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Analysis of Body Composition: A Critical Review of the Use of Bioelectrical Impedance Analysis

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Abstract Bioelectrical impedance analysis (BIA) is a method extensively used in studies assessing body composition, especially in view of the high speed of information processing, as a noninvasive method for generating information through portable, easy to use and relatively inexpensive equipment that estimates the distribution of body fluids in the intra- and intercellular spaces in addition to the body components. This technique consists of the passage of a painless low amplitude electrical current applied through cables connected to electrodes or to conducting surfaces placed in contact with the skin, permitting the measurement of resistance (R) and reactance (Xc). These R and Xc values applied to mathematical equations permit the estimate of the following body compartments: fat mass (FM), fat-free mass (FFM) and total body water (TBW). In this respect, the objective of the present report is to review the main concepts involved in the BIA technique, to describe the types of BIA available, their limitations and applications to clinical practice, especially the monitoring of chronic diseases. After this review, we conclude that BIA is an important instrument for health professionals and that its use can provide safe data about body composition, in addition to complementary data about the clinical course of patients followed up on a medium- and long-term basis.

Keywords: *body composition, bioelectrical impedance, resistance, reactance, fat mass, fat-free mass, body water*

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1. Introduction

Bioelectrical impedance analysis (BIA) is a practical method to assess the body composition and it allows the evaluation of importants body compartments: fat mass, fat-free mass and water. Thus, this critical review aims to discuss the concepts, procedures, types, limitatons and main applications of this method.

The assessment of body composition has reached an outstanding position in studies in the area of nutrition, physical activity and health because of the important role of body components in human health, especially regarding the influence of excess body fat and its distribution on the onset of non-communicable chronic diseases [1]. A series of methods are available for the assessment of body composition and the choice of the method to be used should take into account criteria such as which body compartment one intends to assess, cost, validity/reliability of the values obtained, applicability of the technique, degree of training required for the examiner, risk associated with exposure to radiation, and availability of the equipment at the institution [2].

The present report specifically focuses on the analysis of body composition by bioelectrical impedance analysis, more popularly known as bioimpedance analysis (BIA). This method has been extensively used in studies of body composition, mainly because of its rapid processing of information, its noninvasiveness, and the production of information with a portable instrument of easy handling and relatively inexpensive which estimates the distribution of body fluids in the intra- and intercellular spaces [3].

2. Conceptual Assumptions

BIA is a method consisting of the passage of a painless electric current of low amplitude and low and high frequencies through the organism, applied by means of cables connected to electrodes or to conductive surfaces, which are placed in contact with the skin, permitting the measurement of resistance (R) and reactance (Xc). The R and Xc values are then used to calculate impedance (Z) and the phase angle (ϕ), and total body water (TBW) is estimated in addition to the quantity of extracellular (ECW) and intracellular (ICW) water. Fat-free mass (FFM) can then be calculated, assuming that TBW is a constant part of FFM. On this basis, other body compartments such as fat mass (FM) and body cell mass (BCM) can also be measured [4].

Analysis of body composition by BIA assumes that resistance to a determined electrical current is inversely proportional to the distribution of TBW and electrolytes. And this resistance (R) of the length of a conductor of homogeneous material and uniform cross-sectional area is proportional to its length (L) and inversely proportional to its cross-sectional area (A) (Figure 1). Although the body is not a uniform cylinder and its conductivity is not constant, an empirical relation can be established between the coefficient of impedance (Length^2 / R) and the volume of water that contains electrolytes which conduct the electrical current through the body. In practice, it is easier to measure the height rather than the length of the conductor, which usually is from the wrist to the ankle. Thus, the empirical relation is between the lean mass (typically 73% of water) and Height^2 / R. Due to the lack of inherent homogeneity of the body, the term Height^2/R describes a cylindric equivalent which must be adapted to the real geometry using an appropriate coefficient. This coefficient depends on several factors, among them the anatomy of the segments investigated [3].

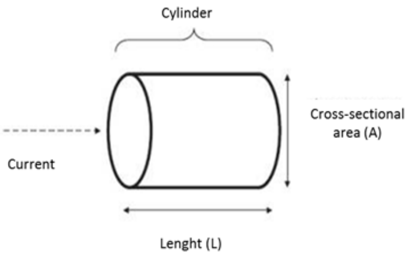

Figure 1. Principles of bioelectrical impedance analysis (BIA). Adapted from: Bioelectrical impedance analysis-part I: review of principles and methods. Clinical Nutrition 2004; 23: 1226-43

BIA is based on the principle that the various body components offer a different resistance to the passage of en electrical current [5], generating resistance vectors (measure of opposition to the flow of the electrical current through the body) and reactance (measure of opposition to the flow of current caused by the capacitance produced by the cell membrane). Thus, after identifying the levels of resistance and reactance of the organism to the electrical current, the analyzer evaluates TBW and, assuming constant hydration, predicts the quantity of FFM. However, if an individual is hyperhydrated, the FFM value is overestimated.

Interpretation of these nomenclatures shows that lean tissues are high conductors of electrical current due to their large amount of water and electrolytes, i.e., they show low resistance to the passage of an electrical current. In contrast, fat, bone and skin have low conductivity and, with a smaller quantity of fluids and electrolytes, they show high electrical resistance. After resistance and reactance are determined, their values can be used to estimate body composition based on specific predictive equations for each clinical situation and for each age range and gender.

