Bioelectrical Impedance Technology in Sports Anthropometry: Segmental Analysis in Karate Athletes

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Abstract. The modern equipment for evaluation of body composition use computerized technology to determine or estimate body components. Having a moderate amount of each component is important for healthy life. Quantification of fat has been prime focus of attention, but many coaches, sport scientists and sport physicians working with elite athletes recognize that knowledge of the amount and distribution of lean tissue, such as bone and muscle, can be just as important in determining sports performance. Bioelectrical impedance analysis (BIA) estimates the amount of total body water (TBW), fat free mass (FFM) and fat mass (FM) measuring the resistance of the body as conductor to a very small alternating electrical current. The investigated group was composed of twenty (20) elite level male karate athletes with the following characteristics (mean $\pm$ SD): age = 22.5 $\pm$3.6 years, age span (18 to 27 years); height = 179.95 $\pm$ 2.3 cm; body mass = 77.5 $\pm$ 9.8 kg. Body composition was diagnosed with the InBody 720, multifrequency (1–1000 kHz) bioelectrical impedance analyzer (BIA). Karate athletes are obliged to maintain their body weight within certain range if they want to stay in optimal weight category. Our results showed that Macedonian karatees have symmetrical and balanced distribution between left and right side of the body. The strongest advantage of BIA methodology and InBody devices, compared to other field methods in sports anthropometry, is the segmental lean mass analysis. Monitoring the segmental analysis could help in following the quality of nutritional and training regime or rehabilitation procedure in athletes.

Keywords: Bioelectrical impedance analysis · Segmental analysis
Lean body mass · Karate

1 Introduction

Body composition represents an unbreakable unity of the humanbody basic structure elements and involves a relative representationof the various constituent elements of the humantotal body weight. The modern devices for evaluation of body composition

S. Kalajdziski and N. Ackovska (Eds.): ICT 2018, CCIS 940, pp. 160–171, 2018.
https://doi.org/10.1007/978-3-030-00825-3_14

use computerized technology to determine or estimate body components. Having a moderate amount of each component is important for healthy life [18]. The human body can be quantified at several levels, such as atomic, molecular or tissue, depending on the clinical concerns. Criterion methods measure certain properties of the body, like density or conductance, and measure or estimate the body structural elements [13].

The closest researchers can get to a direct measurement of body composition as far as accuracy goes is by using the multi–compartment model technique. These indirect methodsare also commonly said to be the best "reference" techniques. The reference method are by definition, the most accurate techniques for assessing body composition and have been often employed as criterion against which other methods compared [26]. Criterion methods include medical imaging techniques, computed tomography (CT), magnetic resonance imaging (MRI), densitometry and dual X ray absorptiometry (DEXA) [10]. Although some authors classified these methods as direct others define them as indirect. The group of the indirect methods for body composition analysis includes the bioelectrical impedance method. Bioelectrical impedance analysis (BIA) estimates the amount of total body water (TBW), fat free mass (FFM) and fat mass (FM) measuring the resistance of the body as conductor to a very small alternating electrical current [6, 27, 38].

The actual parameter measured with BIA is the voltage (V) that is produced between two electrodes located most often at sites near to, but different from the sites where current is introduced. The measurement normally is expressed as a ratio, V/I, who is also called impedance (Z). The measuring instrument is therefore called a bioelectrical impedance analyzer. Impedance has two components, resistance (R) and reactance (X). In BIA the resistance is nominally about 250 Ω, and reactance is about 10 percent of that amount, so the magnitude of Z is similar to that of R. In many BIA reports, Z and R are used as they are interchangeable [30]. Impedance (Z), from electrical point of view, is the obstruction to the flow of an alternating current and, is dependent on the frequency of the applied current. Bioimpedance is a complex quantity composed of resistance (R) which is caused by total body water and reactance (X_c) that is caused by the capacitance of the cell membrane [22]:

