, which are associated with the nutritional status [7]. Summing-up, PhA is the marker of cellular health, integrity of the cell wall, functional status and number of cellular membranes, as well as an indicator of the distribution of fluids between inter- and intracellular space [5, 13]. Selberg et al. emphasize that PhA values depend primarily on the tissue structure of the limbs [7]. PhA is currently considered as a valuable marker of training and nutritional status [14].

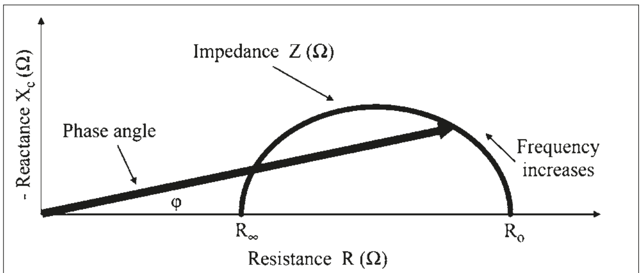

Figure 1. Geometric mapping projection of the dependency between phase angle (φ) and resistance (R), reactance (Xc), impedance (Z), and the frequency of the current.
Source: [2, 7 with own modification]

In many studies, lower PhA values were confirmed in patients with various pathologies, compared to healthy individuals, and the predictive value of PhA was also confirmed in envisaging worse health outcomes and mortality. For example, a study by Selberg et al. showed significant differences in PhA values between healthy individuals and hospitalized patients (mean 6.6° vs. 4.9°; $p<0.001$), in whom in various clinical situations, requiring dietary nutritional support by the nutrition team were enrolled into the study group [7]. A number of publications have dealt with the problem of differences in PhA values in clinically different groups of patients [for more comprehensive information see, among others, 1, 9, 15, 16, 17], and also with the importance of PhA as a predictive factor [9, 18, 19].

OBJECTIVE

The aim of the observational study was preliminary identification of anthropometric, body composition and behavioural predictors of the phase angle (PhA), assessed by means of BIA, in a cohort of young Polish adults.

MATERIALS AND METHOD

Study population. During the period October 2017 – 30 October 2018, a cross-sectional observational study was carried out in a group of 92 young adult volunteers aged 18–24 (mean age – 19.33, STD 0.915), including 71 females and 21 males. The respondents were selected by the purposive, non-random sampling method. The criteria of inclusion into the study group were: being a student of the speciality of dietetics or physiotherapy, and expression of informed consent to participate in the research project. The study was conducted during winter and autumn months in order to avoid seasonal determinations of physical activity (PA). In the study group, 9 respondents self-reported the occurrence of chronic health problems. This group was compared with the study participants who did not report any health problems, according to anthropometric parameters, bioelectrical impedance body composition indices, and intensification of behavioural variables. It was found that respondents who reported health problems were taller (mean height – 176.2 vs. 169.9 cm; $Z=-2.27$; $p=0.02$) and had a higher volume of visceral adipose tissue (0.65 vs. 0.52 l; $Z=-2.23$; $p=0.02$). The result obtained with respect to height evidences lack of the effect of self-reported diseases on the process of the respondents' growth. However, the difference in visceral adipose tissue was not associated with either differences in the level of the respondents' PA, or the mode of nutrition. The two groups did not differ according to the remaining variables considered in the study (Tab. 1). Taking into account the lack of differences in basic bioelectrical impedance body composition indices between both groups, including the lack of differences in PhA, it was decided to consider the whole study group in statistical analyses. In all respondents, the BMI values remained within the range in which a positive correlation was noted between BMI and PhA values [10]. All respondents were students of the medical university and studied dietetics (61.96%) and physiotherapy (38.04%); almost 48% of respondents were permanent residents of rural area and 52% indicated town as their place of permanent residence.

The majority of respondents continued school education or university study (88.03%). 2.17% had permanent employment and 9.8% worked casually, combining employment and education.

Anthropometric measurements were performed in accordance with the World Health Organization (WHO) guidelines [20], with consideration of the measurement of weight up to the nearest 0.1 kg, and height to the nearest 0.5 cm. The accuracy of the measurements of weight and height were adjusted to the BIA requirements, according to the recommendations by Kyle et al. [3]. Waist circumference was measured according to the WHO guidelines ('at the midpoint of the last palpable rib and the top of the hip bone') [20]. The BMI (in kg/m^2) was calculated as body weight divided by the square of height expressed in meters. Measurements were obtained using the measuring station Seca with stadiometer Model No. 7997021289.