The classical BIA method consists of the use of four electrodes attached to the hand, wrist, foot and ankle of the nondominant side of the body. The method is based on the conduction of a painless low-intensity, imperceptible electrical current (500 to 800 μA) at a fixed (≈ 50 kHz) or multiple frequency which is introduced in the organism by means of cables connected to source (distal) electrodes on the hand and foot and on the fall in voltage provoked by impedance and captured by the sensor (proximal) electrodes located on the wrist and ankle or by conducting surfaces placed in contact with the skin.

More recently, BIA has also been used to assess the nutritional risk [8], with the phase angle being the most clinically established impedance parameter [9].

The use of the phase angle has become more popular over the last few years because of its high association with clinical results, time of hospitalization [8] and mortality in various diseases. Based on the principles of BIA, which mainly works by measuring body resistance and reactance in order to alternate an electric current, the storage of this current is thought to be able to create a change in phase which is considered to be the ratio between resistance and reactance and which is expressed geometrically as phase angle (Figure 2), being directly calculated as: arc tangent = (Xc / R) x 180° / π [9].

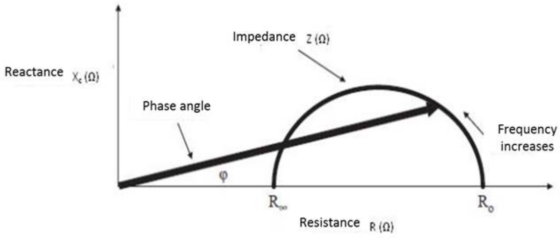

Figure 2. Graphic derivation diagram of the phase angle and its relation to resistance (R), reactance (Xc), impedance (Z) and frequency of the current applied. Adapted from: Bioelectrical impedance analysis-part I: review of principles and methods. Clinical Nutrition 2004; 23: 1226-43

Among all the direct measurements of BIA, the phase angle has proved to be a good predictor of prognosis and mortality regarding hemodialysis [10], cancer [11], human immunodeficiency syndrome (HIV) [12], and liver [13] and geriatric [14] diseases. This measurement has attracted strong interest by being a noninvasive, objective and rapid (less than 2 minutes) tool for the determination of nutritional status and risk of patient morbidity, whereas other nutritional screening tools, although also noninvasive, require more time and / or are highly subjective.

In a recent publication, Norman *et al.* [9] summarized in detail the major studies dealing with the phase angle and their respective cut-off points and describing the impact of this measure on the prognosis of some diseases, with phase angle values of 5.3 to 5.6 being observed for HIV, values of about 6.0 for peritoneal dialysis and values ranging from 4.5 to 5.6 for cancer, depending on the type and location of the tumor.

Other authors such as Mally and Ditmar [15] have tested different techniques of multifrequency tetrapolar BIA in healthy individuals, comparing resistance, reactance and whole body and body segment phase angle values. By comparing their data to those previously reported in the literature, these authors proposed that the posture of the individual during the exam, and the contact and location of the electrode may lead to inconsistent resistance and reactance values, impairing comparisons of different populations. Still other authors such as Hsieh *et al.* [16] have looked for the improvement and / or development of new equations for the estimate of FFM in specific populations, in their case elderly women from Taiwan, in order to provide more precise measurements. Finally, Leahy *et al.* [17] investigated the accuracy of BIA for the assessment of total and regional body composition in healthy subjects in comparison to DXA, the method considered to be the gold standard for these measurements. The authors concluded that the small, although statistically significant, 4% difference between the two methods indicates that BIA can be used instead of DXA to determine FFM in young adults.

Table 1. Bioelectrical impedance equations reported in the literature since 1990 for fat-free mass (FFM) classified according to individual category (adults, elderly, overweight) and standard error of the estimate (SEE)