$$Z = R + jX_c \; [22]$$

$$Z = \sqrt{R^2 + X} \quad [20, 28].$$

BIA provides a reliable estimate of total body water under most conditions. It can be a useful technique for body composition analysis in healthy individuals and in those with a number of chronic conditions such as mild-to-moderate obesity, diabetes mellitus, and other medical conditions in which major disturbances of water distribution are not prominent [23]. BIA values are affected by numerous variables including body position, hydration status, consumption of food and beverages, ambient air and skin temperature, recent physical activity, and conductance of the examining table. Reliable BIA requires standardization and control of these variables. A specific, well-defined procedure for performing routine BIA measurements is not practiced. Therefore, the scientific experts emphasized the needs of specific equations (for different population groups) and setting instrument standards and procedural methods.

1.1 The Importance of Body Composition Analysis in Athletes

Tests of anthropometry include measurements of body size, structure, and composition. There is a wide range of ideal body shapes and compositions, depending on the sports, the playing position and the fitness level. For many sports it is an advantage to be short, tall, heavy or light. In terms of ideal body composition, an athlete may wish to have anything from high muscularity to high fat levels.

In weight-sensitive sports many athletes use extreme methods to reduce mass rapidly or maintain a low body mass in order to gain a competitive advantage. Quantification of fat has been prime focus of attention, but many coaches and scientists working with elite athletes recognize that knowledge of the amount and distribution of lean tissue, such as bone and muscle, can be just as important in determining sports performance [1, 29]. The reference methods may have limited applicability for monitoring athletes. Limitations include feasibility (e.g. cadaver dissection), time and financial costs involving (e.g. MRI), a lack of published normative data and unnecessary radiation exposure (CT scanning) [10]. Several international sport federations have considered implementation of programmed aimed to discourage athletes from extreme dieting or from rapid mass loss by means of dehydration, and i n order to improve the low mass problem [32, 41].

1.2 Bioelectrical Impedance Analysis Technology

The ability of electrolyte solution to conduct an electric current contributes the human tissues to be the conductor. The tissues which are compound of greater percentage of water, consecutively electrolyte solution, are the major conductor of an electrical current. The tissues such as blood and urine are the best conductor, muscle tissue has moderate conductance properties and a fat tissue is among the poorest conductors [8]. The BIA measurements are performed using a couple of electrodes (two, four or eight) attached at certain position, usually wrists and ankles. The current which is generated from BIA device should be so "weak" to not harm the tissues and so "strong" to override the obstacles i.e. cell membranes. BIA applied small currents throughout the body and measures the voltage to get value called resistance also known as impedance. The principal behind BIA is to flow electrical currents throughout the water in the body and to measure the amount of resistance the current encounters as it travels. Simply more water will lead to lower impedance [18].

The meaning of the word impedance is the effective resistance of an electric circuit or component to alternating current, arising from the combined effects of ohmic resistance and reactance [11]. The electrical impedance is the measure of the opposition that a circuit presents to a current when a voltage is applied. Impedance extends the concept of resistant to alternating currentcircuits, and possesses both magnitude and phase, unlike resistance, which has only magnitude. When a circuit is driven with direct current (DC), there is no distinction between impedance and resistance; the latter can be thought of as impedance with zero phase angle. Impedance is a complex number, with the same units as resistance, the ohm (Ω). Its symbol is usually Z, and it may be represented by writing its magnitude and phase in the form $|Z|\angle\theta$ [32, 33]. To translate this data to a volume approximation, two basic assumptions are used. First, the body can be modeled as an isotropic cylindrical conductor with its length proportional to the subject's height (Ht). Second, the reactance (X) term contributing to the body's impedance (Z) is small, such that the resistance component (R) can be considered equivalent to body impedance. When these two assumptions are combined, it can be shown that the conducting volume is proportional to the term Ht^2/R, called the impedance index. It should be noted, however, that the human body is not a cylindrical conductor, nor are its tissues electrically isotropic, and the reactance component of the body's impedance is nonzero [2]. At 50 kHz, the body's impedance has both resistive and reactive components. The reactive component is assumed to be related to the portion of the current that passes through cells which act like capacitors that shift the voltage and current out of phase. In electrical terms, the phase angle (φ) is defined by the relationship: $\tan(\varphi) = X/R$, where $Z^2 = R^2 + X^2$. In healthy adults, the phase angle at 50 kHz is usually in the range of 8–15° [7] but varies widely at high frequencies [34, 35]. Several investigators have used the phase angle to assess body composition in various clinical conditions. In renal patients, for example, the phase angle at 50 kHz is typically < 5° and has been interpreted as an indication of an expanded ECW space concurrent with a reduced ICW volume [3, 19].

