Changes in bioimpedance and body composition parameters depending on measurement conditions

Zmiany bioimpedancji a wskaźniki składu ciała w zależności od warunków pomiaru

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Wstęp. Określone właściwości oporności elektrycznej tkanek są podstawą metody analizy impedancji bioelektrycznej (BIA). Należy zadać sobie pytanie, czy zmiana warunków pomiarów w metodzie BIA nie będzie wpływała na wyniki badań. Przy zmianie warunków pomiaru impedancji ciała przewodność może drastycznie się zmieniać, co może to mieć istotny wpływ na ocenę składu ciała.

Metody. Badaniom składu ciała poddano 8 osób w grupie wiekowej od 25 do 62 lat. W badaniach zastosowano wieloczęstotliwościową metodę BIA. W celu wykazania wpływu warunków badania na zmiany parametrów składu ciała, badania przeprowadzono w 9 różnych warunkach środowiska.

Wyniki. Przeprowadzone pomiary wykazały, że środowiskowe warunki badania wpływają na wyniki, a różnice kształtowały się w granicach 4,43% do 21,95%.

Wnioski. Warunki pomiaru wpływają i zmieniają wyniki badań składu ciała. Wyniki badań ich ocena mogą być wykorzystane do standaryzacji procedury pomiarowej. Dla uzyskania najlepszych wyników ważnym jest aby znać precyzyjne warunki pomiaru, co pozwoli uniknąć błędu w ocenie wyniku.

Słowa kluczowe: *BIA, bioimpendancja, masa tłuszczu, całkowita zawartośc wody w ciele, skład ciała*

Background. Determined properties of bioimpedance and bioelectrical impedance analysis (BIA) method lead us to a question whether a change in conditions will have any effects on measurements. With change of measuring conditions the impedance and body/contact conductivity can drastically change. This can have major influence on the body composition assessment.

Methods. Eight subjects, in the age group of 25 to 62 years were included in the monitoring of body composition. The bioimpedance multi-frequency method was used. Nine changes of measurement conditions applied were between 4.43% to 21.95%.

Results. The performed measurements showed that there are differences caused by change of environmental conditions.

Conclusions. Measurement conditions influence and change results of body composition. Further investigation must be verified by repeated and extended experiments. These changes and their evaluation can lead to important conclusion and further standardization of the measurement procedure. For best outcome values it is crucial to know precise measurement conditions to overcome biases in evaluation.

Key words: *BIA, bioimpedance, fat mass, total body water, body composition*

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Introduction

Recently obesity has become a worldwide problem [1]. With obesity there are connected comorbidities such as: diabetes mellitus, high blood pressure, stroke etc. To indicate the degree of obesity (or slimness) lot of examiners use BMI (body mass index) [2, 3]. BMI is a calculated parameter that uses patient's height and weight. Therefore two persons having the same height and weight can have the same BMI although their body composition can be diametrically different. The focus on BMI only can lead to biases in classification if no other information is obtained [4].

Thus, a method allowing measurement of more informative quantities is necessary in order to evaluate the amount of body fat more objectively and precisely. Obesity does not refer to excessive body weight but it refers to the condition in which the individual has an excessive amount of body fat.

The Body Impedance Analysis (BIA) represents one of the methods for classification of body composition. This method uses electrical current that is injected into the body [5]. The voltage is measured and from these values are calculated parts of body composition such as FFM (fat-free mass), TBW (total body water), ICW (intracellular water), ECW (extracellular water), fat% etc [6].

Nowadays the devices for impedance measurements are on the wide scale from basic to very complex ones. Basic machines use just single frequency measurements and mostly have only one pair of electrodes. More advanced devices use a wider range of frequencies and mostly have more electrodes, which allow segmental body measurements. It is crucial to know which value is needed in order to choose the right device. For example for first examination basic device is enough, but these devices could be often biased, so it is crucial to use a proper device.

For the best body composition evaluation it is better to determine patient's health state in more than one way. Methods for the obesity characterization are Body Mass Index (BMI) > 30 kg/m² (should be for basic evaluation), bioimpedance, DXA, WH (waist-hip ratio) etc. [7, 8].

Bioimpedance basics and models

Bioimpedance is a passive electrical property of biological materials to oppose electrical current. This simple method needs two (or more) electrodes for the current injection.