Population	Source	N	Criterion measure	Equation	r^2	SEE	BIA equipment
ADULTS							
Healthy subjects, (18-94 years)	Kyle et al. (2001) [18]	343	DXA	- 4.104 + 0.518 Est^2 / R_{50} + 0.231 weight + 0.130 Xc + 4.229 sex	0.97	1.8	Xitron
Healthy adults, (18-29 years)	Lohman (1992) [19]	153	Densitometry †	Women = 5.49 + 0.476 Est^2 / R_{50} + 0.295 weight	NR	2.1	Valhalla
Healthy adults, (30-49 years)	Lohman (1992) [19]	122	Densitometry †	Women = 11.59 + 0.493 Est^2 / R_{50} + 0.141 weight	NR	2.5	Valhalla
Healthy subjects of different ethnic groups	Kotler et al. (1996) [20]	126	DXA	Women = + 0.07 + 0.88 ($Est^{1.97} / Z_{50}^{0.49}$) (1.0/22.22) + 0.081 weight	0.71	6.56% (≈2.6)	RJL-101
Healthy individuals, > 16 years	Deurenberg et al. (1991) [21]†‡¶§	661	Multi – C Densitometry‡	-12.44 + 0.34 Est^2 / R_{50} + 0.1534 height + 0.273 weight – 0.127 age + 4.56 sex	0.93	2.6	RJL-101
Healthy individuals, 12-71 years	Boulier et al. (1990) [22]	202	Densitometry	6.37 + 0.64 weight + 0.40 $Est^2 / Z_{1\,MHz}$ - 0.16 age – 2.71 sex (man = 1. woman = 2)	0.92	2.6	IMP BO-1
Women (18-60 years)	Stolarczyk et al. (1994) [23]	95	Multi- C	20.05 – 0.04904 R_{50} + 0.001254 Est^2 + 0.1555 weight + 0.1417 Xc – 0.0833 age	0.75	2.8	Valhalla
Healthy adults (50-70 years)	Lohman (1992) [19]	72	Densitometry ‡	Women = 6.34 + 0.474 Est^2 / R_{50} + 0.180 weight	NR	2.8	Valhalla
Healthy adults (18-29 years)	Lohman (1992) [19]	153	Densitometry ‡	Homens = 5.32 + 0.485 Est^2 / R_{50} + 0.338 weight	NR	2.9	Valhalla
Healthy individuals (12-94 years)	Sun et al. (2003) [24]	1095	Multi-C	Women: - 9.529 + 0.696 Est^2 / R_{50} + 0.168 weight + 0.016 R_{50}	0.83	2.9	
Healthy subjects of different ethnic groups	Kotler et al. (1996) [20]	206	DXA	Men: + 0.49 + 0.50 ($Est^{1.48} / R_{50}^{0.55}$) (1.0/1.21) + 0.42 weight	0.92	5.45% (≈3.2)	RJL-101
Healthy adults (30-49 years)	Lohman (1992) [19]	111	Densitometry‡	Men = 4.51 + 0.549 Est^2 / R_{50} + 0.163 weight + 0.092 Xc	NR	3.2	Valhalla
Healthy individuals (35-65 years)	Heitmann (1990) [25]	139	Multi-C, doubly labeled water, total potassium count	- 14.94 + 0.279 Est^2 / R_{50} + 0.181 weight + 0.231 height + 0.064 (sex weight) – 0.077 age	0.90	3.6	RJL-103
Healthy adults (50-70 years)	Lohman (1992) [19]	74	Densitometry‡	Men = - 11.41 + 0.600 Est^2 / R_{50} + 0.186 weight + 0.226 Xc	NR	3.6	Valhalla
Healthy individuals (12-94 years)	Sun et al. (2003) [24]	734	4 Compartments	Men = - 10.678 + 0.652 Est^2 / R_{50} + 0.262 weight + 0.015 R	0.90	3.9	RJL-101
OVERWEIGHT							
Overweight women (25-45 years)	Jakicic et al. (1998) [26]	123	DXA	2.68 + 0.20 Est^2 / R_{50} + 0.19 weight + 2.55 ethnicity (Caucasian = 0. African American = 1) + 0.1157 height	0.65	8.8	RJL-101
Overweight women (25-45 years)	Jakicic et al. (1998) [26]		DXA	2.04 – 0.02 R_{50} + 0.19 weight + 2.63 ethnicity (Caucasian = 0. African American = 1) + 0.2583 height	0.65	8.8	
ELDERLY SUBJECTS							
Elderly women (62-72 years)	Haapala et al. (2002) [27]	93	DXA	- 128.06 + 1.85 BMI – 0.63 weight +1.07 height – 0.03 R_{50} + 10.0 waist-hip ratio	0.83	1.6	RJL-101
Elderly subjects	Roubenoff et al. (1997) [28]	294	DXA	Women: 7.7435 + 0.4542 Est^2 / R_{50} + 0.1190 weight + 0.0455 Xc	0.77	2.09	RJL-101
Elderly subjects (65-94 years)	Baumgartner et al. (1991) [29]	98	Multi-C ¶	- 1.732 + 0.28 Est^2 / R_{50} + 0.27 weight + 4.5 sex + 0.31 thigh circumference	0.91	2.5	RJL-101
	Dey et al. (2003) [30]	106	4 compartments	11.78 + 0.499 Est^2 / R_{50} + 0.134 weight + 3.449 sex	0.91	2.6	RJL-101
Elderly subjects (60-83 years)	Deurenberg et al. (1990) [31]	72	Densitometry ‡	7.0 + 0.360 Est^2 / R_{50} + 4.5 sexo + 0.359 weight – 0.20 thigh circumference	0.92	2.5	RJL-101
Elderly subjects (60-83 years)	Deurenberg et al. (1990) [31]	72	Densitometry ‡	3.9 + 0.672 Est^2 / R_{50} + 3.1 sex	0.88	3.1	RJL-101
Elderly subjects (65-94 years)	Baumgartner et al. (1991) [29]	98	Densitometry ‡	15.44 + 0.34 Est^2 / R_{50} + 0.36 weight + 4.3 sexo – 0.57 ankle circumference	0.87	3.2	RJL-101
Elderly subjects	Roubenoff et al. (1997) [28]	161	DXA	Men: 9.1536 + 0.4273 Est^2 / R_{50} + 0.1926 weight + 0.0667 Xc	0.72	3.4	RJL-101
Elderly subjects	Roubenoff et al. (1997) [28]	445	DXA	5.741 + 0.4551 Est^2 / R_{50} + 0.1405 weight + 0.0573 Xc + 6.2467 sex			RJL-101

Adapted from: Bioelectrical impedance analysis - part I: review of principles and methods. Clinical Nutrition 2004; 23: 1226-43.

