Electrical bioimpedance analysis application in clinical and population trials

Zastosowanie analizy bioimpedancji elektrycznej w badaniach klinicznych i populacyjnych

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Key words
electrical bioimpedance, muscle mass, fat mass, fat free mass

Abstract
The study of body composition is a method to determine the content of fat mass, lean mass, muscular and cellular and extracellular water in humans. It plays an important role in the assessment of body composition in states such as improper nutrition: obesity, starvation, cachexia, and in many diseases in which there are invalid content ranges for the individual components of the body, especially when accompanied by changes in the content of muscle tissue and fat and body water. In this paper the theoretical assumptions, techniques, and selected examples of clinical and population trails using the analysis electrical bioimpedance are presented. The authors present the possibility of taking electrical bioimpedance measurements in everyday clinical practice, both by doctors and physiotherapists.

Słowa kluczowe
bioimpedancja elektryczna, masa mięśniowa, masa tłuszczowa, masa beztłuszczowa, skład ciała

Streszczenie
Badanie składu ciała jest metodą umożliwiającą oszacowanie zawartości masy tkanki tłuszczowej, beztłuszczowej, mięśniowej oraz wody komórkowej i pozakomórkowej u człowieka. Odgrywa istotną rolę w ocenie składu ciała w stanach nieprawidłowego odżywienia np.: otyłość, głodzenie, wyniszczenie, a także w wielu chorobach, podczas których dochodzi do nieprawidłowych zakresów zawartości poszczególnych składników ciała, zwłaszcza gdy towarzyszą im zmiany w zakresie zawartości tkanki mięśniowej i tłuszczowej oraz wody w organizmie. W pracy przedstawiono założenia teoretyczne, techniki oraz wybrane przykłady badań klinicznych i populacyjnych z zastosowaniem metody analizy bioimpedancji elektrycznej. Autorzy przedstawiają możliwości wykonywania pomiarów bioimpedancji elektrycznej w codziennej praktyce klinicznej, zarówno przez lekarzy, jak i fizjoterapeutów.

Electrical bioimpedance is a non-invasive method allowing analysis of the body's composition using the electrical resistance of an organism's tissue, so-called impedance (the function of the proper resistance of fat-free tissue, the transverse section of the body and its length)[1,2,3].

Bio-impedance analysis involves the measurement of tissue impedance (i.e., the biological resistance of the conductor), through which a sinusoid alternating current flows with a frequency of from 0 to 500 kHz and an intensity of 0.8 mA[1,2].

The measurement of the total resultant electrical resistance of the body through the application of surface electrodes connected to a computer analyzer and using current of a given frequency and intensity allows one to estimate the body's composition including the content of fatty tissue as well as fat-free mass, comprised of water mass, bones and muscle.[1,2]

This method is based on Ohm's Law and enables the measurement of compositional impedances: of electrical resistance (R) as well as the capacitance resistance (Xc) of the tested tissue. Electrical resistance of tissues is connected with the level of electrolyte concentration, and with the same

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with the water content, while the capacitance resistance on the differences in potentials created on the cell membranes, which as a result of their construction act as condensers. These resistances change, depending on the frequency of the current used[2,3,4].

The body's resistance to alternating current depends on the length of the conductor, which reflects the height of the body and the contents of the conducting (possessing electrolytes) fluids – it is estimated that muscle tissue is composed of around 80% water and electrolytes, whereby it is a much better conductor of electric current than fat, which contains only around 20% water. Therefore muscle tissue as well as extracellular fluids act as conductors, while fatty tissue as an insulator. Each of these masses possesses a different impedance during the flow of current of a high frequency (> 10kHz) [1-5].

The results of BIA tests determine the proportions of the body's fatty and non-fatty mass. The measurement by means of the four electrode technique at a constant frequency equal to 50kHz supplies information on the extracellular water content (*extracellular water*, ECW) as well as its relation to the total body water content (TBW) in the organism, next information is obtained on the subject of changes in the intracellular water content (ICW) i.e., about the body cell mass (BCM)[1,6-8]. This is of fundamental significance because the fat-free mass (FFM) comprises TBW, BCM as well as to a limited degree the mineralisation of the bone, with the remainder of the body mass comprising fat tissue (fat mass, FM) [1,6-8].

Devices for the measurement of BIA may be divided with regard to the number of electrodes as well as the frequencies employed[1,6-8]. There are employed two-, four- and eight-electrode systems with the use of surface electrodes with various electrode configurations, e.g., in combination leg-leg (the dorsal surface of the foot), arm-arm (the dorsal surface of the arm), leg-arm[1,6].

The most frequently applied is a tripolar system in a one-sided arrangement, where two electrodes are placed in the region of the wrist of the patient's forearm, and the two subsequent ones around the ankle[1,6].

