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Peculiarities of changes in parameters of component body composition of representatives of the youth age period detected by the method of bioimpedance analysis

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ABSTRACT

The results of the study of body composition parameters using bioimpedance analysis of representatives of the youth age period of 14–19 years are presented. The obtained data of bioimpedance analysis for this age category are in satisfactory agreement with the literature data. It is determined that the intracellular liquid of individuals, related to the total volume of liquid in it, increases with age of the individual. It has been suggested that the amount of intracellular liquid relative to the total liquid increases due to an increase in the number of cells (since tissue growth occurs due to active cell division) as well as decrease in the number of extracellular liquid, most often caused by an increase in fatty tissue for this age group. This pattern is observed for female and male contingent of the studied. The distributions of relative intracellular liquid depend on age and change from approximately uniform in adolescent to normal in youthful age. The specific basal metabolism is increasing for males between the ages of 14 and 19, which is explained by the increasing secretion of hormones of the anterior pituitary (somatotropic hormone or growth hormone). The hormone causes a pronounced acceleration of linear growth and, as a result, an increase in the specific basal metabolism in the puberty, especially in males.

Аннотация

Приведены результаты исследования параметров состава тела методом биоимпедансного анализа у представителей подросткового и юношеского возрастных периодов 14–19 лет. Полученные собственные данные биоимпедансного анализа данной возрастной категории удовлетворительно согласуются с литературными. Определено, что внутриклеточная масса биологических объектов, отнесенная к общему объему жидкости в нем, растет с увеличением возраста объекта. Высказано предположение, что количество внутриклеточной жидкости по отношению к общей жидкости в рассматриваемой возрастной группе возрастает за счет увеличения количества самих клеток (поскольку рост тканей происходит за счет активного деления клеток), а также благодаря уменьшению количества внеклеточной жидкости, причиной которого чаще всего является увеличение количества жировой ткани. Эта закономерность наблюдается как для женского, так и мужского контингента исследуемых. Распределения относительной внутриклеточной жидкости существенно зависят от возрастной категории и изменяются от приблизительно равномерного в подростковом возрасте до нормального в юношеском. Удельный основной обмен для лиц мужского пола в возрасте от 14 до 19 лет нарастает, что объясняется нарастающей секрецией гормона передней доли гипофиза (соматотропного гормона или гормон роста). В пубертатном периоде, в особенности у лиц мужского пола, он вызывает выраженное ускорение линейного роста и, как следствие, повышение удельного основного обмена.

Keywords: Component composition, bioimpedancemetry, youth age

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1. Introduction

All currently used methods for assessing the component composition of the body are classified into reference methods, laboratory and field ones [1-2]. The reference methods include multicomponent models, computerized tomography (CT), magnetic resonance imaging procedure (MRI). Laboratory methods consist of dual energy X-ray absorptiometry, densitometry, hydrometry, ultrasonic investigation (ultrasound), three-dimensional scanning. Field methods include anthropometry, bioimpedansometry, determination of body mass index. Anthropometric methods are the simplest and most affordable methods based on changes in the morphometric parameters of the body. Based on these indicators the method of calculating body mass index (BMI) or the Kettle index, is used to assess excess or underweight. However, the BMI indicator is the only a factual sign of the presence of excess or underweight, without giving a qualitative assessment of the body components. For this reason, the biophysical method of studying the component composition of the body, founded in 1880, gained great popularity. W. Thomson, who studied the resistance of tissues of individuals, proposed the method. He suggested that in addition to the general resistance inherent in the body, it is possible to determine the resistance of its individual components. The electric resistance of biological tissues which called bioelectric impedance, and the method itself is called the bioimpedance analysis method. The total impedance value includes two components: the active resistance (or tissue inherent resistance) and reactance, characterized by a shift in the phase of the current relative to the voltage due to the capacitive properties of cell membranes. The total water content in the body is calculated by the value of active resistance. The high conductivity of water is due to the presence of electrolytes in it. The values of the main metabolism and active cell mass, namely the mass of muscles and internal organs are calculated by the magnitude of the reactive component of the impedance. The advantages of the method are low cost and availability, the absence of radiation exposure, the ability to conduct studies in dynamics, as well as the non-invasiveness of the method and the ability to perform in the field.