Multi-Frequency Bioelectrical Impedance Analysis (MFBIA) utilizing frequencies between 1 kHz and 1000 kHz (1 MHz). An electric current less than 100 kHz cannot penetrate cell and flows through extracellular water so is used to measure extra-cellular water (ECW). An electric current over 100 kHz penetrates cell membranes and flows through cell so is used to measure total body water (TBW). Using multiple frequencies, ECW and TBW are measured separately and this can be helpful to diagnosis of body water balance, especially edema [30]. Different part of human body has significant difference on impedance. BIA use 6 testing circuits: Left Arm-Right Leg, Right Arm-Left Leg, Left Arm- Left Leg, Right Arm-Right Leg, Left Arm-Right Arm, Left Leg-Right Leg. Only this complex model can give real comprehensive impedance level of whole body.

2 Material and Method

2.1 Participants and Procedure

The sample was composed of twenty (20) elite level male karate athletes with the following characteristics (mean ± SD): age = 22.5 ±3.6 years, age span (18 to 27 years); height = 179.95±2.3 cm; body mass = 77.5 ± 9.8 kg. They have participated regularly in national and international karate eventsduring the period from 2010 until 2015 in the following weight categories: >84 kg (n = 3); <84 k (n = 12); <75 kg (n = 9); <67 kg (n = 3) and <60 kg (n = 1). The measurements were conducted at the Sport Medicine Laboratory, Institute of Physiology and Anthropology, at the Medical faculty in Skopje. The investigation protocol was conducted according to the declaration of Helsinki. All measurements were taken by experienced practitioners in the morning hours between 9 am and 11 am, from all subjects according to manufacturer's guideline. Ethical approval was obtained by the Ethics committee of Medical Faculty, UKIM, Skopje.

2.2 Assessment of Body Composition

Body composition was estimated by the InBody 720, multifrequency (1–1000 kHz) bioelectrical impedance analyzer (BIA). InBody 720 employs eight contact electrodes, which enable segmental analysis of the five basic body parts (upper and lower extremities and trunk). Two electrodes are positioned on the palm and thumb and another two on the front of the foot's heel. The measurement was performed under laboratory conditions according to the user manual instructions (Biospace, 2008).

2.3 Statistics

The statistical analysis was performed in Statistika 7.1 for Windows. All results were subjected to descriptive statistical analysis in order to define the basic measures of central tendency and dispersion of data (mean, SD, CI lower and upper bound, range) in numeric series. The Pearson coefficient of linear correlation (r) between measured parameters was obtained. Multiple regression analysis (R) was performed for the measured parameter "skeletal mass" as dependent variable and the parameters - right arm, left arm, trunk, right legand left legas independent variables. The level of significance was for $p < 0.05$.

3 Results

The results from the descriptive statistics for the general anthropometric characteristics and the BIA section for obesity diagnose of the karate athletes evaluated in this study are presented in Table 1. the participants' mean age was 22.5 ±3.6 years, the mean height was 179.95 ± 2.3 cm and the mean body weight was 77.5 ± 7.8 kg. Mean values for the body mass index (BMI), waist to hip ratio (WHR) and the absolute and relative body fat mass are also fully reported in Table 1.

