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THE USE OF THE BIOELECTRICAL IMPEDANCE VECTOR ANALYSIS

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ABSTRACT. Bioelectrical impedance vector analysis (BIVA) is a non-invasive, quick and inexpensive technique to estimate body composition and healthcare assessment systems. This technique measures the opposition of body tissues to the flow of an alternating current of 800 μA at an operating frequency of 50 kHz, called bioelectrical impedance. This bioelectrical impedance (Z) consists of two components, resistance (R) and reactance (Xc). In biological structures, application of a constant low-level alternating current results in an impedance to the spread of the current that is frequency dependent. All biological structures have a specific resistance, defined as the strength of opposition by a tissue to the electric current flow. The living organism contains intra and extracellular fluids that behave as electrical conductors and cell membranes that act as electrical condensers and are regarded as imperfect reactive elements.

BIVA is a pattern analysis of impedance measurements plotted as a vector in a coordinate system. Reference values adjusted for age, BMI and gender are plotted as so-called tolerance ellipses in the coordinate system. On this basis, a statement can be made with regard to water balance and body cell mass. Specific BIVA is a promising alternative to classic BIVA for assessing two-compartment body composition, with potential application in nutritional, sport and geriatric medicine.

Keywords: *bioelectrical impedance vector analysis, body composition, health, hydration.*

REZUMAT. ***Utilizarea analizei vectoriale prin bioimpedanţă.*** Analiza vectorială prin bioimpedanță (BIVA) este o tehnică neinvazivă, rapidă și necostisitoare pentru a estima compoziția corporală. Această tehnică măsoară opoziția țesuturilor organismului la fluxul de curent alternativ de 800 μA la o frecvență de funcționare de 50 kHz, denumită impedanță bioelectrică.

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Această impedanță bioelectrică (Z) este formată din două componente: de rezistență (R) și reactanță (Xc). În structurile biologice, aplicarea unui nivel scăzut de curent alternativ constant duce la o impedanță de răspândire a curentului, care este dependentă de frecvență. Toate structurile biologice au o rezistență specifică, definită ca puterea de opoziție a unui țesut la fluxul de curent electric. Organismul viu conține lichide intra- și extracelulare care se comportă ca conductori electrici, și membranele celulare care acționează în calitate de condensatoare electrice și sunt considerate ca elemente reactive imperfecte.

BIVA este o analiză model de măsurători de impedanță, reprezentate grafic ca un vector într-un sistem de coordonate. Valorile de referință ajustate pentru vârstă, IMC și de gen sunt reprezentate grafic ca așa-numitele elipse de toleranță în sistemul de coordonate. Pe această bază, o afirmație poate fi făcută în ceea ce privește echilibrul apei și masa celulară a corpului.

Din punct de vedere specific BIVA este o alternativă promițătoare pentru BIVA clasic pentru evaluarea compoziției corporale cu posibile aplicații în medicina nutrițională, sportivă și geriatrică.

Cuvinte cheie: *analiza vectorială prin bioimpedanță, compoziția corporală, sănătate, hidratare.*

Introduction

Bioimpedance is the collective term that describes safe, non-invasive methods to measure the electrical responses to the introduction of a low-level, alternating current into a living organism, and the biophysical models to estimate body composition from bioelectrical measurements. Although bioimpedance techniques have been used for more than 100 years to monitor assorted biological components, the desire to translate bioelectrical measurements into physiological variables advanced the creation of empirical prediction models that produced inconsistent results (Piccoli, et al., 1994; Lukaski, 2013).

The use of bioelectrical impedance analysis (BIA) is widespread both in healthy subjects and patients, but suffers from a lack of standardized method and quality control procedures. BIA allows the determination of the fat-free mass (FFM) and total body water (TBW) in subjects without significant fluid and electrolyte abnormalities, when using appropriate population, age or pathology-specific BIA equations and established procedures. Published BIA equations validated against a reference method in a sufficiently large number of subjects are presented and ranked according to the standard error of the estimate. The determination of changes in body cell mass (BCM), extra cellular (ECW) and intra cellular water (ICW) requires further research using a valid model that guarantees that ECW changes do not corrupt the ICW. The use of segmental-BIA, multi-frequency-BIA, or bioelectrical spectroscopy in altered hydration states also requires further research. ESPEN guidelines for the clinical use of BIA measurements are described in a paper to appear soon in Clinical Nutrition (Kyle, et al., a and b, 2004).