BIA equations are presented in increasing order of standard error of the estimate ( ). They are limited to studies conducted on healthy individuals with a sample of at least 40 subjects and validated against the criterion measure.

*R: resistance; Est^2 / R_{50}: height^2/resistance; Xc: reactance; Z: impedance; Z_5: impedance at 5 kHz; Z_{100}: impedance at 100 kHz; Multi-C: multi= compartments; 1 for men, 0 for women, except when the opposite is indicated; NR: not reported, height in cm; weight in kg; thigh circumference in cm; resistance in Ohms, reactance in Ohms. RJL Systems, Inc, Clinton Twp, MI; Xitron Technologies, San Diego, CA; Valhalla Scientific, San Diego, CA; BIA-2000-M, Data Input, Hofheim, Germany; IMP BO-1, (2 subcutaneous electrodes), I'Impulsion, Caen, France. All subjects are Caucasians except those reported by Jakicic (Caucasian and African American), Stolarczyk et al. (Native American), and Sun (Caucasian and African American).

†% Fat mass = ((4.570/body density) – 4.142) 100.

‡% Fat mass = (4.95/body density) – 4.5) 100.

§% Fat mass = (6.38/body density) – 3.961 bone mineral mass – 6.090) 100.

¶ % Fat mass = ((1.34/body density) – 0.35 age + 0.56 mineral content -1) 205

3. Assessment Procedures

3.1. Body Compartments

Before describing the types of bioelectrical impedance available and their respective assessment procedures, it is necessary to better understand which body compartments these BIA models intend to analyze.

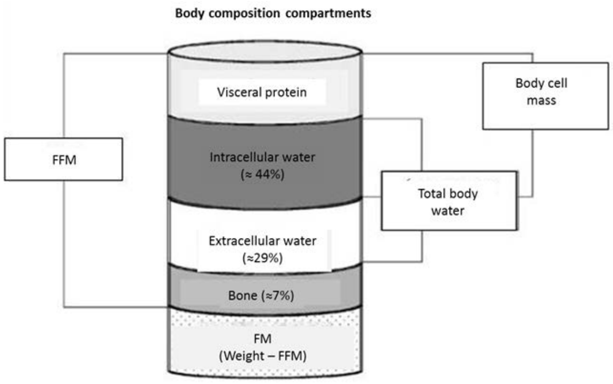

Figure 3. Schematic diagram of fat-free mass (FFM), total body water (TBW), intracellular water (ICW), extracellular water (ECW), and body cell mass (BCM). Adapted from: Bioelectrical impedance analysis - part I: review of principles and methods. Clinical Nutrition 2004; 23: 1226-43

We shall start by describing the compartment known as FFM, which consists of all that is not body fat (Figure 3) and involves the following components: bone mineral content (≈ 7%), extracellular water (≈ 29%), intracellular water (≈ 44%), and visceral protein. Many BIA equations are available in the literature for the estimate of FFM, varying in terms of the parameters included in multiple regression equations and in their applicability to different individuals, as can be seen in Table 1.

The first BIA equations date back to before 1980 and only include height^2 / resistance. Later equations started to include other variables such as weight, age, gender, reactance and anthropometric measrements of trunk and/or extremities in order to improve the accuracy of prediction. Thus, FFM can be determined with a single frequency BIA instrument as long as hydration is normal and the BIA equations are applicable to the study population, taking into consideration gender, age and ethnicity [3].

Anther very important body compartment is total body water (TBW) and its divisions into extracellular water (ECW) and intracellular water (ICW). A single frequency in BIA usually implies a measurement of impedance of 50 kHz and this type of impedance is limited in distinguishing the distribution of body water in the intra- and extracellular compartments. The ability of multifrequency impedance in differentiating between total body water and ICW and ECW is potentially important for the description of the dislocation of fluid balance and for the exploration of possible variations in hydration levels in some special clinical situations, such as renal diseases [32,33]. Thus, equations elaborated for populations in normal states of hydration usually are not valid for individuals with altered hydration since states of hypo- and hyperhydration affect the electrolyte balance, which in turn will influence the BIA measurements regardless of the changes in fluids. Furthermore, in a retrospective study of patients on hemodialysis, Fiedler et al. (2009) verified that the BIA is so good mortality predictor as serum proteins. The authors also suggested monitoring the vectorial graph phase angle, to follow differences in the evolution of nutritional status and hydration levels [34].

The ECW: ICW ratio is a factor known to limit the applicability of predictive equations generated by BIA for external populations. BIA does not permit a precise assessment of TBW and ECW when body water compartments are submitted to acute changes [35] and the mean body hydration of FFM can also vary with age (90% for newborn infants, about 75% for 10-year-old children, and 73% for healthy adults). Beyond these, other clinical situations deserve attention to influence the ratio between ECW and ICW, as hemodynamic changes (including hipovolemic shock, cardiac failure), variations in body temperature (fever, postoperative hypothermia) and gastric stasis [36].

According to Ellis et al. [37], single frequency BIA models (50 kHz) mainly reflect the ECW space, which represents a constant proportion of TBW under normal conditions. An increase in ECW or in the ECW / TBW ratio may indicate edema and / or malnutrition. In contrast, multiple frequency BIA seems to be sensitive to these changes even when no significant change occurs in body weight.