Table 1. Body mass components and obesity diagnose BIA parameters in elite karate athletes.

	N	Mean	SD	CI -95%	CI +95%	min	max
Age (year)	20	22.5	3.6	19.13	21.84	18.0	29.0
Height (cm)	20	179.95	2.3	176.81	181.09	175.5	191.0
Weight (kg)	20	77.5	7.8	72.86	80.58	64.0	107.4
BMI	20	23.78	2.35	22.96	24.78	19.8	29.8
Fat free mass (FFM)	20	67.74	7.69	64.21	71.08	58.0	94.6
Soft lean mass (SLM)	20	64.11	7.36	60.66	67.15	54.7	89.3
Skeletal muscle mass	24	38.16	4.66	36.16	39.78	29.4	54.6
Body fat mass (kg)	20	9.84	3.65	8.39	11.25	4.8	19.4
Body fat percent (BF%)	20	13.51	4.81	11.04	14.78	6.6	21.7
Waist-to-hip ratio	20	0.83	0.04	0.81	0.85	0.75	0.90

Table 2. Segmental analysis variables in elite karate athletes (all parameters are in kg).

	N	Mean	Std. Dev.	CI −95%	CI +95%	min	max
Right arm	20	3.92	0.42	3.63	4.19	3.12	5.98
Left arm	20	3.91	0.55	3.63	4.18	3.13	5.89
Trunk	20	28.54	6.83	25.3	31.56	21.4	40.9
Right leg	20	11.12	1.27	9.95	12.04	9.18	14.3
Left leg	20	10.85	1.17	9.93	11.01	9.17	13.7

The segmental analysis obtained by InBody 720 showed lean mass distribution into trunk and left and right part of the body. Descriptive statistics for these parameters, which are available only in individuals older than 18 years, are presented in Table 3. The mean values of lower limbs show insignificantly higher values for right leg, and the mean values of right and left arm are almost the same (Table 2).

In order to find out how the one part of the body influence on the whole lean body mass we made regression analysis for skeletal mass as dependent and four limbs and trunk as independent variables. It was found that for $R = 0.99$ and $p < 0.05$ ($p = 0,000$) in the investigated relation is determined maximal positive correlation. The strongest influence on this relation has showed the left arm (Beta = 0.49), right arm ($ß = 0.44$), left leg ($ß = 0.09$), right leg ($ß = 0.07$) and the weakest influence was from trunk ($ß = -0.0006$). The Fig. 1 displayed positive linear correlation between right arm as independent and skeletal muscle as dependent variable ($R = 0.98$, $p < 0.05$).

Table 3. Correlation's analysis between segmental BIA variables as independent and skeletal muscle as dependent variable.

Regression summary for dependent variable: skeletal mass: R = 0.9; F(5.15) = 155.32 and p < 0.001						
	Beta	Std. Err. Beta	B	Std. Err. B	t(15)	p-level
Intercept			7.41	1.87	3.95	**0.001**
Right arm	0.44	0.26	3.26	1.91	1.70	0.11
Left arm	0.49	0.23	3.82	1.78	2.14	**0.04**
Trunk	0.0006	0.04	−0.0004	0.03	−0.01	0.99
Right leg	0.07	0.05	0.001	0.0009	1.46	0.17
Left leg	0.09	0.12	0.35	0.45	0.78	0.45