BIA. Non-invasive analysis of body composition was performed using the phase-sensitive, multi-frequency 8 electrode SECA medical Body Composition Analyser 525 device, operating with the software Seca analytics 115 (Seca GmbH & Co., Hamburg, Germany). Multi-frequency devices for the measurement of BIA provide more precise assessment of TBW and ECW than those based on a single frequency [1]. The Seca mBCA 525 device uses 4 pairs of surface standard electrodes attached 2 to each hand and foot, connected with a computer analyser (for a detailed anatomic description of the applied positioning of electrodes see: [21]). The measurement of impedance was performed with a current of 100 µA at frequencies between 1 – 1,000 kHz [21]. The measurement was performed maintaining standardized conditions in the supine position, while lying on a non-conductive surface, with body position: lower extremities relative to each other at an angle of 45°, and upper extremities relative to the trunk at an angle of 30°, fasting, after 10-minute rest (recommendation acc. to [3]). The PhA value expressed in degrees (^{0}) was automatically obtained from the device. The measurement of PhA was performed at the frequency of 50 kHz. In all respondents, clinical circumstances were excluded which would ensure the safe performance of BIA (pacemaker, defibrillator, etc.), as well as those affecting the reliability of the results obtained (extreme BMI values: <16 and >34 kg/m^2; fluid abnormalities; body deformation). An interval of at least 4 hours was maintained from the last meal and from intensive physical exercises. The duration of the examination was approximately 75 seconds [3, 21]. The body composition indices taken into account in the analysis were calculated by the SECA mBCA 525 device based on raw bioimpedance data (R, X_c) and were then transferred to the statistical programme through the software Seca analytics 115. This type of device (phase-sensitive 8-electrode system) enabled segmental analysis of the whole body, and thereby the calculation of skeletal muscle mass, taking segmental muscle mass into account. On the question of the procedure for generating calculation formulas used in the SECA mBCA 525 device for predicting SMM see [21].

Behavioural variables. Selected behavioural variables included in the category of health-promoting lifestyle were assessed using a survey technique by means of standardized questionnaires.

The level of physical activity (PA) was assessed using a long version of the *International Physical Activity Questionnaire (IPAQ)*. This instrument enables the evaluation of energy expenditure in the domains of daily living specified in the questionnaire, as well as an overall result informing about the respondents' total PA, which was considered in statistical analyses. The results obtained were expressed in MET-min/week. Calculations of the levels of PA were performed by multiplying the number of days a week when the given activity was carried out by the duration of a given activity in minutes per week, and by a coefficient ascribed to a given activity. The values of coefficients corresponding to the multiples of basal metabolic rate, ascribed to the given activities, are indicated in the methodological manual for IPAQ. It was assumed that effort of low intensity was 3.3 MET, of moderate intensity – 4.0 MET, and of high intensity – 8.0 MET [22]. The methodological guidelines for the use of IPAQ permit the use of a PA measure expressed in MET-min/week without conversion to kcal/week [22]. The Polish version of the research tool was used, as adapted by R. Stupnicki and E. Biernat [22], with the consent of the authors. Considering the high PA levels in the examined cohort, the calculations of total physical activity reported by the respondents were additionally verified in order to exclude calculation errors.

Eating behaviours and nutritional knowledge were assessed using the standardized KomPAN questionnaire, recommended by the Committee of Human Nutrition Science of the Polish Academy of Sciences (version 1.2 to be completed by the respondent) [23]. Eating behaviours were assessed using closed questions which concerned the frequency of consumption of specified food products, beverages and meals. Based on data concerning the frequency of consumption, the pro-Healthy-Diet-Index-10 (pHDI-10) and non-Healthy-Diet-Index-14 (nHDI-14) were calculated. The pHDI-10 includes data pertaining to the consumption of the types of products which have a potentially beneficial effect on health, whereas the nHDI-14 deals with data which concern the consumption of the types of products exerting an unfavourable effect on health. Indices were calculated in such a way that indices concerning the daily frequency of consumption (times/day) were summed-up, and subsequently the obtained values of total frequency of consumption of the 2 groups of food were expressed as scores. Score values of both indicators were used for statistical analyses. The range of possible values for each indicator was 0–100. Scores within the range 0–33 were interpreted as low intensity of the given characteristics of nutrition, 34–66 – as moderate, and 67–100 as high. Nutritional knowledge was assessed by means of 25 statements which were qualified by the respondents as true or false. One score was ascribed to each correct answer, and the scores were subsequently summed-up. The results within the range 0–8 scores evidenced insufficient nutritional knowledge, 9–16 – satisfactory knowledge, and 17–25 – good knowledge [23].