Still regarding the body compartments and now considering FFM to be all that is not body fat, it can be seen that BCM is the protein-rich compartment that is affected in catabolic states and the loss of BCM is associated with unsatisfactory clinical results. In hyperhydrated patients, a precise determination of FFM may fail to detect protein malnutrition due to the expansion of ECW. Estimating the size is difficult since this is a complex compartment consisting of all non-adipose cells and of the aqueous compartment of the adipocytes.

Finally, the last body compartment to be described is FM, consisting of total body fat and obtained by subtracting FFM from total body weight.

3.2. Types of Bioelectrical Impedance

After the above presentation of the body compartments, it is now possible to describe the main types of BIA, starting from single-frequency BIA, (SF-BIA) as previously mentioned. In this method, a 50 kHz current is passed between surface electrodes placed on the hand and foot. Some BIA instruments use other sites such as foot-foot and hand-to-hand electrodes. In this case, the subject is positioned vertically and the conducting surfaces enter in contact with one of the body extremities, foot-foot or hand-to-hand. The vertical model is easy to apply since it only requires the subject to stand up barefoot on the platform that contains the electrodes (foot-foot), or to hold a hand-to-hand device [38]. The foot-foot system is usually employed for domestic use, i.e., it is a portable scale of easy use [3]. This type of BIA is of low cost, is commercially available in several stores, is portable and easy to handle; however, in most cases it does not provide crude resistance and reactance values. However, the foot-foot system is also available in some professional models.

Another model of BIA equipment uses four electrodes, two of which are fixed to the dorsal region of the hand and two to the dorsal region of the foot of the subject on the same side of his body. An electrical current is then applied to the source (distal) electrodes and the fall in tension due to impedance is detected by the proximal electrodes. For this type of analysis, the subject must be in the horizontal position [3].

These 50 Hz BIA instruments do not strictly measure TBW, but rather a weighted sum of the resistivity (≈ 25%) of ECW and ICW. In this way, SF-BIA permits an estimate of FFM and TBW but differences in ICW cannot be determined. Although SF-BIA is not valid under conditions of significantly altered hydration, it can be used to estimate absolute FFM or TBW in normally hydrated individuals.

In contrast, multifrequency BIA (MF-BIA) uses different frequencies (0, 1, 5, 50, 100, 200 and 500 kHz) to estimate FFM, TBW, ICW, and ECW. Poor reproducibility has been observed at frequencies below 5 kHz and above 200 kHz, especially for reactance at low frequencies [39]. Donadio *et al*. [40] assessed the adequacy of SF-BIA and MF-BIA compared to DXA for the assessment of body composition in patients on hemodialysis and concluded that BIA, even SF-BIA, is appropriate for the assessment of body composition, lean mass in particular (FFM minus bone mass) in these patients, with BIA results showing concordance with DXA and with biochemical markers of nutritional status [40].

In general, multifrequency impedance does not improve the estimate of body composition compared to single-frequency impedance, but can provide an accurate and precise estimate of TBW and ECW, which is limited when a single-frequency (50 HZ) instrument is used. Some relevant aspects to be considered during the application of this method are: safety, standardization of the measurements, bioelectrical parameters, validity, clinical use, and limitations.

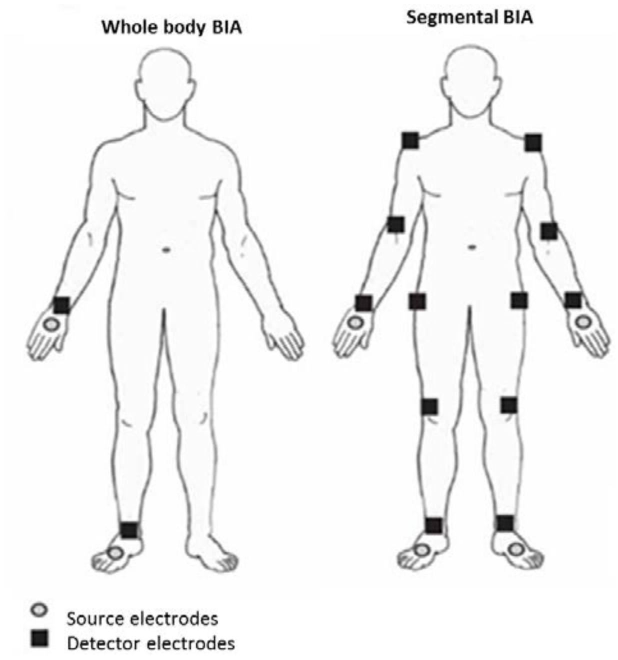

Figure 4. Schematic presentation of the anatomic positions for the placement of electrodes for whole body and segmental bioelectrical impedance analysis. Adapted from: Applicability of a segmental bioelectrical impedance analysis for predicting the whole body skeletal muscle volume. J Appl Physiol 2007; 103(5): 1688-95

Obeying the same principles as those of total body bioelectrical impedance, segmental bioelectrical impedance has been increasingly used for the evaluation of diseases that affect the balance of body fluids [41] (Figure 4). Chumlea *et al*. [42] showed that the assessment of specific resistance for arm, leg and trunk could be used to directly calculate total FFM, and Baumgartner *et al*. [43] demonstrated that the phase angle (reactance / resistance ratio) of the trunk was significantly correlated with percent body fat. In addition, Settle *et al*. [44] suggested that whole body resistance can be estimated by arm and leg resistance. On this basis, it would be possible to predict body composition in an accurate manner using length and resistance measurements of somebody segments such as arm, leg and trunk [43].