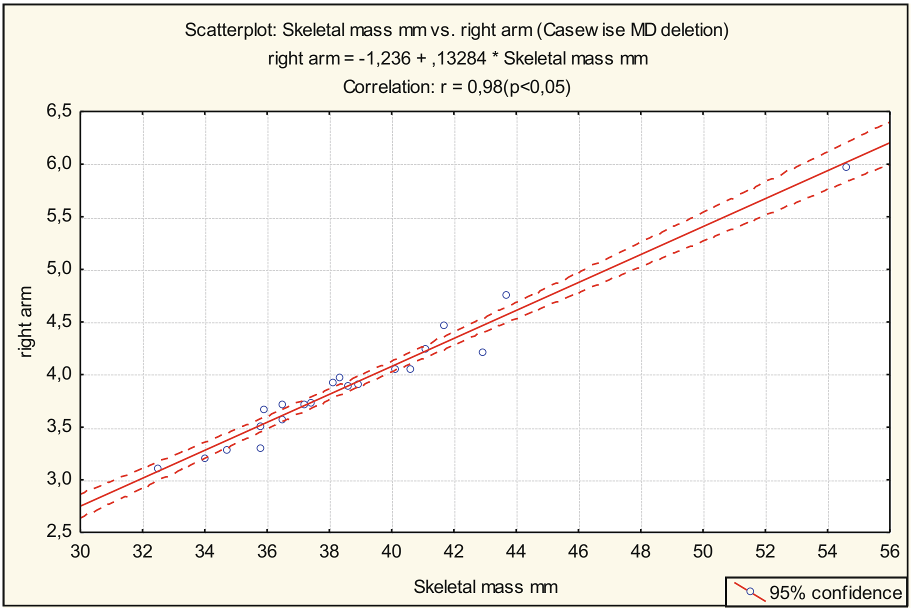

Fig. 1. Multiple regression and correlation's analysis between right arm as independent and skeletal muscle as dependent variable.

4 Discussion

Bioelectrical impedance analysis (BIA) is recognized as suitable in field studies and larger epidemiological studies because it is relatively simple, inexpensive and non-invasive technique to measure body composition. In the overview from 55 published studies of healthy population, with very broad age span 6–80 years, BIA was proved as good instrument to differentiate which type of body composition is better relates to the risk of cardiovascular diseases and all-cause mortality [19]. The older BIA devices, which have used monofrequency BIA technology and looked on subjects body as one cylinder, has been criticized as appropriate only for estimating adiposity of groups in epidemiologic and field studies but has limited accuracy for estimating body composition in individuals [31].

The unique characteristics of athletes body structure can lead to large errors when predicting fat mass (FM) and fat-free mass (FFM). Relatively new review of bioelectrical impedance body composition analysis in athletes, which overviewed the researches made until 2013, conclude that the BIA method shows potential for estimating body composition in athletes, future research should focus on the development of general athlete-specific equations using a TBW-based three- or four-compartment model [31]. Liu et al. [25] developed and cross-validate bioelectrical impedance analysis (BIA) prediction equations of total body water (TBW) and fat-free mass (FFM) for Asian pre-pubertal children from China, Lebanon, Malaysia, Philippines and. Theirs equation for the estimation of TBW was as follows: TBW = 0.231 × height(2)/resistance + 0.066 × height + 0.188 × weight + 0.128 × age + 0.500 × sex-0.316 × Thais-4 .574 (R (2) = 88.0%, root mean square error (RMSE) = 1.3 kg), and for the estimation of FFM was as follows: FFM = 0.299 × height(2)/resistance + 0.086 × height + 0.245 × weight + 0.260 × age + 0.901 × sex − 0.415 × ethnicity (Thai ethnicity = 1, others = 0) − 6.952 (R (2) = 88.3%, RMSE = 1.7 kg). No significant difference between measured and predicted values for the whole cross-validation sample was found.

4.1 The Importance of Bioimpedance Technology in Body Composition Analysis

Since 1990, BIA has become a popular method for estimation of body composition. Bioelectrical impedance analysis is simple quick and non-invasive technique which gives reliable measurements with minimal intra and inter-observer variability [39]. The results are available immediately and reproducible with <1% error on repeated measurements [4]. BIA results are influenced by factors such as the environment, ethnicity, phase of menstrual cycle, and underlying medical conditions. BIA measurements validated for specific ethnic groups and populations can accurately measure body fat in those populations. BIA may not be appropriate choice for body composition assessment for large epidemiological studies unless specific calibration equations are developed for different population groups [12]. BIA is useful in describing mean body composition for groups of individuals but large errors for an individual could limit its clinical application, especially among obese [9]. BIA is suitable for body composition monitoring in elderly people and may be good choice for detecting the prevalence of sarcopenia in this age population [42].