When the human body is compared to an electrical circuit (see Fig 1a), the cell membrane (consisting of lipids) that separates the ECE (extra cellular environment) and ICE (intracellular environment) is considered to be a capacitor Cm. At a low frequency such as 5 kHz the current is not sufficient to penetrate cell membranes and only Re is measured. Accordingly, impedance measured at a low frequency has a significant correlation with ECW. At a high frequency, the electric current flows through the cells via the cell membrane capacitor and RTot is measured (see Fig 1b). Impedance in this case has a significant correlation with TBW (total body water). ECW (extracellular water) is estimated from the low-frequency results while TBW is estimated from the high-frequency results and ICW (intracellular water) resistance Ri is calculated as parallel conductor from

$$R_i = \frac{R_e R_{Tot}}{R_e - R_{Tot}} \quad (1)$$

Various frequencies guarantee that all tissue properties will be measured respectively. Hence the bioimpedance spectroscopy (BIS) method is often used

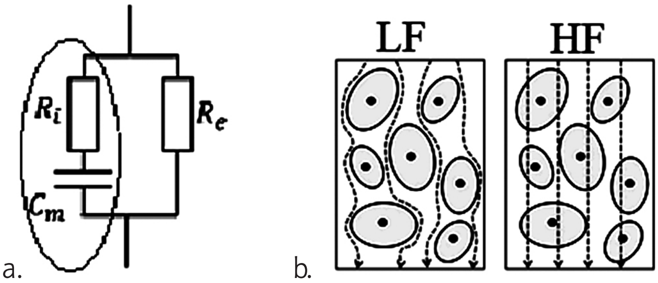

Fig. 1. a. Electrical model of human body, Ri – intracellular resistance, Cm – membrane capacity, Re – extra cellular resistance, b. penetration of current, left part – low frequency, right part – high frequency

Ryc. 1 a. Model elektryczny ciała człowieka, Ri – oporność wewnątrzkomórkowa, Cm – pojemność membrany, Re – oporność komórki, b. analizowany przekrój (LF) – niska częstotliwość, (HF) – wysoka częstotliwość

[9, 10]. In this method a multi-frequency approach is used. Common frequencies are 1, 5, 50, 250, 500 and 1000 kHz.

Basic concept of bioimpedance is impedance Z [ohm, Ω] which is

$$\mathbf{Z} = R - \frac{j}{2\pi f C_m} \rightarrow \mathbf{Z} = R + jX \rightarrow \mathbf{X} = \frac{-1}{2\pi f C_m}$$

where j is the square root of -1 and the asterisk denotes a complex quantity. R is resistance and X is reactance. From this equation Cole model impedance can be formed as

$$\mathbf{Z} = \left[\left(\frac{R_e}{R_e + R_i}\right)\left(R_i + \frac{R_e}{1 + \left(j\omega C_m (R_e + R_i)\right)^{\alpha}}\right)\right] \quad (2)$$

where **Z** is impedance, R_{Tot}, R_E, R_I and C_m stands for circuit values, ω is frequency in rad/sec and j is √-1.

This equation was improved by the factor $e^{-j\omega T_D}$ by (De Lorenzo 1997) that includes frequency invariant time delay TD. Thus final equation was formed as

$$\mathbf{Z} = \left[\left(\frac{R_e}{R_e + R_i}\right)\left(R_i + \frac{R_e}{1 + \left(j\omega C_m (R_e + R_i)\right)^{\alpha}}\right)\right]\left(e^{-j\omega T_D}\right) \quad (3)$$

This value expresses relationship between an ac sinusoidal current and ac sinusoidal voltage. Impedance is complex because a biomaterial not only opposes current flow but also adds phase-shift of the voltage with respect to current in time domain (Kylea et al, 2004).

These properties of bioimpedance and BIA method lead us to a question whether a change in conditions will have any effects on measurements. With change of measuring conditions the impedance and body/contact conductivity can drastically change. This can have major influence on the body composition assessment [11].

Materials and methods

Eight subjects of the university in the age group of 25 to 62 years were included in the monitoring in the first task. The height and weight were measured in standard way and the BMI was calculated. BMI mean was 23,05±5,86. All individuals were people having average values of biological parameters. The Tanita MC 180 MA (Tanita Co., Ltd, Japan) device was used. Tanita MC-180 MA is able to make measurements on frequencies of 5 kHz, 50 kHz, 250 kHz and 500 kHz. It is also possible to do segmental measurements.