This clinical method of handling BIA reveals important variations in nutritional status that would not be detected using anthropometry alone. BIA used in this way would allow more accurate assessment of energy sufficiency in children with neurodisability and may provide a more valid identification of children at risk of underweight or obesity in field and clinical settings (Wright, et al., 2008).

The main concepts of bioimpedance measurement techniques including the frequency based, the allocation based, bioimpedance vector analysis and the real time bioimpedance analysis systems.

The single-frequency bioelectrical impedance vector analysis (SF-BIVA) and multi-frequency bioelectrical impedance spectroscopy (MF-BIS) systems provide similar readings for bioelectrical parameters, and the wide variation in the quantification of volume and body mass must be attributed to the different equations used for calculation (Teruel-Briones, et al., 2012).

BIVA or Vector bioelectric impedance analysis (vector- BIA) or the RXc graph method is a noninvasive, low cost and a commonly used approach for body composition measurements and assessment of clinical condition and has recently been developed to assess both nutritional status and tissue hydration (is a useful method to evaluate tissue hydration) (Savastano, et al., 2010, Dumler, et al., 2003; Espinosa Cuevas, et al., 2010; Erdoğan, et al., 2013). The impedance vector produced by an alternating current in the bioimpedance analysis can be seen as a standardised test of cellular mass and function since reactance is believed to reflect the mass and integrity of cell membranes (Norman, 2009).

The use of the bioelectrical impedance vector analysis

The BIVA approach has gained attention as a valuable tool to assess and monitor patients' hydration status and nutritional status since it is independent of disputable regression equations for calculation of lean body mass and fat mass as well as independent of measurement of body weight (Piccoli, et al., 1994).

Technique BIVA - introduced by Piccoli et al. - is a non-invasive, quick and inexpensive technique to estimate body composition. This technique measures the opposition of body tissues to the flow of an alternating current of 800 μA at an operating frequency of 50 kHz, called bioelectrical impedance. This bioelectrical impedance (Z) consists of two components, resistance (R) and reactance (Xc). All biological structures have a specific resistance, defined as the strength of opposition by a tissue to the electric current flow. Fat-free tissues and fluids are good conductors, while bone and fat tissues are bad conductors, being electrically resistant. In terms of impedance, the human body can be schematically considered as a system composed of several conductors in parallel, which pass through two pathways: the extracellular tissue and intracellular membranes. In order to simplify the measurements, the human body is approximated as a sum of five interconnected cylinders that act as conductors in parallel and, while the R is inversely related to the amount of total body water (TBW), the Xc is considered proportional to body mass. Therefore the resistance is inversely related to the TBW, thus representing an indirect measure of the amount of body fluid. The body fluids and electrolytes are responsible for electrical conductance, and cell membranes are involved in capacitance. Bioelectrical impedance measurements have been related to biological function such as pulsatile blood flow and to determination of total body water in healthy and diseased individuals (Piccoli, et al., 1986; Kushner, 1992; Di Somma, et al., 2014).

BIVA is performed with a portable battery-operated device that can be applied in every critical setting requiring quick evaluation.

A diagnostic, clinically relevant BIVA test should be performed with the test person in supine position, aiming at a more uniform distribution of body fluids. We recommend a laying time of 5 minutes, in adipose subjects of 10 minutes before the test. In principle the bio-impedance test can be carried out in any body position, also sitting. To avoid erroneous tests due to skin contact between extremities and trunk, arms and legs should be slightly abducted, in particular in obese individuals.

Each human research subject, clothed but without shoes or socks, was supine in the horizontal position on a bed. For its measurement, the subject must be supine with inferior limbs at 45° and superior limbs abducted at 30° to avoid skin contacts with the trunk and with the stretcher (Di Somma, et al., 2014).

