DETERMINATION OF BODY COMPOSITION BY BIO-IMPEDANCE ANALYSIS IN YOUNG STUDENTS

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Abstract. Using experimental data for adults (a total number of adults examined -236 out of which 74 male and 162 female students at Yanka Kupala State University of Grodno, Belarus) comparisons between the fatty mass body determined by a bio-impedance analysis method, and the body mass index (Quetelet's index) calculated on the basis of anthropometrical measurements have been carried out. A statistical calculation of the experimental data has been applied. At a stage of the specification pair exponential regression has been selected. Its parameters were estimated by method of the least squares. The statistical importance of the equation was verified using the determination coefficient and Fischer's criterion. The correlation coefficient based on the experimental data between the fatty mass body and Quetelet's index is b =0.042. The analysis showed that deviations when calculating the same object using the coefficients as provided in literature can reach 30%. For group of male students the parameters determined by anthropometrical and electric characteristics of the person have been analysed. The analysis revealed that relative fatty mass characterizes norm of a body state more precisely in comparison to the body mass index.

Keywords: bio-impedance analysis, nutrition, youth, body composition.

Introduction

The study of the component composition of a human body is of great interest for both medical workers and researchers of bio-objects (Nikolaev et al, 2009; Hakobyan et al., 2007; Ryabova, 2017; Bessesen and Kushner, 2004). There are both direct and indirect methods to measure the components of the body composition. At the same time, direct methods of obtaining information make it possible to obtain only one component and are costly. Indirect methods allow to receive estimates of the body composition based on physical patterns. A number of parameters are measured during the research, yet some parameters are either insignificantly dependent or independent on the individual and are considered as constants (invariants of the body composition). The reliability of the parameters obtained in this way is due to the comparison with the measurement of a similar parameter by a direct method (Nikolaev et al., 2009).

One of such methods to examine the body composition is the bio-impedance analysis method, which allows to estimate absolute and relative values of parameters of the body composition and metabolic correlates based on the measured values of the electrical resistance of the human body and anthropometric data. This method makes it possible to correlate these values with intervals of normal values, to assess capabilities of the body and risks of developing diseases. The bio-impedance analysis is a contact method to measure electrical conductance of biological tissues making it possible to assess a wide range of morphological and physiological parameters of an organism. It is based on measurements of active and reactive resistance of the human body or its segments at various frequencies. On their basis, the characteristics of the body composition are calculated, such as fatty, lean, cellular and skeletal-muscle mass, volume and distribution of water in the body (Nikolaev et al., 2009).The calculation of these characteristics is performed using a software package installed on the personal computer connected to the analyser. In this way, the bio-impedance analysis makes it possible to obtain reliable estimates of lipid, protein and water metabolism and a number of metabolic correlates that can be successfully applied to assess the nutritional status of the organism (Karbauskiene, 2016)

Materials and methods of research

As a research object, male and female students of Yanka Kupala State University of Grodno voluntarily took part in the research. A total number of 236 young student examined, 74 of them male and 162 female students. Initially, anthropometric indicators have been evaluated, e.g. height, weight, waist circumference and hips.

After measurements of anthropometric index examinations were conducted using the ABC-01 Medass analyser connected with the specially tailored software "Sport" on a personal computer. On the basis of these anthropometric indexes and electric characteristics measured by the Medass analyser, the protocol of a dynamic condition of the person determining key parameters of the person has been generated: fatty weight (FW), lean (fat-free) weight (LW), fissile cell-like weight (FCLW), total fluid (TF), extracellular fluid (ECF) and intracellular fluid (ICF). In addition, energy characteristics, such as basal metabolism (BM) and specific basal metabolism (SBM) have been determined.

Research

The bio-impedance analysis is based on measurement of active and reactive components of human body when exposed to electric fields of variable frequency. The active component of the resistance is determined by the ion currents of the intra- and intracellular fluid and the reactive component by the cell membranes. All analysers used in practice can be classified into:

a) frequency − one-two- and multi-frequency. Generally, in analysers frequencies 5 and 50 kHz are used;

b) on areas of measurements of resistances on the human body, which are both local (parts of the body) and integral;

c) tactics of measurements - single, episodic, etc.