Health behaviours were evaluated using the Health Behaviour Inventory by Z. Juczyński (HBI) [24]. The licence for use of the instrument was made available by the Laboratory of Psychological Tests of the Polish Psychologists' Association. The HBI questionnaire contains 24 items. The respondents indicate how often they undertake the health behaviours mentioned using a 5-degree scale. The instrument allows assessment of the total level of health behaviours and determination of the intensification of behaviours in 4 domains: correct nutritional habits, prophylactic behaviours, and positive psychological attitude. In statistical analysis, the total result was considered, which remained within the range 24–120 scores [24].

Consent for the study was obtained from the Bioethics Commission at the Medical University in Lublin (Resolution No. 0254/248/2017).

Statistical analysis. Statistical analysis was performed using the software STATISTICA version 13.3; TIBCO Software Inc., 2017, and statistical data analysis software system, version 13. (http://statistica.io). Data obtained in own study were expressed in the form of mean values, SD, median values, in selected cases minimum and maximum values were provided. In order to calculate differences between groups according to gender, due to the different numbers of respondents in the groups of males and females, the non-parametric Mann-Whitney U test was applied. Statistical analysis using the W Shapiro-Wilk test showed that the distribution of the analyzed variables in the compared groups differed significantly from the normal distribution. Correlations between variables were calculated using Pearson correlation (r); $p<0.05$ was considered as statistically significant. In order to assess the effect of anthropometric and behavioural variables on PhA, considering the quantitative character of the dependent variable, a stepwise multiple regression analysis was applied. Concerning the size of the sample, the assumption of regression analysis was met pertaining to the examination of at least 15 study participants per one predictor [25].

RESULTS

Table 1 presents the characteristics of the study group with consideration of differences between groups according to gender. Males showed higher values of anthropometric variables investigated in the study. The PhA values in the whole group examined remained within the range from min. 4.9 to max. 8.5; mean 6.38 (STD 0.75). With respect to BIA body composition, the PhA values, as well as the remaining parameters of body composition, with the exception of the FM absolute value, were higher in males. Gender-related differences were observed concerning behavioural variables – females were characterized by higher general intensification of health behaviours, a higher pro-Healthy-Diet-Index (pHDI-10), and a lower non-Healthy-Diet-Index (nHDI-14), with the lack of differences according to gender with respect to PA and nutritional knowledge.

Table 2 demonstrates Pearson correlation values between PhA and anthropometric variables, body composition parameters, and behavioural variables. Skeletal muscle mass (SMM) (r=0.79; p=0.00) showed the strongest positive correlation with PhA. Weaker positive correlations were found between PhA values and height, weight, BMI and waist circumference, as well as fat free mass (FFM). In turn, a negative correlation was found between fat mass (FM) and PhA (-0.24). From among the behavioural variables, only the level of nutritional knowledge was correlated with PhA (r=-0.23; p=0.03) where, paradoxically, a higher nutritional knowledge was related with lower PhA values.

Table 1. Characteristics of the study group with consideration of differences between groups according to gender