Currently, the bioimpedance analysis method is used in a wide range from examining the parameters of the human body condition, including medical aspects [1–5] to attempts to determine the biological age of an individual and the nutritional status [6–8]. A number of literature reviews [7–11] present an analysis of modern literature regarding the potential of the bioimpedance method in assessing of the human body composition.

The bioimpedance analysis method (BIA) based on measuring the electric conductivity of biological tissues, allows to evaluate the morphological and physiological parameters of the body in a wide range. In the BIA the active and reactive resistance of the body (or its segments) are

measured at frequencies from 5 to 500 kHz. Using the numerical values of the obtained resistances in combination with anthropometric data (mass, height, gender and age of the individual), such characteristics of the individual composition as fat, cell and musculoskeletal mass, volume and distribution of extra- and intracellular liquid in the body are calculated [1]. A special equipment called a bioimpedance meter is used to conduct BIA. Currently, BIA is successfully used by physicians of various specialties (nutritionists, endocrinologists, cardiologists, sports medicine and etc.) in their practice [11].

The bioimpedance measurements show that there are significant differences in the composition of the human body, depending on the age and gender [1, 6, 8, 11]. It has been established that for women in the range from youthful to old age, fat mass monotonously increases, however, its decrease is noted at senile age [1]. The proportion of lean mass and its individual components (musculoskeletal, total liquid volume, intracellular and extracellular liquid) simultaneously decrease with an increase in fatty tissue in the body. The lean mass is up to 80% of body weight in adolescent and youthful categories of women (16–20 years old), and its decline starts from the first period of adulthood (21-35 years old), and it becomes less on 10% in the second adulthood (36-60 years old) than in adolescence. A complete decrease in lean mass from youthful to old age is 15%.

The study of the dynamics of body parameters in children is of particular relevance for dynamic monitoring of the development of the body [8, 12, 13, 16, 18]. The results of studies conducted by anthropologists and pediatricians show the possibility of using BIA in child anthropology, starting at the age of 10. One of the directions of modern research is the study of body composition in youth age periods [5, 14, 18, 19], when the formation of the main parameters of the human body occurs. The puberty occurring during this stage is a process of changes in the body of adolescents, as a result of which they become adults and able to continue the generation. Despite individual differences, the average pubertal period begins at 12-14 years and ends at 18-20 years. Puberty is triggered by signals from the brain through the pituitary-hypothalamus system to the gonadotropic hormones, testes and ovaries. The gonadotropic produce various hormones that stimulate the growth and development of the brain, bones, muscles, skin, and reproductive organs in response to these signals. The growth of the tubular bones of the skeleton accelerates in the first half of puberty and ends completely with the completion of puberty. Prior to puberty, differences in the structure of the body of a girls and boys are reduced exclusively to primary sexual characteristics. The significant differences in the size, shape, composition and function of many structures and systems of the body are related to secondary sexual characteristics during the period of puberty. For a given age period (14-19 years), the physical development takes place in human ontogenesis, which is considered as a dynamic process of growth (increase in length and body mass,

development of organs and body systems, etc.) and biological maturation of a given individual. The development process of morphological and functional properties of the organism (growth rate, mass gain, a certain sequence of increase in various parts of the body and their proportions, as well as the maturation of various organs and systems at a certain stage of development) are mainly programmed by hereditary mechanisms and implemented according to a certain plan optimal living conditions. Physical development reflects the processes of growth and development of the organism at certain stages of postnatal ontogenesis (individual development), when the transformation of the genotypic potential into phenotypic manifestations most clearly occurs. First of all, the human body is biological, organic and natural body, which is characterized by the term “physical condition” or “state of morphofunctional development”. The main parameters, properties and qualities of the biological organization of human include the type of constitution (or physique), morphofunctional organization and motor skills.