Each two electrodes are placed on the hand and foot of the right side of the body. Should the right side not be available for testing due to an amputation, metal implants, or for any other valid reason, the left side can be used. Repeat tests should always be applied to the same side of the body. In the area where the electrode is to be attached, the skin surface should be cleaned using an alcoholic swap or spray, removing fatty substances, such as body lotion, and skin residue.

Aluminum foil spot electrodes were positioned in the middle of the dorsal surfaces of the hands and feet proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints, respectively, and also medially between the distal prominences of the radius and the ulna, and between the medial and lateral malleoli at the ankle. Specifically the proximal edge of one detector electrode was in line with the proximal edge of the ulnar tubercle at the wrist, and the proximal edge of the other detecting electrode was in line with the medial malleolus of the ankle (Lukaski, et al.,1986).

Four cutaneous electrodes, two on the wrist and two on the ipsilateral ankle, are applied with an inter-electrode distance of at least 5 cm to prevent interaction between electrodes.

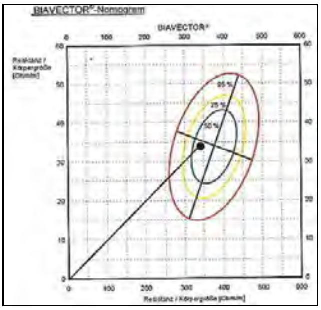
This method was used to minimize contact impedance or skin-electrode interaction. Measurements were made 2 h after eating and within 30 min after voiding (Lukaski, et al., 1986).

The exact, repeatable position of the proximal electrode, oriented on anatomical landmarks, determines test precision and comparability. Small difference in electrode positioning can lead to substantial differences in test result.

Therefore no predictive equations are used to translate bioelectrical measurements into body composition variables, but a semiquantitative assessment of both body composition and hydration status is performed by directly interpreting the bioelectrical measures (that is, the impedance vector).

The bioelectrical impedance is measured in about 30 s, and the results can be displayed in two different modalities: as a vector or as a single number expressed in percentage in a specific scale.

The first method plots the two components R and Xc on a graph to provide a vector (and yields a vector that has length and direction) whose length is proportional to TBW, and the angle above the x axis (referred to as the phase angle) is reflective of cellular integrity. Reference values are adjusted for patient's age, body mass index, gender and height (Lukaski, 2013; Di Somma, et al., 2014). Given that *R* is inversely related to the ICW and ECW, and that Xc is directly related to the amount of soft tissue structures (mass), the vector length provides information about tissue hydration, and vector direction (that is, phase angle) provides information about the amount of cell mass contained in soft tissues (Camina Martín, et al., 2014). Three tolerance ellipses are plotted, corresponding to the 50th, 75th and 95th vector percentile of the healthy reference population of same sex and race. The major axis of this ellipses indexes hydration status, while the minor axis reflects tissue mass.



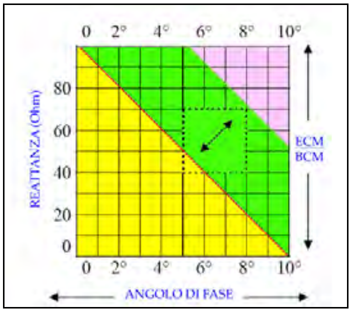


Fig. 1. - BIVA Nomogram **Fig. 2.-** BIVA Biagram **Fig. 3.-** BIVA Biagram
(*https://www.google.ro/search?q=biva+nomogram&source*; Talluri et Maggia, 1995.)

The second method expresses the state of hydration as a percentage in a scale called the hydrograph (or biagram, hydrogram). A normal value, corresponding to the 50th percentile, is included in the range between 72,7 and 74,3 % (Piccoli, et al., 1995).