n=92	All respondents		Males (n=21)		Females (n=71)		Z statistics	p
	mean ± SD	median	mean ± SD	median	mean ± SD	median		
Anthropometric characteristics								
Weight (kg)	63.0± 10.8	60.0	74.4± 11.7	73.0	59.6± 7.9	59.0	-5.210	0.000
Height (cm)	1.71± 0.074	1.7	1.80± 0.05	1.82	1.68± 0.05	1.67	-5.888	0.000
Body mass index (kg/cm²)	21.80±2.57	21.4	23.17±2.91	22.74	21.39±2.33	21.2	-2.544	0.011
Waist circumference (cm)	75.30±9.18	73.0	83.52±9.88	81.0	72.87±7.44	71.0	-4.359	0.000
Bioimpedance body composition indices								
Fat mass absolute value (kg)	15.30±5.82	15.05	12.71±6.91	11.95	16.07±5.28	15.48	2.758	0.006
Fat mass index (kg/m²)	5.31±1.96	5.18	3.94±2.07	3.59	5.71±1.75	5.49	3.846	0.000
Fat free mass absolute value (kg)	48.33±9.54	45.27	63.13±6.72	65.09	43.96±4.50	43.52	-6.786	0.000
Fat free mass index (kg/m²)	16.55±2.05	16.08	19.50±1.56	19.7	15.68±1.18	15.74	6.581	0.000
Visceral adipose tissue (litre)	0.5319±0.57	0.365	0.9494±0.84	0.66	0.4084±0.39	0.32	-3.460	0.001
Skeletal muscle mass (kg)	22.80±5.65	20.78	31.53±4.06	32.83	20.21±2.66	20.08	-6.781	0.000
Phase angle (°)	6.38±0.75	6.3	7.22±0.72	7.2	6.13±0.57	6.1	-5.251	0.000
Total body water (litre)	35.67±6.92	33.6	46.17±5.25	47.4	32.56±3.40	32.4	-6.753	0.000
Extracellular body water (litre)	15.23±2.46	14.6	18.64±2.04	18.8	14.21±1.47	14.1	-6.386	0.000
Behavioural variables – indicators of health behaviours								
General index of intensification of health behaviours acc. to Health Behaviour Inventory (range 24–120)	79.71±12.99	79.5	74.10±12.51	74.0	81.37±12.75	81.0	2.061	0.039
Total weekly energy expenditure (MET-min./week)	7322.29 ±7797.03	5038.5	9967.74 ±12348.8	6303.0	6539.83 ±5722.06	4809.0	-0.669	0.502
pHDI-10 (score value)	33.57±5.55	34.0	30.62±5.79	31.0	34.45±5.20	35.0	2.638	0.008
nHDI-14 (score value)	38.13±6.24	39.0	42.62±5.37	41.0	36.80±5.88	38.0	-4.005	0.000
Level of nutritional knowledge (score value)	14.72±3.40	14.0	14.23±2.66	15.0	14.87±3.59	14.0	0.544	0.586

SD – standard deviation; MET – metabolic equivalent; pHDI-10 – pro-Healthy-Diet-Index; nHDI-14 – non-Healthy-Diet-Index
The presented results of the statistical analysis with U Mann-Whitney test refer to the comparison of groups distinguished in terms of gender.

Table 2. Pearson correlation coefficients (r) between PhA and anthropometric, body-composition and behavioural variables

Variable	r
Height	0.35
Weight	0.48
BMI	0.40
Waist circumference	0.37
Absolute fat mass value	-0.24
Fat free mass	0.73
Skeletal muscle mass value	0.79
Total body water	0.72
Extracellular body water	0.58
Level of nutritional knowledge	-0.23

All correlations significant at the level p<0.05

Striving for identification of the PhA predictors in the examined cohort of young adults, a regression model was constructed explaining the variability of the dependent variable of interest to the researchers. At the first stage of analysis, the following characteristics were considered: age, gender, anthropometric variables, and BIA body composition parameters. The method of backward stepwise multiple linear regression was applied in the analysis of independent variables. The model occurred to be significant and allowed explanation of 82.48% of variability of the dependent variable [F(5.86)=81.022; p<0.0000]. The model error estimation, while adopting the mean PhA value in the study group equal to 6.3837, was 5%, thus, this was a small error. The following predictors had the greatest effect on PhA: gender, BMI, FM, VAT and SMM. All the mentioned explanatory variables (independent) were related with PhA value (p<0.05) (Tab. 3).

Table 3. Stepwise multiple regression model explaining PhA considering anthropometric variables and bioimpedance body composition indices

N=92	R^2= 0.8248; Standard Error of Estimate: 0.32510 F(5,86)=81.022; p<0.0000			
	β	Standard Error of β	t(86)	p
Intercept	1.402	0.421	3.325	0.001
Gender	-0.997	0.188	-5.294	0.000
Body mass index	0.217	0.033	6.500	0.000
Fat mass	-0.128	0.014	-8.865	0.000
Visceral adipose tissue	0.202	0.096	2.103	0.038
Skeletal muscle mass	0.102	0.016	6.544	0.000

The same statistical procedure was performed in order to assess the effect of behavioural variables on PhA values (Tab. 4). This model also occurred to be significant [F(3.88)=21.9; p<0.0000], and the predictors considered in this model explained jointly 42.75% of the dependent variable. Three predictors exerted a significant effect on PhA: male gender, level of nutritional knowledge, and general intensification of health behaviours assessed using the HBI scale. Estimation error for this model, while adopting in the examined group the mean PhA value equal to 6.3837, was 9.1%; thus, this is a greater error compared to the model considering anthropometric variables; however, it is still a relatively small error.