An analysis of the literature data [5, 14, 18, 19] shows that currently there is sufficient quantitative material for the measured parameters of the bodies of individuals in adolescence and youth age. It has been also stated that these parameters for adolescents and youths are different depending on nationality and place of residence. This indicates the need for a detailed analysis of the accumulated experimental data. This paper analyzes the features of the development and formation of the basic parameters of a person and energy characteristics for people from the age of 14 to 19.

The aim of research is to determine differences in changes of parameters of the human body composition for representatives of the youth age period.

Interest to this age category of individuals is that significant differences in the size, shape, composition and function of many structures and systems of the human body are formed at this age. The hypothalamic-pituitary system of the body that produces somatotrophic hormone is responsible for these processes. It is in childhood and adolescence somatotrophic hormone (or growth hormone) causes an acceleration of linear (in length) growth. This is due to the growth of the tubular bones of the skeleton. Somatotropin secretion gradually decreases with age. It reaches minimum values at the elderly and second period of mature age. Maximum values are reached during puberty in adolescents. This phenomenon is accompanied by an acceleration of metabolism, and as a result, the active growth of tissues due to cell division.

2. Material and Methods

Volunteers Volunteers of adolescent (school) and youth (junior students) age periods from 14 to 19 years old have been involved in this study. Volunteers were divided into three age groups: 1) adolescent - 14-15 years old, 2) first

Table 1 | The composition of the volunteers. Состав выборки исследуемых лиц.

Age, years	Gender	Number of participants, man	Total, man
14-15	F	40	76
	M	36	
16-17	F	52	100
	M	48	
18-19	F	61	122
	M	61	

youthful - 16-17 years, 3) second youthful - 18-19 years old. Written consents to the bioimpedance analysis were obtained from each volunteer (the age group 18–19 years) or from their parents (the age group 14-17 years).

Table 1 presents the age and gender composition of the volunteers.

The studies were conducted by bioimpedance analysis using the MEDASS ABC-01 body water balance analyzer with the software «Sport» [20]. BIA is based on measuring the body's electric resistance (impedance) using a bioimpedance analyzer [1, 2, 15, 16]. In this case, two pairs of disposable bioadhesive electrodes are used in the «arm – trunk – leg» circuit with a probing sinusoidal current of constant frequency and low power (not more than 500–800 μA). Measurements were performed for each volunteer twice. An electric current, depending on the frequency of the probing signal, flows both around the cell (at low frequencies) and through them (at high frequencies). In the used analyzer, the probe signal is supplied at 2 frequencies: $f_1 = 5$ kHz and $f_2 = 50$ kHz. It is believed that at the first frequency, the current passes only through the extracellular liquid (analogue of direct current), at the second frequency, the current passes through both the extracellular and intracellular liquids. The main parameters (fatty mass (FM), lean mass (LM) – body mass without fat, musculoskeletal mass (MSM) and active cell mass (ACM), as well as the total water volume (TWV) differentiated into intracellular liquid (IL) and extracellular liquid) are determined based on the measured active and reactive resistances of a person using also anthropometric data. In addition, data on the energy balance of an individual (the basal metabolism (BM) and the specific basal metabolism (SBM)) are given. As a rule [1, 17, 21], regression equations are used to determine the composition of an individual. Regression equations include the anthropometric and electric parameters of the individual. For example, to determine the total water volume in the body m_{TWV} one have to use the regression formula [21, 25, 27] in the form:

$$m_{TWV} = \frac{a_1 L^2}{R_{50}} + a_2 M + a_3 t + A + a_4 \quad \text{Equation 1}$$

where L – the height of the person, R_{50} – the active resistance at a frequency of 50 kHz, M – mass of the person, t – age, the value of A is determined by the gender of the volunteer.

Table 2 | Electric indicators for humans of different age and gender groups. Электрические показатели у лиц разных половозрастных групп.