The bio-impedance methods are based on Ohm's law for alternating current I:

$$I = \frac{U_m}{Z_m},$$

where Um – the measured voltage at the object is a total resistance determined by the active and reactive components: $Z_m^2 = R^2 + X_C^2$. The values of tension and currents recorded from a body of the person allow defining impedance components on which based absolute values of components of a body are calculated (Deurenberg& Tagliabue, 1995; Heitmann, 1990; Kushner &Schoeller, 1986)

The alternating current generator maintains a given current I regardless the magnitude of the human impedance Zm. Voltage from the biological object is fed to the detectors. These detectors work in one of two options. In one of them amplitude and phase detectors are used. In the amplitude detector, constant tension at the exit is proportional to the impedance module. In a phase detector, the constant tension proportional to phase shift between alternating stress on an object and generator current is formed. In blocks of information processing units of the OI, the values of the voltages from the detectors are converted into module values and the phase angle of the impedance $tg\varphi = \frac{X_c}{R}$, which can then be converted into active and reactive resistances. The active resistance will be determined by the state of the conducting medium. For biological tissues, this medium is aqueous solutions of electrolytes in the extracellular and intracellular fluids. The active component of the impedance is responsible for the dissipation of electrical energy into heat according to the Joule-Lenz law. The reactance is equivalent to the capacitive resistance of cells in the body. The capacitive resistance is created by dielectric partitions between the conducting regions. In biological objects, these partitions are membranes of cells and cellular organelles. In the electrolyte solution on both sides of the membrane, ions under the action of an electric field move to its surface, until the field of accumulated charges equilibrates the applied external field. As a result, the charge accumulates in the vessel and electrical energy, accordingly. It is considered (Nikolaev et al., 2009) that at the frequency of the acting electric field of 5 kHz, the main contribution to the total current is due to the resistance of the extracellular fluid. At a field frequency of 50 kHz, both intracellular and extracellular resistance determines current components. At frequencies of 500 kHz and higher, the cells do not work as capacitors, but as active conductors.

Results of Research

In practice, electrical circuits with four, eight or more electrodes are used. In this case, half of the electrodes are used as setting voltages (AA, BB, CC), and the second half (A_1A_1, B_1B_1, C_1C_1) - current sensing (Figure 1).

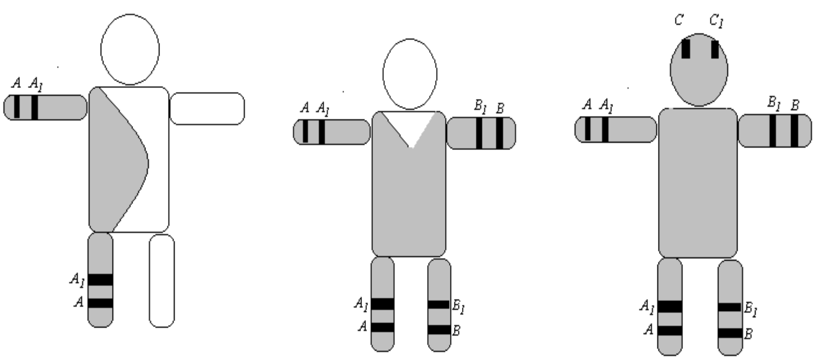


Figure 1. – Schemes for connecting bio-impedance analyzers: a - four-electrode, b - eight-electrode, c - ten-electrode

In figures with four (a) and eight (b) electrodes, the current does not go through the entire human body. Therefore, the recorded resistances and reactive resistance do not correspond to the real ones. In the most accurate way, the active and reactive resistances of the human body are measured according to the scheme in Figure 1 b. A four-electrode circuit analyser ABC Medass operates according to the scheme as indicated in Figure 1 a. Both the active and reactive components of the impedance will be overestimated in this case, since the current does not go through the entire cross- section of the person. However, if necessary, to identify the exact values of the resistances measured with four-electrode circuits (such as ABC-01 Medass), it is possible to determine the conversion factor. For this, it is necessary to measure the same group on different analysers. The coefficient, which connects the resistance close to the real one (according to Figure 1 b), with the resistance according to Figure 1 a, turned out to be equal to $k = 0{,}795 \pm 0{,}064$.