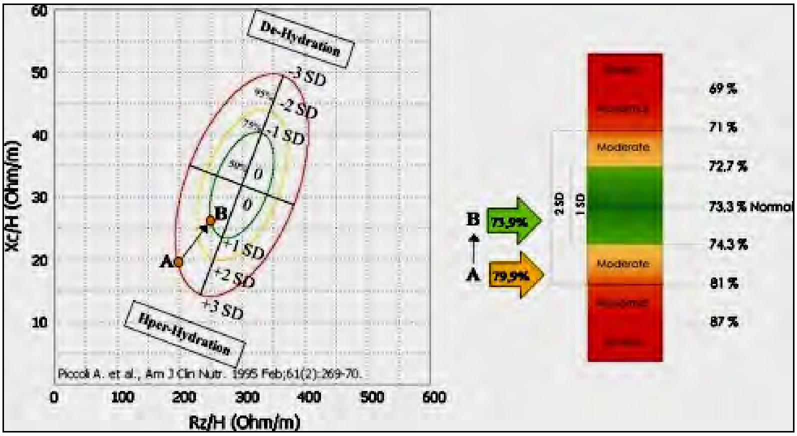


Fig. 4. - BIVA nomogram and numeral scale (Piccoli, et al.,1995)

The RXc graph method was used to identify bivariate pattern distributions of mean vectors (95% confidence ellipses by sex, age, and body mass index), and individual impedance vectors (50%, 75%, and 95% tolerance ellipses) (Piccoli, et al., 2002; Norman, et al., 2009).

The graphs and vector analysis were performed with the software. An integral part of the Bodygram PRO software, BiaVector® and BiaGram are indispensible clinical tools allowing an at-a-glance analysis of nutrition and hydration states as well as therapy follow-up. While the determination of body compartments depends on entered co-predictors such as weight, age, and gender, BiaVector® and BiaGram represent results based on factual BIA measurement only. This clinically validated and meanwhile widely practiced method facilitates body analysis also under difficult conditions, e.g. in obesity, nephrology, oncology, and cardiology. BIVA is particularly suited to follow hydration states in haemodialysis, to analyse emergency and ICU conditions, as well as optimize nutritional or physical activity programs.

The test itself takes only a few seconds. Preparing the test and performing the evaluation with take a total of three to five minutes.

The inter-subject variability of the impedance vector is represented by the bivariate normal distribution with elliptical probability areas (50, 75 and 95%) in the tolerance ellipses for individual vectors.

The main advantage of BIVA over other methods for body composition analysis is that it does not yield any absolute estimate of body compartments, makes no assumptions about body geometry, hydration state or the electrical model of cell membranes and is unaffected by regression adjustments. Thus, BIVA is valid for body composition analysis both in healthy (Piccoli, et al., 1995; Wright, et al., 2008; Buffa, et al., 2009) and pathological populations (Dumler & Kilates, 2003; Marini, et al, 2012; Teruel-Briones, 2012; Camina Martín, 2014).

In countless scientific studies bio-impedance testing was validated against reference methods. The current scientific literature documents a high validity (accuracy, repeatability, and operator independence) for essential body composition parameters, such as total body water, fat free mass, fat mass, cell mass, extracellular water, relative to so-called gold standards.

BIA is applied to children and infants. The Bodygram software contains pediatric predicted norms. The electrode placement differs from that of adults.

BIA ever been applied in cats, cows, ice bears, brown bears, pigs, sheep, apes, horses, and other animals. Testing of animals requires techniques and methodology different from that of humans.

For the application of bio-electrical impedance testing only a limited number of contraindications exists. The following persons should not be tested: persons with implanted cardioverter-defibrillator (ICD), persons with high fever and pregnant women (only out of ethical reasons). While the following persons can be tested: persons with prostheses or metal implants, persons with amputations and persons with pace makers.

BIVA is a pattern analysis of impedance measurements (resistance and reactance) plotted as a vector in a coordinate system. Reference values adjusted for age, BMI and gender are plotted as so-called tolerance ellipses in the coordinate system. On this basis, a statement can be made with regard to water balance (normo-, hypo-, hyperhydration) and body cell mass (nutritional status).

The essential fundamentals of bioimpedance measurement in the human body and a variety of methods are used to interpret the obtained information.

Specific BIVA is a promising alternative to classic BIVA for assessing two-compartment body composition, with potential application in nutritional, sport and geriatric medicine (Buffa, et al., 2014).

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