Age, years	Gender	j, degree		R _i , Om		X _c , Om		R ₀ , Om
		own	literary	own	literary	own	literary	
14-15	F	6 ± 1	7 ± 1	673 ± 75	680 ± 80	74 ± 11	70 ± 11	756 ± 79
	M	7 ± 1	7 ± 1	556 ± 54	540 ± 70	67 ± 7	64 ± 7	634 ± 55
16-17	F	6 ± 1	7 ± 1	653 ± 64	655 ± 75	70 ± 8	68 ± 11	736 ± 71
	M	7 ± 1	7 ± 1	530 ± 70	530 ± 70	65 ± 9	63 ± 7	615 ± 78
18-19	F	6 ± 1	7 ± 1	670 ± 71	640 ± 80	75 ± 9	67 ± 11	760 ± 79
	M	7 ± 1	7 ± 1	560 ± 52	520 ± 80	69 ± 7	62 ± 8	646 ± 58

The constants a_i in the regression equation (1) are determined empirically. To select the constants a_n, the component of the individual is measured in other ways (for example, the dilution method [1] is used to determine the numerical value of the total body liquid mass) and the same component is compared in the form of equation (1). In this case, the desired constants a_i are determined by minimizing the error.

Equation (1) can be represented through the electric characteristics and anthropometric data of the human body. In this case, it becomes equivalent to the equation:

$$m_{TWV} = a_1 \frac{V}{\rho_e} + a_2 \rho_T V + a_3 t + A \quad \text{Equation 1*}$$

where V - the volume of the body, ρ_e - the resistivity of the body, ρ_T - density.

It is believed that one of the main indicators characterizing the state of a individual is the phase angle φ [6, 7, 13, 22]. The phase angle characterizes the phase shift of the alternating current relative to voltage, its values characterize the degree of fitness and endurance of the body, the functional state of the cells and the intensity of metabolism. The phase angle φ is determined from the ratio:

$$\varphi = \arctg \frac{X_c}{R} \quad \text{Equation 2}$$

where X_c - reactive, R - active resistance, which are defined for the three-parameter model in the form [21]:

$$R = \frac{R_0 + \omega^2 C^2 R_0 R_i (R_0 + R_i)}{1 + (\omega C (R_0 + R_i))^2} \quad \text{Equation 3}$$

$$X_c = \frac{\omega C R_0^2}{1 + \omega^2 C^2 (R_0 + R_i)^2} \quad \text{Equation 4}$$

where C - total capacity of cell membranes, R_i and R₀ - active components of the resistance of intra-and extracellular liquids.

The table processor Microsoft Office Excel 2007 and the statistical package “Statistica for Windows” 6.0 were used for statistical processing of the results. A control on normal (Gaussian) distribution was carried out using the Shapiro-Wilk W-test. It was believed that with the analyzed distribution does not differ from normal. If the distribution corresponded to the normal one, then the arithmetic mean and standard deviation were determined for the measured parameter: $\bar{X} \pm \sigma$.

3. Results and Discussion

The active resistance at the frequency of 5 kHz (R₀), the active and reactive components of the impedance at a frequency of 50 kHz (R_i, X_c) and the phase angle (φ) were determined as a result of bioimpedance studies. The numerical values of the presented parameters are given in Table 2 in comparison with the literature data [21].

As can be seen from table 2, the phase angles for the gender and age categories are generally consistent with the data [22]. Active and reactive resistances monotonously fall with an increase in height and their insignificant growth is observed for the age group of 18-19 years in the conducted study.

Regression-coupling equations allow to determine the main parameters of the human body and are compiled based on electric characteristics with known anthropometric parameters. The data analyzed for the considered age and

Table 3 | Parameters of body composition in individuals of different age and gender groups. Параметры состава тела у лиц разных половозрастных групп.