To assess the components of the body composition, both anthropometric and electrical parameters of the human body are used. Moreover, both of these parameters are integral as it is not possible to take into account the real geometric shape of a person.

To increase the accuracy in the calculation of human body components, several measured parameters are introduced with coefficients determined experimentally. At the same time, for the group of people investigated, the value of this parameter is measured applying a different reference method. Coefficients which ensure the minimum root-mean-square error of estimates for a given group of people, are calculated. In mathematical statistics, such problem is called identifying a multiple linear regression, the resulting equation for the parameter being studied is called regression.

Several components determined by the bio-impedance method using anthropometric data. To determine the volume of total body fluid (TF), the following formula is used (Nikolaev et al., 2009):

$$TF = b_0 + \frac{b_1 * L^2}{R_{50}} + b_{мт} * BM + b_в * Age + b_n * Gender + Add \qquad (1)$$

where bi - coefficients determined experimentally, R50 - the human active resistance at 50 kHz, L - human growth, BM - the body mass, Age - the person's age, Add and b0 = constant and variable constituents. Regression equations may possibly have other components.

The second component in formula (1) shows the relationship between the amount of the conducting liquid and the length of the object and its resistance. The remaining components are not derived from the physical model, but their presence in (1) improves the accuracy of the TF estimates. Measurement of the resistance R50 should be performed at a sufficiently high frequency, thus that the alternating current penetrates into the cells, and the intracellular fluid contributes to the overall conductivity. In most bio-impedance analysers, this frequency is f = 50 kHz.

The parameters for the regression equation (1), according to the data of some authors, determined for N people, are presented in Table 1.

Table 1. Parameters of regression equations for estimating TF

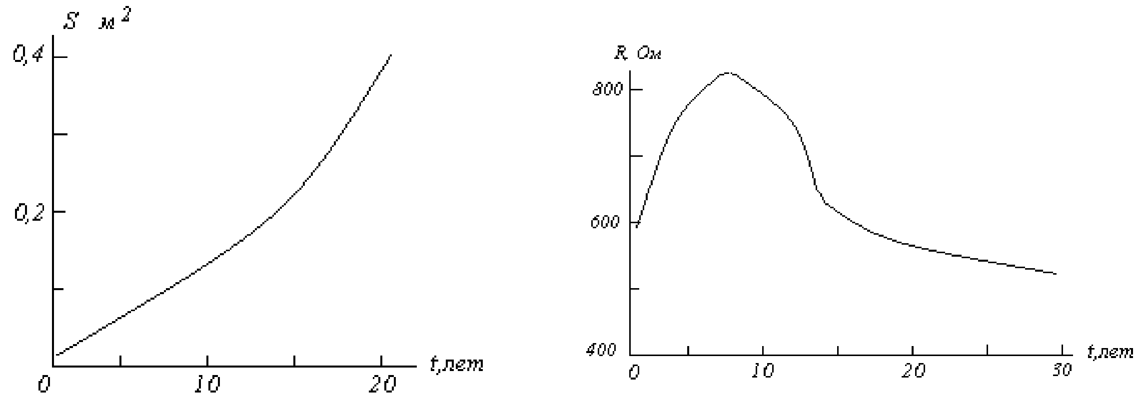
	b_0 (kg)	b_1 (kg*Om/m^2)	$b_{мт}$	$b_в$ (kg/year)	Add	N (human)	link
1	6,53	0,1753	-0,11	2,83	-	139	[5]
2	-17,58	-0,172	-	0,04*MT	0,165L	139	[6]
3	8,399	0,143	-			40	[7]
4	8,315	0,105	-			40	[7]
5	1,203	0,176	-			734	[8]
6	3,747	0,113	-			1095	[8]

Taking into account these parameters and using the impedance components and anthropometric data, a calculation of TF for several people was carried out according to the formula (1). The spread of TF values reaches 10%, calculations for a lean (fat-free) weight coincide within 30%, which indicates that there are no universal regression equations for calculating these quantities so far. Furthermore, it should be noted that the manufacturers of bio-impedance analysers do not specify formulas for calculating the main components of biological objects.