BIA applied to segments represents a great advance in clinical practice by being able to overcome the limitations of the traditional BIA technique [30]. It permits the analysis of body composition with edema and ascites or having muscle tissue or fat deposit depletion [43]. Another challenge for the use of BIA refers to its application in the assessment of body composition in children and adolescent, since according the different stage of growth and development there is wide variation in the various body components [40].

4.2 Segmental Analysis Discussion

The strongest advantage of BIA methodology and InBody devices compared to other field methods in sports anthropometry is the segmental lean mass analysis. InBody 720 observes the human body as a composition of five cylinders, with different lengths and widths and therefore these different segments could be partially analyzed. This kind of analysis provides us with more useful data. The lean mass distribution in upper limbs in our participants showed almost the same mean values of fat free mass in the right and in the left arm. Similar distribution of skeletal muscle mass was found in the inferiorextremities, where the right leg showed insignificantly more mass than the left leg. The trunk of the body, withits huge volume in comparison with upper and lower extremities, contributes approximately 50% of whole body mass [16].

The analysis of lean body mass distribution in athletes informs us of symmetry or asymmetry in the body composition of the athlete. The symmetry of the athlete's body depends on the motor requirements of the particular sport. The nature of during karate training imposes to karate athletes to move in various directions and attack their opponents with both upper and lower extremities in different moment of the match [5]. Unlike some other sport activity (tennis, basketball) karate mainly activates all segments of the body equally. Karateist's somatotype is characterized by higher mesomorphy and lower ectomorphy [17]. Our results showed that Macedonian karatees have symmetrical and balanced distribution between left and right side of the body.

In the investigation of the precision of BIA (InBody 720) in the body composition analysis using the DEXA as the reference method in large sample of healthy adults, Ling et al. concluded that BIA was a valid instrument for whole body composition and segmental lean mass measurements [24]. Although some investigators revealed discrepancies between BF and FFM determined with BIA and DEXA as criterion method, segmental analysis appeared to provide excellent agreement for the measurement of total body and segmental lean soft tissues [15]. An examination of the agreement of segmental multifrequency bioelectrical impedance analysis (SMF-BIA) for the assessment of whole-body and appendicular fat mass (FM) and lean soft tissue mass (LSTM) compared with dual-energy X-ray absorptiometry showed high coefficients of determination for fat mass (R2 = 0.91; SEE = 1.4 kg in men and R2 = 0.94; SEE 1.2 kg in woman [21]. Skeletal muscle mass (SMM) determined by InBody 720 showed maximal strong positive correlations with the changes in total water and its compartments TW, ECW and ICW ($r = 1$; $p < 0.05$) [37].

Karate athletes are obliged to maintain their body weight within certain range if they want to stay in optimal weight category. The body mass should be composed of optimal amount of body components to achieved a better sport performance. The need of systematic control of body composition involves a reliable and valid method for the body composition analysis and good understanding of coaches and other sport's experts for the meaning of the obtained parameters. As this study showed bioelectrical impedance analysis with InBody 720 generates a plethora of information about body components, nutritional status, obesity diagnose and fitness core of karatees. Segmental analysis of lean body mass gave us awareness into the way the LBM is distributed to main parts of athlete's body: trunk, upper and lower extremities. This analysis informed the sportsmen, his physician and coach if there is asymmetry in LBM distribution, which could be result of inappropriate training regime or injury. Monitoring the segmental analysis could help in following the quality of nutritional and training regime or rehabilitation procedure. The application of BIA technology make available abundance of information regarding the body composition of athlete which could help to sport experts to provide better health and better sport performance for athletes.

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