Age, years	Gender	m _{ACM} /m _{LMb} %		BM, kcal/day		SBM, kcal/(day*m ²)		m _{IL} /m _{TWV} %
		own	literary [17]	own	literary [24]	own	literary [17]	
14-15	F	55 ± 4	56 ± 3	1305 ± 100	1250 ± 100	820 ± 53	845 ± 30	0,56 ± 0,01
	M	58 ± 3	55 ± 3	1573 ± 152	1420 ± 110	867 ± 39	910 ± 30	0,59 ± 0,01
16-17	F	55 ± 2	57 ± 4	1460 ± 184	1300 ± 100	818 ± 38	835 ± 35	0,57 ± 0,01
	M	58 ± 2	56 ± 3	1677 ± 116	1560 ± 110	868 ± 41	920 ± 40	0,6 ± 0,1
18-19	F	55 ± 2	57 ± 4	1351 ± 86	1380 ± 100	814 ± 41	830 ± 40	0,57 ± 0,01
	M	59 ± 2	58 ± 3	1675 ± 104	1700 ± 120	880 ± 40	930 ± 40	0,60 ± 0,01

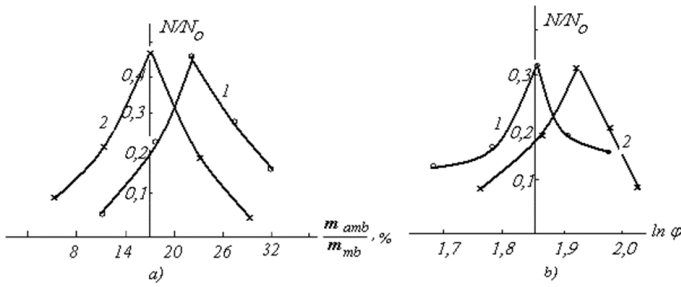


Figure 1 | Distributions by fat mass (a) and natural logarithm of phase angle (b) for adolescents 14-15 years old: 1 – teenage girls, 2 – teenage boys. Распределения по жировой массе (a) и натуральному логарифму фазового угла (б) для подростков 14-15 лет: 1 – девочки-подростки, 2 – мальчики-подростки лаборатории Тюменской области.

gender categories in the present work are presented in Table 3.

The figure 1 shows the distribution of body fat mass, referred to the mass of the body and from the natural logarithm of the phase angle. In the given data, N_0 indicates the total number of investigated individuals (teenage boys or girls), and N the number of investigated, related to the interval of relative fat mass indicated in the figure 1.

As follows from the processing of experimental data, the measurement results can be described by a normal distribution, which can be considered as the evidence of the reliability of the sample. The shifts of the maxima for the presented distributions also correspond to known literature data. It should be noted that distributions are similar for other age and gender categories. There is a high correlation between the relative cell mass (table 3) and the phase angle. The relationship between them is:

$$\frac{m_{ACM}}{m_{LM}} \approx 0.3 \ln \varphi \quad \text{Equation 5}$$

The figure 2 shows the mass distribution of intracellular liquid, referred to the total volume of the liquid phase in the human body. Such data are not presented in the available

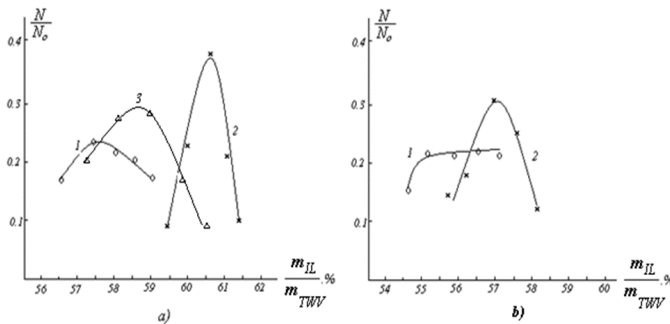


Figure 2 | Distribution of intracellular liquid (IL), related to the total water volume (TWV) in the body: a) – females: 1 – 14-15 years; 2 – 18-19 years old; 3 – 16-17 years old; b) – males: 1 – 14-15 years; 2 – 18-19 years old. Распределения по клеточной жидкости (КЖ), отнесенной к общему водному объему (ОВО) в организме: а) – лица женского пола: 1 – 14-15 лет; 2 – 18-19 лет; 3 – 16-17 лет; б) – лица мужского пола: 1 – 14-15 лет; 2 – 18-19 лет.