Table 4. Stepwise multiple regression model explaining PhA considering behavioural variables

N=92	R^2= 0.4275; Standard Error of Estimate: 0.581; F(3.88)=21.9; p<0.0000			
	β	Standard Error of β	t(86)	p
Intercept	6.028	0.433	13.912	0.000
Gender	1.127	0.149	7.587	0.000
Level of nutritional knowledge	-0.05	0.019	-2.716	0.008
General index of intensification of health behaviours acc. to Health Behaviour Inventory	0.01	0.005	2.115	0.04

Thus the model considering anthropometric variables allowed explanation of the considerably higher percentage of PhA variability than the behavioural model. A model which would simultaneously consider anthropometric variables and behavioural variables could not be constructed.

DISCUSSION

Selberg et al. proposed considering PhA values lower than 4.4° as abnormal, those within the range 4.4° – 5.4° as borderline, and values higher than 5.4° as normal. The PhA values over 7.8° may occur in physiological conditions in athletes and body-builders, and in these situations they are associated with high values of the BMI resulting from high muscle mass [7]. Significant differences in PhA values were confirmed between populations from various countries (Switzerland vs. USA vs. Germany); however, the causes of these differences have not been fully explained [for additional information, see: 10]. The PhA values obtained in own study in the whole study group (mean 6.38°±0.75°), as well as in gender groups (males 7.22°±0.72°; females 6.13°±0.57°), should be considered as normal [7]. Considering the strong relationship between PhA and gender, age and BMI, and also taking into account differences in PhA reference values in various populations, the values obtained in own study should be referred to the reference values for European cohorts gender, age and BMI-stratified. The available reference values for PhA, which are closest geographically, come from a German study by Bosy-Westphal et al., conducted in a group of more than 200,000 persons [10]. For the age group 18–19 years and normal values of BMI (18.5–25), the PhA reference value in that study was for females – 5.93°, and for males – 6.82° [10]. Thus, the values obtained in the presented study are higher than the above-mentioned German reference values. It cannot be excluded that the high levels of PA in the examined cohort of young adults may be responsible for the higher percentage of muscle mass in BMI values than in the German population. The lack of data concerning body composition in the cohort investigated by Bosy-Westphal et al. [10] does not allow verification of this presumption. In turn, the results of own study concerning PhA are lower than in an Indian population in which Kumar et al. [26] found in a cohort of healthy adults at mean age of 32.64±12.25 mean PhA values 7.32°±1.17°, and in the groups of females and males: 7.05°±1.58° and 7.43°±0.98°, respectively. Barbosa-Silva et al. [5] indicated 6.55°±1.1° as the reference PhA value for an Asian population; therefore, the results of the study by Kumar [26] differ *in plus* from the indicated values. It is not known to what extent these differences result from technical characteristics of the BIA devices used [9], or structural differences concerning the anatomical structure of the torso and limbs [1].

In the presented study, significant differences in PhA values were observed according to gender, i.e. PhA values were lower in females. This result is in accordance with the current state of knowledge; for example, in an American study in a group of 1,967 healthy adults, significantly lower PhA values were observed in females than males [5]. In a German study by Bosy-Westphal et al. [10] in a population of young adults, gender and age were the basic determinants of PhA (higher PhA values in males and younger persons), and these 2 variables explained 7% of the PhA variance [10]. The differences in PhA according to gender are ascribed to the differences in body composition, i.e. a higher average content of lean body mass in males [1].