An important factor in BIA method testing is the frequency of the current. At low frequencies (< 50Hz) or close to zero the current does not pass through the cell membrane barrier, which acts as an insulator. While at extremely high frequencies (> 50kHz), the cell membrane behaves as an almost perfect capacitor and therefore the whole impedance of the body reflects both the volume of the intra- as extra-cellular water[1,6-8]. At a frequency of 50kHz, (and this is the one most frequently used in apparatus to measure the BIA of a single current frequency), the current passes both through the intra-cellular as the extra-cellular fluid, while the result obtained is the average of their impedance[1,9].

There exist two main types of apparatus for BIA testing: using a single frequency (*single frequency bio-impedance analysis*, SF-BIA) as well as multiple frequency (*multi-frequency bio-impedance analysis*, MF-BIA). The first is considered to be especially useful in evaluating the body composition for healthy individuals, while the second enables a more exact analysis of changes in the body composition in the organism of patients either post-operational or while ill[1,9]. In devices of the SF-BIA type the most often used frequency is 50kHZ at an intensity of 0.8-1mA, while in MF-BIA apparatuses the frequency range is from 0 to 500 kHz, although the greatest repetition of results occurs at the range of 5kHz to 200kHz[1,9].

Exceptionally important, as a result of the difficulty in the clinical evaluation of the optimal state of hydration, is the measurement of water space in patients treated with dialysis[10-13]. For an appropriate evaluation of a patient's state it follows to give both the capacity as well as the extent of water spaces, such as: total body water (TBW), Extracellular water spaces (ECW) as well as intracellular water spaces (ICW), the content of Na ions influencing the quick exchange of fluid between ECW and ICW as well as the magnitude of weight increase during the inter-dialysis period[10-12]. One of the non-invasive methods serving an evaluation of the state of hydration, which at present enjoys increasingly widespread recognition, is the electric bioimpedance of the whole body[10-12].

The results of research conducted, among other places, at the Nephrology Department and Clinic of the Medical University in Lublin[10] as well as at the Renal Research Institute in New York[11] have shown the significant role which is played by the technique of electrical bioimpedance in the precise assessment of water space as an integral component of patients' body composition in the diagnosis of chronic kidney diseases. Assessment of the magnitude of extracellular space as well as the conduction index is incredibly helpful in evaluating the expected mass during the inter-dialysis period in patients with identified advanced kidney failure[13-15]. Measurements of bioimpedance enable one to monitor the state of hydration in the aspect of effective treatment of arterial hypertension resulting in overhydration of the organism.

Measurements of bioimpedance have applications equally in assessing the state of nutrition in patient suffering from chronic obstructive pulmonary disease (COPD) as well as in the evaluation of the influence of diet on the risk of its appearance[16].

One of the most common non-pulmonary symptoms of COPD is disturbance in nourishment and muscle strength weakness[17-19].

To gain energy as a result of malnutrition there occurs disintegration of the proteins building the cross striated muscles (including the intercostals muscles and the diaphragm) the result of which is a fall in body mass and muscle strength. Which is why malnutrition with muscle loss is one of the causes of further complications in patients suffering from COPD and is strictly connected with increased risk of death[18-20].

A correct assessment of the state of nourishment should also cover the evaluation of the fat-free mass of the body, as equally the body's fatty mass, this is possible with BIA testing[23,24]. On the basis of the FFM one may calculate the fat-free mass index (FFMI): FFMI = FFM (kg) / growth (m^2). Values lower or equal to 15 kg/m^2 for women and 16 kg/m^2 for men represent a deficiency in the body's fat-free mass[17,18,19,20].

The aim in evaluating the state of nourishment is the identification of patients at risk of malnutrition or