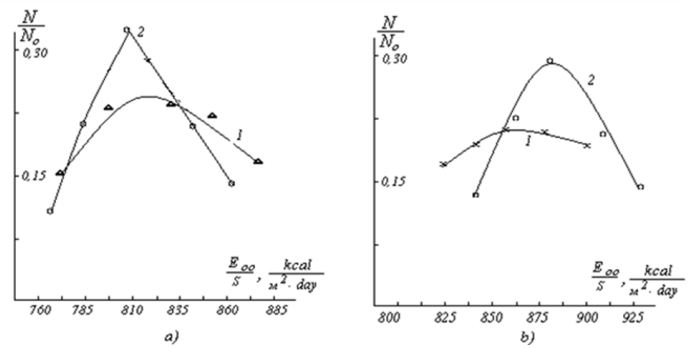


Figure 3 | Distributions by specific basal metabolism: a) – females: 1 – 16-17 years old; 2 – 18-19 years old; b) – males: 1 – 14-15 years; 2 – 18-19 years old. Распределения по удельному основному обмену: а) – лица женского пола: 1 – 16-17 лет; 2 – 18-19 лет; б) – лица мужского пола: 1 – 14-15 лет; 2 – 18-19 лет.

literature. In general, it is considered [23-28] that the mass percentage of intracellular liquid is 60% of the total mass of the liquid and depends on the age and gender of the individual.

The data presented on the figure 2 confirm the integral fact, however it follows that during the period from 14 to 19 years, the average relative intracellular liquid also increases from 57.5% to 60.5%. At the same time, the type of distribution for different age and gender categories also changes significantly. If uniform distributions over relative ACM are characteristic for 14–15 years of age, then it assumes the form of a normal distribution for 18–19 years of age. Perhaps, the reason is the pubertal period and the corresponding processes of active growth. There are currently no published data about the interconnection of intracellular liquid with age-related changes, but it can be assumed that the amount of intracellular liquid relative to the total liquid. The total liquid may increase during this period due to two mechanisms: 1) an increase in the number of cells, since tissue growth occurs due to active cell division; 2) a decrease of the amount of extracellular liquid, the cause of which is most often an increase in the amount of fatty tissue, because fatty tissue is little hydrated and there is a direct relation (the higher the number of fat cells themselves, the lower the total body liquid). This pattern is observed for both female and male contingent of the studied.

The figure 3 shows the dependence of the relative number of the studied volunteers from the energy characteristics of a human (SBM). As follows from the literature data (table 3), this characteristic should slowly decrease with increasing age. The obtained experimental data for the female category confirm this fact; however, a contradiction is obtained for the males. The SBM value also increases with age for the given age group.

To explain this phenomenon, it is necessary to investigate the ratio:

$$SBM = \frac{BM}{S} \quad \text{Equation 6}$$

where S – the body surface area of the individual .

The ACM is associated with the LM ratio (5). Since the phase angle varies insignificantly for the studied age categories, it is obvious that the change in ACM will be determined by the change in the lean mass of the individual, which also increases with age. The BM is associated with an active cell mass ratio. It follows that, since ACM is increasing, the energy released by a person per unit of time will also increase.

As follows from relation (6), the SBM is determined by two competing values: the growing values of BM and the growing surface square of the body of the individual, defined by the Du Bois formula:

$$S (m^2) = 0.007184 * m^{0.425} * L^{0.725}, \text{ or } S (m^2) = \sqrt{\frac{m * L}{3600}} \quad \text{Equation 7}$$

where m – is body mass (kg), L – is height (cm).

Calculations of absolute values of S by both formulas coincide with a sufficiently high degree of accuracy. The values of BM and the body surface square of individuals (S) are presented in Table 4.