Concerning the variables correlated with PhA, the results of own study do not deviate from the current state of knowledge. In the presented study, both FFM and SMM were strongly positively correlated with PhA ($r=0.73$ and 0.79, respectively), and SMM was included into the regression model as a significant predictor of PhA. In own study, the BMI index was positively correlated with PhA ($r=0.40$), and was also a predictor of the PhA considered in the regression model. While referring these findings to the state of knowledge, attention should be paid to the fact that, e.g. in the study by Kumar et al. [27], PhA values were positively correlated with BMI ($r=0.011$; $p<0.001$). While interpreting these findings, it should also be pointed out that this relationship reflects the larger number of cells and cellular membranes of the muscle tissue or adipose tissue (BMI does not provide information concerning body composition). In the study by Gonzales et al. [6], a strong correlation was confirmed between PhA and FFM. As early as in the pioneer study by Baumgartner et al. [26] conducted in a group of healthy individuals, PhA was positively correlated with FFM in males, whereas negatively correlated with %FM in both genders. In the study by Gonzalez et al. [6], a strong predictor of PhA in both genders was FFM measured by the method of underwater weighting (UWW). In the presented study, SMM, an important component of FFM, was a positive predictor of PhA, whereas FM was a negative predictor. While referring to the relationship between SMM and PhA observed in own study, the results of investigations by Selberg et al. [7] should also be recalled, which confirmed that PhA was positively correlated with muscle mass as well as with muscle strength. Therefore, the above-quoted researchers defined PhA as 'simple muscle index'. However, in the area of discussed correlations, not only muscle mass is important, but also muscle quality, with consideration of such parameters as: composition, metabolism, aerobic capacity, insulin resistance, fat infiltration, fibrosis, etc. It should also be remembered that the loss of muscle mass does not fully explain the loss of function [28]. Positive correlations between FFM, SMM, as well as BMI and the PhA values, result from the fact that PhA increases together with an increase in the number of cellular membranes, exerting an effect on the magnitude of the reactance. Persons with higher FFM and SMM parameters have a larger number of muscle cells, while persons with higher BMI – a larger number of muscle cells or fat cells, which results in an elevation of PhA.

In a number of clinical situations negatively projecting on FFM, changes in PhA are also observed [6]. However, when changes in FFM do not yet occur, e.g. in an early phase of malnutrition or in sepsis, an increase occurs in the volume of extracellular fluids, which results in an increase in the ECW/ICW ratio and decrease in PhA. This mechanism of PhA decrease occurs in obese individuals [6]. The relationship between PhA and BMI is of bimodal character, which means that until the value 40 kg/m^2, together with an increase in BMI, the PhA increases; however, after exceeding the threshold for morbid obesity – PhA values begin to decrease. This is associated with a physiological higher extracellular to intracellular water ratio of the fat tissue, as well as fluid overload in advanced obesity [10].

The basic determinants of PhA differ according to the stage of the life cycle. As mentioned previously, in adults, higher PhA values occur in males and younger persons [10]. Nevertheless, in children and adolescents in the same German study by Bosy-Westphal et al. [10], it was confirmed that the basic determinants of PhA are age and BMI (PhA increases together with age and increase in BMI). In this group, age is a basic predictor of PhA (explains 10.8% of variance), while BMI is a weak predictor (explains 1% of variance). In the age group below the age of 14, no differences in the PhA value occur according to gender [10]. In the study by Bosy-Westphal et al., the BMI was a positive predictor of PhA, both in children and adults; however, in the group of adults, as mentioned before, the values of PhA increase together with an increase in BMI up to the value of approximately 40 kg/m^2, and above this value the direction of this correlation is reversed [10].

The model of regression considering anthropometric and body composition variables showed a great explanatory strength (82.48%). The results of own study differ from the current state of knowledge concerning the predictors of PhA, because age was not considered in any of the regression models explaining the PhA variability. In the study by Gonzalez et al. [6], age occurred to be the most important biological factor determining the PhA variability, because BCM decreases with age, and extracellular volume increases, which elevates the ECW/ICW ratio. Discrepancy between the results obtained by Gonzalez et al. [6] and the results of own study may result from the fact that in own study a homogenous group of young adults was examined where the mean age was 19.33 (STD 0.915). In turn, Selberg et al. consider that the effect of age on PhA is relatively small [7]. However, in the study by Wu, older age was related with lower reactance and lower PhA values [29]. The latest meta-analysis by Matiello et al. [30], considering 46 research projects including a population of almost 250,000, informs that PhA changes during the human life cycle in the way that PhA increases until the age of adolescence (16–18 years), then stabilizes during the period of adulthood (age 18–38 years in males and 18–48 years in females), and subsequently gradually decreases as the body ages. Males show higher PhA values in all age groups, except from early childhood (0–2 years) and individuals aged over 80 [30].