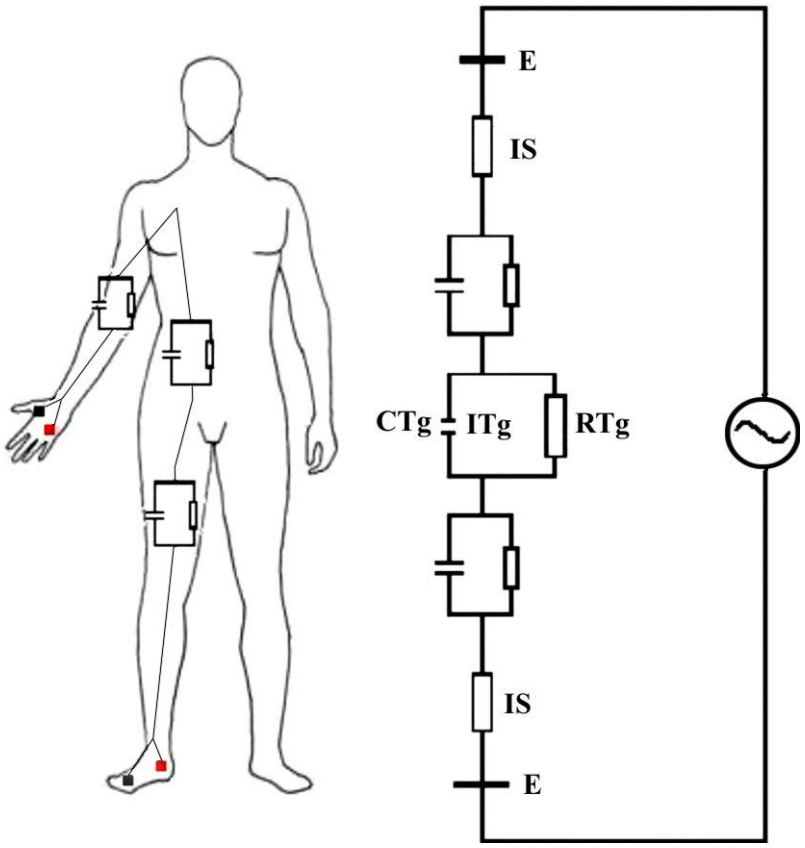

Figure 1

Circuit diagram of the human body during the examination of electrical bioimpedance (BIA) E - electrode, IS - skin impedance, CTg - deep tissue volume, RTg - deep tissue resistance, ITg - deep tissue impedance.

those malnourished, determining the degree of malnutrition as well as monitoring the effectiveness of nutrition and rehabilitation treatment[19-24].

In individuals with a correct body mass there may occur undiagnosed disturbances in the nutritional state[25]. patients with nutritional disturbances may be divided into four groups: those with a correct body mass and correct FFM, with correct body mass and lowered FFM, being underweight and with correct FFM, as well as those underweight with lowered FFM[25].

Information obtained on the composition of the body allows one to develop an appropriate plan for physical exercises in order to consciously influence the shaping of individual body components – in particular fatty and muscle mass as well as the water content in the organism.

Measurements of the body's composition are useful also in tests on patients with disturbances in the functioning of the endrocrine (hormonal) system, in the course of which irregularities in the depositing of fatty tissue is observed, with which other metabolic disturbances may be connected increasing the risk of diseases of the circulatory system[26].

BIA may offer huge possibilities in the monitoring of treatment and changes in the body composition of individuals suffering from diabetes (particularly Type 2) where non-pharmacological treatment methods play a greater role than in the case of Type 1 diabetes[27].

BIA testing is conducted also to compare the suitability of this method and indexes of body mass in the evaluation of fatty tissue in children.

The results of BIA measurements conducted on healthy children have allowed the value of the system's entire water value to be calculated, the fat-free body mass and that of fatty tissue, which has enabled a later setting of the centile charts for the individual components (FFM and FM) in relation to sex, height and age. However, as a result of the significant differences in the content of fatty tissue amongst individuals of different races and population it seems important to develop norms for a given country.

Drożdż et al.[4]'s testing of children stated that the method of bioimpedance analysis allowed one to differentiate the increase in the fatty tissue content from the muscle mass increase, by doing so this is a more exact method than the BMI index in the evaluation of body composition for children and young people. The early diagnosis and treatment of obesity may prevent the development of cardiovascular complications and metabolic disturbances[4].

BIA measurements are equally carried out as standard amongst sportsmen. In disciplines in which there occur various weight categories it is desirable that body mass reduction takes place at the cost of fatty tissue[28]. When body mass exceeds permissible limits yet the content of fatty tissue is at the minimum level (around 5-7 %) its further reduction is possible through the reduction in fat-free tissue and dehydration of the organism, which in both cases may result in a drop in strength and physical ability[28]. Therefore, equally data from body composition measurements are used to determine the somatic predispositions of competitors to start at a light weight, and subsequently to adapt their body masses (reduction in fatty tissue without the need to reduce the fat-free mass of the body) to the limits determined by the relevant sporting regulations[28].

The widespread use of the BIA measurement has led to interest amongst researchers as to its reliability[29,30].

Through the appliance of safety measures and the maintaining of correctly taken measurements, the repeatability of BIA method results is very high: the coefficient of test-retest reliability for the said four-electrode system is 99%[1,31-33]. Besides, the results obtained by Segal et al.[32] have shown almost no deviation within five measurements, if the electrodes are placed in the same place and the values obtained did not differ from those anticipated by more than 2%.

In widespread research conducted on a large sample of individuals of various age, sex, and origin (including

healthy individuals and AIDS sufferers) Kotler et al.[33] have claimed a high rate of repeatability in the results of BIA tests.

The BIA measurement in its tetrapolar version in the evaluation of the total value of fatty tissue in the organism is encumbered with a low (2–2,7 %) measurement error[1,36,37] and therefore is recommended for population and clinical testing[4,8,19,29,31].