All individuals were measured in the following conditions: 1. normal conditions (no environmental change, patient's state in time of arrival), 2. application of water (normal water used from laboratory water supply), 3. solution saline (Baxter Czech, NaCl 0.9%, pH=5.5), 4. EEG gel (Eci electro-gel, Electro-Cap International, Inc., USA), 5. hand cream with oil (Indulona Universal, Zentiva, k.s., Hlohovec, Slovenská republika) – hand application, 6. oil-free hand cream (Nivea Creme, Biersdorf, Germany) – hand application, 7. hand cream with oil-hand and foot application, 8. oil-free hand cream-hand and foot application, 9. oil-free hand cream and water-based foot cream (Foot works active cooling gel, Avon Co. Poland). For better outcome each measurement was doubled and average values were used.

In the second task, a multi-frequency eight-electrode approach of body impedance was considered. BIA was carried out on the following frequencies: 5 kHz, 50 kHz, 250 kHz and 500 kHz.

Results and discussion

First measurement was considered as standard, with no change of conditions (hands and feet were clean). The results of other measurements (different conditions) were compared with the results of measurement number one. We did not observe statistically important changes in TBW. The correlation between impedances, body fat % and TBW was calculated as well.

Figure 2 left side shows changes of TBW and right side illustrates changes of body fat % in dependence on conditions of measurement.

Measurements of fat % can be divided into groups according to percentage (fat mass under 15% and over 19%). Changes in conditions in some cases were significant. Cream no. six (Indulona), seven (Nivea), and number four (EEG gel) have statistically significant (P=0.05) changes from initial measurement setup. These lotions changed the outcome values of measured body composition parameters.

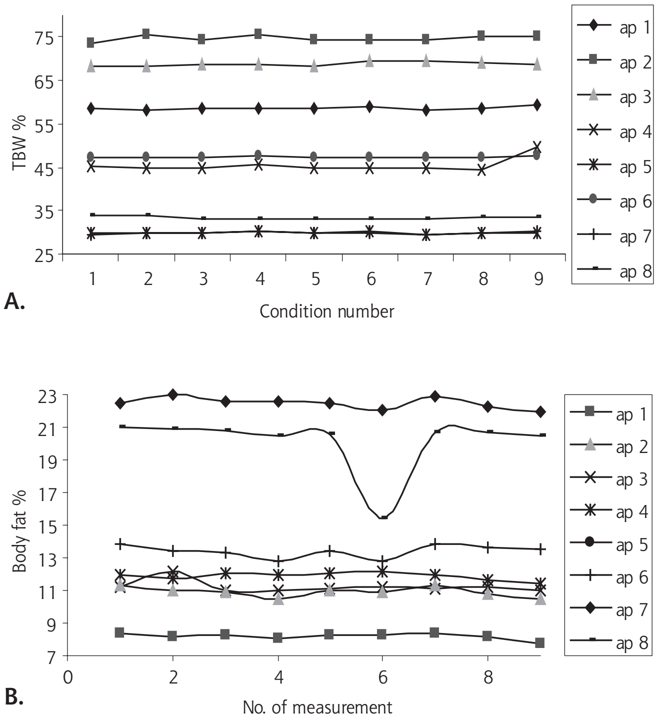

Fig. 2. A. Changes of TBW in dependence on measurement conditions. B. Changes of body fat % in dependence on measurement conditions. Each patient's change is described separately

Ryc. 2. A. Zmiany w TBW w zależności od warunków pomiaru. B. Zmiany % zawartości tłuszczu w zależności od warunków pomiaru. Każdego pacjenta opisano osobno

Finally correlations were calculated for TBW, fat mass % and frequency of used current. Best correlation was achieved with the frequency of 250 kHz with Pearson correlation coefficient 0.9228±0.012. On the contrary in TBW no significant correlation was found.

The present study shows that bioimpedance has significant importance in the body composition description. BIA has many advantages compared to other methods. It is non invasive, rapid, cheap, the obtained values are repeatable and can be very precise.

These days there are used several models for body composition parameters calculation. One of the most precise models for the calculation that is used in most commercial devices is the Hanai suspension model (Hanai, Fenech). This model describes the body as an approximation with several conductive cylinders in series which are representing the arms, legs and the trunk. The cylinders are filled with a suspension containing nonconductive elements embedded in a conductive medium (TBW). This also takes into account that current path is not crossed with external conditions such as we used for our measurements. So we have to keep in mind that use of certain models does not consider different measuring setups.

Conclusions

1. In our study we showed that external conditions have undisputable importance. Furthermore the experiment showed that BIA and body composition from bioimpedance can be biased by external conditions.
2. Our measurements show that when we measure and evaluate body composition with use of the BIA method, standard conditions for measurement should be used.
3. More research should be made to concretize precise conditions for measurements to have same values from the BIA method obtained by various examiners. The BIA/BIS measurements are very suitable for all kinds of body composition assessment.

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