Tanaka *et al*. [45] confirmed the superiority of segmental bioelectrical impedance over total body bioelectrical impedance in predicting total muscle volume. In another study, Shafer *et al*. [46] emphasized that multifrequency segmental bioelectrical impedance (SEG-BIA, eight electrodes) is a valid method for the estimate of body fat in adults with BMI in the normal weight and overweight range, but not in obese adults. The authors proposed that the estimate of trunk resistance with the current SEG-BIA instruments may explain the underestimate of percent body fat in obese adults.

SEG-BIA can be performed using the placement of either one of the two additional electrodes on the wrist and the foot on the opposite side [47] or by placing electrode sensors on the shoulder, wrist (acromion), superior iliac crest and ankle, or by placing electrodes on the proximal part of the forearm and on the lower part of the leg and trunk, and an electrode on the shoulder and upper part of the thigh.

In synthesis, SEG-BIA is a simple, convenient, inexpensive and practical alternative method for reference techniques aiming at the assessment of total body composition at the population level. SEG-BIA requires a previous standardization, particularly when different BIA instruments are used, with the need to standardize both the type of electrodes used and their placement [48].

4. Variations and Limitations of the Technique

The technique of assessment of body composition by BIA has been extensively explored over the last three years, especially in terms of the interpretation and reproducibility of the method [49]. New models and multifrequency instruments have contributed to the development of assessment of body composition, although barriers against their application still exist in some situations. The following limitations of BIA can be described:

Restriction or contraindication of the use of the technique: among pregnant women, children and subjects wearing a pacemaker [49]. There are no references in the literature that contraindicate the assessment of nursing women, although the interpretation of the results in these cases may be compromised, so that the procedure is not justified.

Relative or temporary restriction: the test should not be applied to patients with skin lesions that do not permit the use of electrodes, patients with limited contact (patients with hospital infections), and patients with changes in hydration status such as hyper-or hypovolemia [49].

In order to obtain reliable test results, care should be taken with the preparation of the patient, of the equipment and of the measuring instruments such as scale and stadiometer, as well as the place where the test will be performed, preventing errors of measurement [49].

Despite its easy technical use and high reproducibility, BIA may result in less precise estimates in situations in which the water-electrolyte balance is altered. Thus, care should be taken before evaluation to prevent interference with the hydration of body tissues that might change the resistance to the electrical current, since an altered hydration status is the main limitation of this method [3]. Other factors that may affect the results are eating, intense physical activity and alcohol and fluid intake before the evaluation, states of dehydration or of water retention, use of diuretics, and the menstrual cycle [6]. Acute body mass changes such as obesity or protein malnutrition may also represent a limitation of the use of BIA [7].

For patient preparation, it is important to instruct them to avoid alcoholic beverages for at least 8 hours before the test and to fast and drink no water for 4 to 6 hours. Some authors have stated that, if the test is applied within a 2-4 hour interval after a meal, the reading may yield a 4-15 Ohms higher value, contributing to an erroneous interpretation. In addition, the subject should be instructed to perform no physical activity on the day of the test and to remove all removable metal items from their body. If the patient performs the test while lying down, care should be taken to check whether he is in contact with any metal structures or tissues and objects that might conduct electrical current. The subject should remain in the supine position, with his limbs at a distance from the trunk, the arms forming an angle of approximately 30° and the legs forming an angle of 45°. If necessary, a dry towel is used for this purpose. The surfaces that receive electrodes should be cleaned with alcohol [49]. If the subject to be evaluated shows increased hair growth in the areas for electrode fixation, the hair should be shaved with a razor.

In situations in which there is some condition or characteristic that would limit the placement of the electrodes on the body surface, such as amputation, malformation, atrophy and hemiplegia, the electrodes should be fixed on an unaffected body portion [50]. For other situations such as lipodystrophy, Cushing's syndrome, myxedema, ascites, obesity, and metabolic syndrome, among others, with the subject showing irregular distribution of body composition, alternative should be used, such as correction equations and segmental assessment (BIA-SEG), as show in Table 2;

Table 2. Body characteristics and their influence on the assessment and recommendations for the execution and interpretation of the test [50]

	Characteristics that may influence the assessment	Recommendations
Biological determinants		
Ethnicity	Structural differences between trunk and limbs and regarding lean mass hydration	Use ethnicity-specific equations
Age	Variations in tissue hydration and in segment composition	Use age-specific equations
Gender	Structural differences between genders	Use gender-specific equations
Clinical conditions		
Abnormal hydration situations	Change in the precision of the measurement	Use of segmental BIA
Obesity	Variations in hydration, increased fat mass	Reinforced attention for patients with BMI>35*; use segmental BIA
Severe malnutrition or anorexia nervosa	Variations in hydration	Reinforced attention for patients with BMI < 16*;
Neurological disorders	The conductivity of the current may be impaired by tissue irregularity and/or malformations	Use segmental BIA and maintain longitudinal follow-up.