To calculate fatty weight (FW), a similar formula is used, which includes the active component of resistance at frequency f = 50 kHz, height, weight, age and sex of the human (Nikolaev et al., 2009):

$$FW = 14{,}94 - \frac{0{,}079 * L^2}{R_{50}} + 0{,}818 * BM + 0{,}077 * Age - 0{,}064 * Gender * BM - 0{,}231 * L \quad (2)$$

In all formulas for calculation of the component composition of a human body, either active or reactive components of the impedance are present. In terms of determination of body composition for elder persons, such data is provided in the literature, therefore, thus data is available to compare the experimental results obtained. Regarding school and preschool age, such data is not available, therefore, based on anthropological parameters, trials will be done to qualitatively determine the behaviour of the active resistance as a function of age (Figure 2b).



a) b)

Figure 2. – a) – "effective"cross-sectional area, b) – active resistance of the human body as a function of age

Using the averaged data of the mass and growth of a person from birth to 20 years (the time of growth retardation), it is possible to approximate them as follows:

$$m(t) = 4 + 1{,}7916t + 0{,}10417t^2 \ (kg); \ l(t) = 0{,}4 + 0{,}16026t - 0{,}00347t^2 \ (m) \quad (3)$$

Using functional dependencies for mass and growth, it is possible to determine the "effective" cross-sectional area S and, accordingly, the active resistance of the human body for the age $0 \le t \le 20$ of years:

$$S(t) = \frac{m(t)}{\rho l(t)}; \quad R(t) = \rho_{эл} \frac{l(t)}{S(t)} \quad (3)$$

The theoretical dependences of the cross-sectional area and the active resistance of the human body on age are shown in Figure 2. As seen, the active resistance grows to 8 years, and then gradually falls. The explanation of this dependence of resistance, according to equations (2) - (3), is explained by competing processes associated with the growth of the cross section and the length of the human body (equation 3 and figure 2 a). Up to 8 years, the length of a person increases faster than its cross-sectional area, from 8 to 20 years the area grows faster, over 20 years only the cross-sectional area is slightly increasing, at this age the active resistance slowly decreases.

In the study of the component composition of a biological object, an anthropometric index of body mass index (BMI) is used, defined as the ratio of body weight to the square of its length (measured in kg/m^2):

$$BMI = \frac{m}{L^2} \quad (4)$$

It is believed, that this index (also called the Quetelet index) characterises the physiological state of a person. Experimental data of bio-impedance research, carried out on a voluntary basis, among students are fully presented (Sun et al. 2003).

Using experimental data for the student's contingent comparisons between the fatty mass body determined by a bio-impedance method have been carried out according to formula (2) and Quetelet index (4), defined on the basis of anthropometrical measurements.

A statistical calculation of the experimental data has been carried out. At the specification stage, a pair exponential regression has been selected. Its parameters have been estimated by the method of least squares.

The statistical importance of the equation has been verified by means of coefficient of determination and Fischer's criterion. The coefficient of correlation has been calculated by a formula:

$$b = \frac{\overline{xy} - \overline{x} * \overline{y}}{S^2(x)},$$

where $\overline{x},\ \overline{y},\ \overline{xy}$ - selective averages, S(x) – selective dispersion.

The correlation coefficient based on the experimental data between FMB and Quetelet's index is b = 0.042.

Conclusions

1. Measurements of active components of an impedance of a biological object on four-electrode and eight-electrode analysers have been compared. The coefficient of recalculation of the actual active and reactive resistance of the person using experimental data received on the four-electrode bio-impedance analyser has been defined.
2. The regression equations for calculation a component of structure of a human body have been analysed. It has been identified that deviations when calculating the same object with use of the coefficients as provided in literature can reach 30%.
3. For a group of male students (62 people), the parameters determined with the help of human anthropometric and electrical characteristics have been analysed. It has been determined that the relative fat mass of the body more accurately characterizes the norm of a body state, rather than the body mass index.

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