As follows from table 4, the average mass for the age group of 18-19 years is less than at the age of 16-17 years, while the average growth values exceed. This leads to the fact that the average values of body surface square of categories 16-17-year young men exceed the same parameter for 18-19 year olds. This determines the contradictions between the SBM data presented in the literature and the obtained values of the specific basic exchange in our own studies.

4. Concluding Remarks

The intracellular liquid of individuals referred to the total volume of liquid in it depends on the age of the individual. An increase in relative intracellular liquid is observed in the period from 14 to 19 years. It is assumed that the amount of intracellular liquid relative to the total liquid during this period may increase due to an increase in the number of cells themselves, since tissue growth occurs due to active cell division; and also due to a decrease in the amount of extracellular liquid, the cause of which is most often an increase in the amount of fatty tissue, since fatty tissue is a little hydrated. This pattern is observed for both female and male contingent of the studied.

The specific basal metabolism for males increases between the ages of 14 and 19, which can be explained by the increasing secretion of the anterior pituitary hormone

(growth hormone) in this category of studied. It causes a marked acceleration of growth in the puberty, especially in males, what confirms the numerous literature data, and, therefore, the reliability of the bioimpedance analysis method in assessing the component composition of the body.

The results of the study can be used to simulate the ways of correction of the components of the body composition and the biophysical parameters of the body based on the identified relationships between them. The possibility of using indicators such as phase angle, active cell mass, specific basal metabolism as indicators of the body's functional state of cells in adolescent and youthful age groups becomes apparent.

The revealed interconnections between the indicators can be used in educational institutions with the aim of monitoring the functional state of the organism of persons of adolescent and youthful age by creating and updating the database.

Заключение

Отношение объёма внутриклеточной жидкости биологических объектов к общему объёму жидкости в них зависит от возраста. В период от 14 до 19 лет наблюдается рост относительной внутриклеточной жидкости. Предполагается, что количество внутриклеточной жидкости по отношению к общей жидкости именно в этот период может увеличиваться за счет увеличения количества самих клеток, так как рост тканей происходит за счет активного деления клеток; а также благодаря уменьшению количества внеклеточной жидкости, причиной которого чаще всего является увеличение количества жировой ткани, поскольку жировая ткань мало гидратирована. Данная закономерность наблюдается как для женского, так и мужского контингента исследуемых.

Удельный основной обмен для лиц мужского пола в возрасте от 14 до 19 лет нарастает, что можно объяснить нарастающим выделением именно у данной категории исследуемых гормона передней доли гипофиза (соматотропный гормон или гормон роста), так как именно в пубертатном периоде, а, особенно, у лиц мужского пола, он вызывает выраженное ускорение линейного (в длину) роста и, как следствие, повышение удельного основного обмена, что подтверждает многочисленные литературные данные, а, значит, и

Table 4 | Parameters for calculating the energy characteristics and their values. Параметры для расчетов энергетических характеристик и их значения

Age, years	Mass, m, kg	Height, L, cm	S (m ²)	BM, kcal/day	SBM,
14-15	63 ± 9	178 ± 7	1,8 ± 0,1	1573 ± 152	867 ± 39
16-17	72 ± 9	181 ± 4	1,9 ± 0,1	1532 ± 198	868 ± 41
18-19	70 ± 8	182 ± 7	1,9 ± 0,1	1675 ± 104	880 ± 40

достоверность метода биоимпедансного анализа в оценке компонентного состава тела.

Результаты исследования могут быть использованы для моделирования путей коррекции показателей компонентного состава тела и биофизических показателей тела на основе выявленных взаимосвязей между ними. Становится очевидной возможность использования таких показателей, как фазовый угол, активная клеточная масса, удельный основной обмен как показателей функционального состояния клеток у подростковой и юношеской возрастных групп.

Выявленные взаимосвязи между показателями могут быть использованы в учебных заведениях с целью мониторинга функционального состояния организма лиц подросткового и юношеского возраста путем создания, периодического пополнения и обновления базы данных.

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