*BMI = body mass index; higher than 35 k / m^2 and lower than 16 kg / m^2 body surface, respectively

Adapted from: Bioeletrical impedance analysis. In: Sobotka L, editor-in-chief. Basics in Clinical Nutrition. Semily, Czech Republic: Galen, 2011 (13-21)

BIA applied to segments represents a great advance in clinical practice by being able to overcome the limitations of the traditional BIA technique. It permits the analysis of body composition in patients with edema and ascites [31], or having muscle tissue or fat deposit or depletion. In this respect, Codognotto *et al*. [51] demonstrated that the application of segmental BIA to the leg opposite to the one with the presence of edema is not sensitive to localized edema and can be used for the assessment of body composition in subjects having edema in only one leg. For patients with a severe fluid overload such as patients with ascites, the interpersonal difference in lean tissue hydration are probably too high to permit the elaboration of uniform equations for the assessment of BCM. Pirlich et al. [52] concluded that the application of the BIA standard is inappropriate for the assessment of BCM in patients with marked changes in body geometry or in state of hydration.

In a detailed review, De Lorenzo and Andreoli [53] proposed that the trunk, with its large crosswise section, contributes as little as 10% of whole body impedance, which represents 50% of the entire body mass [54]. This implies that three aspects should be considered for the analysis of body composition: (1) changes of impedance are intimately related to changes in FFM or BCM of the limbs, (2) changes of trunk FFM probably are not properly described by measurement of whole body impedance, and (3) even marked changes in fluid volume inside the abdominal cavity have only a minor influence on the measurement of FFM or BCM, as could be demonstrated in patients with cirrhosis of the liver and ascites submitted to paracentesis [55].

The correct placement of the electrodes is extremely important for a reliable result. The conventional arrangement (hand-foot) is easier to perform, since it occurs in body areas that do not receive clothing, do not cause embarrassment to the patient and are easier to identify, even in obese patients, unlike what happens with points on shoulders and thigh. Displacements of electrodes 1 cm can result in faulty measuring up to 2% in impedance [56,57].

Another concern was with the dispersion of electric current between segments, since the technique assumes that the body would be a cylinder, which is not observed exactly, considering the various tissues that constitute the organs and anatomical structures. The technique of BIA-

SEG means the body as a cylinder, but with very different characteristics, since resistance is inversely proportional to the area, there is the cross section of the arms exerting greatest influence on impedance in the body, but, with a smaller contribution of volume, however, the trunk has the highest volume and lowest impedance [56,57].

In addition to these points, the measured impedance is proportional to the square of the length of the conduction path, illustrating how variations in electrode placement can represent significant flaws in the ratings [56,57].

Another challenge even greater for the use of BIA, refers to its application in the assessment of body composition in children and adolescents, since according to the stage of growth and biological maturation there is a wide variation in the various body components (water, proteins, minerals etc.) from birth to adulthood. This variation can significantly affect the estimate of fat mass (FM) and fat free mass (FFM), especially in models bicompartimentais [58].

Some studies investigated the accurate assessment of neonatal body composition because it is essential in studies investigating neonatal nutrition or developmental origins of obesity. Lingwood (2013), shows that there is a critical need for improved technologies to monitor fluid balance and body composition in neonates, particularly those receiving intensive care and BIA appears to be effective for monitoring physiological trends [59,60].

According to Lingwood (2013) prediction equations for total body water, extracellular water and fat-free mass have been developed to use in neonates, but many require further testing and validation in larger cohorts. This author suggested that alternative approaches based on Hanai mixture theory or vector analysis in the early stages of neonates investigation [60].

Finally, regarding the instrument, periodic maintenance should be planned in order to avoid pitfalls at the time of the exam, with verification of the charge of the battery on the eve of the test, guaranteeing sufficient autonomy for 20 tests. It is also essential to check the length of the cables when the subject to be tested or the sample measures more than 2 m in height. The electrodes must be specific for BIA, measuring 4 cm² and should be packed individually, if possible under refrigeration in order to guarantee good adhesion to the skin [49].

5. Application to Clinical Practice and to the Monitoring of Chronic Diseases

As commented at the beginning of this chapter, different models of BIA instruments are currently available on the market, differing in cost, electrode presentation and type of measurement. The use of different instruments can satisfy specific demands such as research, use in specialized hospital units such as hemodialysis sector, liver transplantation, and oncology, among others, and use in medical offices, clinics, spas and gyms, as well as the patient’s home. Thus, it is important to know the product and the purpose for which it is intended. The following are some of the important characteristics of the instrument in terms of functionality:

5.1. Single-Frequency Bioimpedance (SF-BIA): Nutritional Assessment and Support during the Treatment of Chronic Diseases

It is the model most commercialized, affordable and available in hospitals, clinics, doctors’ offices, spas, and training center. This instrument has a single 50 kHz frequency, which permits the calculation of TBW and FFM using regression equations. By having a single frequency, this instrument may mask the interpretation of the data in tests in which the subject has altered body composition in some compartment. Thus, as commented earlier, its use is not recommended in situation of altered hydration.

For instance, a nutritional approach often neglected in treating patients with mental illnesses. It is usual in these treatments gain weight as a consequence of the use of drugs, as with most cases of schizophrenia. Literature presents some works describing the nutritional status of these patients based on BMI only. The assessment of body composition by BIA showed that individuals with schizophrenia under treatment had fat mass equivalent of an obese (above 30 wt%), despite being classified as overweight. T. This worrying statistic shows that more nutritional attention should be given to these clients [61].