The regression model constructed with the use of behavioural variables allows explanation of the lower percentage of PhA variability (42.75%). The predictors of PhA were: gender, general health behaviour index measured by means of the Health Behaviour Inventory, as well as the level of nutritional knowledge, which occurred to be a weak negative predictor of PhA. None of the indicators of the quality of diet used for evaluation of the respondents' mode of nutrition (pHDI, nHDI), was a significant predictor of PhA. While discussing this result, attention should be paid to the novel research by Barrea et al. [31], which demonstrated the importance of adherence to the Mediterranean diet, assessed by means of a questionnaire, as a predictor of PhA in the Italian population. This explained a considerable percentage of PhA variability (44.5% in males and 47.3% in females), irrespective of the effect of gender, age and weight [31]. However, the cross-sectional character of that study excludes the possibility of drawing conclusions concerning cause-effect relationships between the investigated variables.

In a Turkish study by Koseoglu et al. [32], no correlation was confirmed between PhA and health behaviours among females, with consideration of the levels of consumption of micro-components of diet evaluated using the dietary record and the level of PA. These results are consistent with the result of own study, where nutritional variables were not included in the regression model. While interpreting these results it should be remembered that the assessment of behavioural variables by means of self-reported questionnaires is burdened with the risk of occurrence of a number of errors affecting reliability of the data obtained, including a recall bias [33, 34]. However, it should be emphasized that the research instrument of the food frequency questionnaire (FFQ) type applied in the presented study, containing 47 items concerning the frequency of consumption of the groups of food products/beverages, should be qualified as the FFQ with shorter food lists (100 items and below), which is considered a less reliable source of data pertaining to the frequency of consumption, compared to the FFQs with longer food lists [35]. It should also be taken into account that questionnaires concern the intensification of behavioural variables within a specified time interval, while body composition remains under the influence of long-term influences.

The results concerning the level of the respondents' PA require comment. The observed levels of PA should be considered as high: both in the group of males and females, as well as with respect to the total study group, mean results expressed as MET-min/week remain within the category of high PA, exceeding the cut-off point at the level of 3,000 MET-min/week [22]. Also, concerning the results of the assessment of the level of PA among occupationally-active Polish males, performed using the same instrument [36], the results should be considered as high. In turn, the results concerning PA obtained in the presented study which, in the whole examined group, were 7,322.29 MET-min/week, on average, are comparable to the level of physical activity of Polish and Irish physical education students which, in the study by Górski et al., for Polish students was 11,477 MET-min/week (thus, it was higher than in own study), whereas for the students from Ireland it was 7,205 MET-min/week [37]. Also, Pastuszak et al., in their study conducted among students of physical education from Warsaw and the Charles University in Prague (Czech Republic) reported the level of PA among Czech students on the level of 9,525.2 in males and 10,964.3 in females, whereas among Polish students – on the level of 4,034.3 and 2,469.8, respectively (mean MET-min/week values were provided.) [38].

Referring the results of own study to the results reported in the above-quoted publications, allows the presumption that the obtained results may be typical of young adults studying specialties which include intensive education in the area of health promotion and the principles of a health promoting lifestyle, and also contain elements of the education programme which imply the PA of students during classes at university. While interpreting the results obtained, it should also be remembered that the shortcoming of the IPAQ is overestimation of the level of PA in the case of persons exercising intensively [22]. It cannot be excluded that this phenomenon also exerted an effect on the result of the presented study.

Nevertheless, the respondents' PA was neither a significant predictor of PhA, nor was it correlated with PhA values. In turn, meta-analysis of cross-sectional studies by Mundstock et al. [13] indicated that PhA is higher among persons who are physically active ($p<0.001$), and in longitudinal studies the mean PhA values were significantly higher in persons who received PA intervention ($p=0.002$) [13]. It is also known that PhA is positively correlated with the level of general muscular fitness [28].

To the best of the authors' knowledge, the presented results are the first attempt in Poland to identify anthropometric, BIA body composition, and behavioural predictors of PhA in a cohort of the young adult population. Also, in international literature this issue has not been extensively examined. It would therefore be justified to undertake studies of this profile in a sample which would be representative for the Polish population.

Limitations of the study. The method of selection of the respondents who were students of one university makes it impossible, based on the results obtained, to formulate generalized conclusions concerning the entire Polish young adult population.

CONCLUSIONS

1) Anthropometric variables, bioelectrical impedance body composition indices and gender explain the highest percentage of PhA variance in the examined group of young adults.
2) PhA predictors considered in the regression model explaining the highest percentage of variability of the dependent variable in the examined group of young adults are: gender, BMI, FM, VAT and SMM.
3) It was not possible to construct a regression equation which would simultaneously consider behavioural and anthropometric predictors.

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