However, the reliability of measurements of electrical bioimpedance is dependent on many factors, hence the condition for the obtainment of a accurate result is appropriate patient preparation. An individual to be subjected to BIA testing should not have consumed during the 24-hour period prior to testing any alcoholic or caffeine drinks; 12 hours prior to measurement no intensive physical exercise should be taken, nothing should be eaten 6 hours before – consequently it is the best to conduct testing during the morning on an empty stomach, while 10 minutes before the measurements the patient should lie on their back with legs splayed at an angle of 45º to the torso[1,31-33]. The second group of factors that influence the accurate outcome of tests is connected with the correct use of the apparatus. Electrodes must be placed on the skin in such a way so as to ensure adequate electrical conduction (following a prior cleaning of the area of application with alcohol to remove dirt). The next important factor is the correct positioning of the electrodes – in the tetrapolar system they are placed on the central line of the dorsal surface of the arms (hands) and feet (the movement of the electrodes by 1 cm may result in a change in measurement results of 2%).[1,31-33] Only when conducted measurements fulfil the required conditions in accordance with the norms of the European Society of Parenteral and Enteral Nutrition (2004), do BIA method results display the reliability and high rate of repeatability confirmed through numerous clinical and epidemiological tests[1,4].

Electrical bioimpedance testing has been recognised as a safe procedure (to date no unfavourable effects of this method have been noted) [1]. Nonetheless, there has still to be resolved the problem of the influence of the apparatus used in BIA on other instruments creating electromagnetic fields and vice versa[1]. For this reason analysers of body composition should not be used in connection or in proximity of such devices as: defibrillators, cardiostimulators, as well as other automatically controlled electronic devices implanted into patients (e.g.,: drug release systems)[1,38].

Electrical bioimpedance testing also has its limitations – a simplified treatment of the geometry of the human body. The majority of apparatuses treat it as a homogeny shape which results in the obtained measurements being exact approximations (estimates) and not measurements of an absolute value[39].

The results of fatty tissue measurement is also encumbered by error resulting from the methodology of measurement applied in the apparatuses or the programming attached to the apparatus. The majority of apparatuses calculate firstly the total water content (TBW), the next step is the establishment of the quantity of fat-free mass (FFM) applying the assumption that its hydration is 70%. The fatty mass (FM) is the difference in the body weight and the FFM. Hence in overhydrated individuals e.g., those with edema, there may arise a situation in which the apparatus shows a low fat content index (or the result may even be negative) which does not correspond to the real state[39].

Analysis of the body composition is of fundamental importance in the diagnosis and monitoring of patient states. It allows one to determine the quantity of fatty tissue in overweight individuals, the obese and those who are malnourished. It displays a high degree of use in controlling changes in the course of dietary and rehabilitative therapy, equally amongst emaciated patients[16–25]. Of great clinical value is equally the knowledge of fluid location in water spaces particularly in stroke patients, hemodialysis patients, with kidney failure, heart disorders, diseases of the liver, when diarrhoea occurs[6–15]. Evaluation of the muscle mass is used in the process of the rehabilitation of patients with neuro-muscular diseases, dystrophy and sarcopenia. Analysis enables control of the changes within the body's composition as a result of the physical activity undertaken as well as the appliance of physiotherapeutic methods within the process of rehabilitation. While in healthy individuals who engage in sport an evaluation of the body's composition enables a control of progress in the preparation for sporting competitions through a monitoring of the water content, that of fatty tissue, the muscle mass and glygogen stores. Knowledge of the metabolism at rest, which is dependent on the quantity of fat-free body mass, makes it easier to plan daily energy expenditure. The method also allows for financial savings as it may replace many expensive testing techniques such as the isotope dilution method[26]. This method equally allows epidemiological research to be conducted defining the composition of the body, which as a result of inter-population differentiation, ethnic origin, age, sex, life style, level of physical activity, body build, may be the cause of the observed differences in tissue content in the organism[32–42].

The results obtained during the testing of the body's composition constitute the basis for the formulation of recommendations during treatment or preventive treatment, allowing one to determine an appropriate dietary and rehabilitation strategy aimed at, for example, the reduction or increase in body weight while simultaneously obtaining a favourable relation of muscle tissue quantity to fat issues together with water amount[32-42]. In practice, correctly conducted tests in conjunction with an individualised diet and physical training programme constitutes the basis for the prevention and treatment of many diseases[32-42]. These tests allow for a more exact control of the treatment results of patients as well as for an analysis of changes at individual stages of therapy with the aim of evaluating its effectiveness. Therefore the BIA method should be also more widely popularised within medical circles and more exactly be recommended in tests supplementing antropometric measurements. The presented data should persuade researchers, also doctors, nurses, physiotherapists and medial sport specialists to utilise BIA measurements more widely in daily practice.

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