Another issue is the measurement of skeletal mass (SM). There is great interest in determining muscle mass by BIA method for tracking elderly as marker of protein catabolism in critical and surgical patients, myopathies, degenerative diseases and individuals in physical training. Janssen et al. (2000) developed an equation to estimate SM, using a multiethnic population and variables such as height, resistance, age and sex in subjects with different ages and FM. A limitation of their study was that this result is not reproducible in Asian, addition to being impractical to use it in conditions with water variability, situations that need to be further explored [62].

Correction equations should be used according to the characteristics of the subject evaluated (biological determinants and clinical conditions) [50] and, over long-term follow-up periods, may contribute more complete information and records about the variations in body weight during treatment / follow-up.

5.2. Multifrequency Bioimpedance (MF-BIA): Monitoring of Critically Ill Patients and Cancer Patients

This method has more resources for assessment such as the determination of ICW since it involves currents with frequencies ranging from 5 to 100 kHz. Lower frequencies are membrane permeable, permitting the measurement. Regression equations are used to determine TBW, providing more precise results because of the use of varied frequencies. Another resource of this instrument is its use as a marker of cell integrity, mentioned as a prognostic factor in some literature reports. This fact is due to the observation of some situations in which even very low frequency currents cannot penetrate the cell membrane and relate them to chronic diseases such as bacteremia, HIV and cancer [50,63].

There are a large number of publications which relate to weight loss and sarcopenia and mostly tolerability of chemotherapy [64,65]. Antineoplastic agents are usually aggressive and often lead to cachexia. The phase angle (PA) is being investigated in diagnosed with cancer and most of these studies in patients with advanced stage and therefore, related to the patient's prognosis and an expectation of life [11]. This assignment should be to the fact that change in PA indicate a change in the ability to conduct current tissue showing a smaller capacitance of the membranes. The maintenance of the resistance values implies a reduction in PA - remembering the formula:

$PA = arc - tangentXc / R\ x\ 180degrees / \pi$. These changes in conductivity precede cancer cachexia are related to survival patient [11].

As in other identified situations in a hospital routine, the MF-BIA has proven a more trustworthy marker in relation to ECW, as important for the follow-up of patients with eating disorders. Mika et al. (2004) used this feature to monitor hydric changes, result of diarrhea and vomiting, frequent in these patients as well as therapies predictors to refeeding in malnourished patients. In comparison with the control group, there were no significant differences in BMI, but the phase angle showed changes as well as reactance, showing a satisfactory evolution of patients who would not be observed through the use of more traditional methods [66].

In the same way, chronic kidney disease (CKD) patients on dialysis have significant fluctuations in weight and FFM, because of fluid variações. A isolated measurement of ECW is not a good parameter, however, the use of these data in combination with BMI using dry weight can more accurately characterize the nutritional status of dialysis patients as well as their evolution during therapy [67].

Further investigations with these characteristics are needed to explore this observation, as standardization of cutoffs related to age, BMI and sex, working as prognostic indicators [68].

MF-BIA is limited in its ability to quantify the magnitude of fluid volumes over time because it correlated well with changes in weight and body fluid compartments in patients going from overhydration to euvolemia, but did not correlate with these changes in patients going from dehydration to euvolemia. This suggests that confounding effects, such as simultaneous changes in electrolyte concentration, changes in cylinder (leg) diameter and skin temperature in addition to changes in impedance, may be in part responsible for the inability to measure changes in hydration [47].

This is a more expensive instrument normally found in specialized treatment centers, research units and university hospitals, but experiments with malnourished patients, renal disease, among others, has shown great relevance in interepretação and monitoring of nutritional status in patients with limitations for use of the SF-BIA [3].

5.3. Bioelectrical Impedance Spectroscopy

This technique measures impedance using 50 or more frequencies and the values are used to calculate the resistance of ECW and ICW. The resistance values can then be used to calculate the size of the fluid compartments by employing calculations using predictive equations. This calculation, however, is based on the laws of physics and has low specificity for body segments. Nevertheless, the results show that the differences in body structures and the specific resistivity of fluids combine to overthrow this assumption. So far, the use of these calculation is recommended for healthy individuals with no structural or hydration abnormalities in view of the scarcity of equations or references for comparison in the literature [48].

6. Final Considerations and Future Research Directions

In summary, BIA is an important supporting tool for health professionals. However, it is necessary to have a good knowledge of the fundamentals of this method, of correction equations and of the resources that the method can offer for the assessment of body composition, clinical follow-up and biological markers.

The future researchers should explored better the use of this method in more specific segments of the population, such as athletes, in order to provide safe data about body composition and also in clinical practice, providing complementary data about the evolution of patients on medium- and long-term follow-up.

The determination of changes in BCM, ECW and ICW requires further research using a valid model that guarantees that ECW changes do not corrupt the ICW and vice versa. The use of segmental, MF-BIA or BIS in altered hydration states also requires further research.

Finally, future research studies should employ multicomponent models to accurately address the dynamic changes in body composition using, as predictors, whole body measures that could be used in multidisciplinary and multi-approach interventions.

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