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REVIEW

Bioelectrical impedance vector analysis (BIVA) for the assessment of two-compartment body composition

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This review is directed to define the efficacy of bioelectrical impedance vector analysis (BIVA) for assessing two-compartment body composition. A systematic literature review using MEDLINE database up to 12 February 2014 was performed. The list of papers citing the first description of BIVA, obtained from SCOPUS, and the reference lists of included studies were also searched. Selection criteria included studies comparing the results of BIVA with those of other techniques, and studies analyzing bioelectrical vectors of obese, athletic, cachectic and lean individuals. Thirty articles met the inclusion criteria. The ability of classic BIVA for assessing two-compartment body composition has been mainly evaluated by means of indirect techniques, such as anthropometry and bioelectrical impedance analysis (BIA). Classic BIVA showed a high agreement with body mass index, that can be interpreted in relation to the greater body mass of obese and athletic individuals, whereas the comparison with BIA showed less consistent results, especially in diseased individuals. When a reference method was used, classic BIVA failed to accurately recognize FM% variations, whereas specific BIVA furnished good results. Specific BIVA is a promising alternative to classic BIVA for assessing two-compartment body composition, with potential application in nutritional, sport and geriatric medicine.

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INTRODUCTION

Normal ageing involves variations of body mass and composition[1–3] that expose elderly individuals to the risk of protein-energy malnutrition[4] and have a role in the pathogenesis of geriatric syndromes, such as sarcopenia,[5] sarcopenic obesity,[1] frailty,[6] and of metabolic and cardiovascular diseases[7] or of Alzheimer's disease.[8]

The comprehension and monitoring of body composition variations in ageing is relevant to the development of preventive strategies and timely therapeutic interventions for nutritional status-related diseases. However, the most frequently used nutritional indicators, such as the mini nutritional assessment[9] and anthropometric indices, have only a limited value in capturing body composition variations.

On the other side, the more accurate techniques for the assessment of body composition, such as densitometry, computed tomography, magnetic resonance imaging and dual-energy X-ray absorptiometry (DXA) may be unsuitable in routine geriatric practice because of their cost, procedural complexity and limited availability.[3]

Bioelectrical impedance analysis (BIA) is a portable technique for assessing body composition; it is practical, inexpensive, noninvasive, and appropriate for routine evaluation, even in bedridden patients. The conventional approach involves the use of prediction equations for the estimation of body compartments.[10,11] However, the equation application can lead to estimation errors in the elderly and in pathological subjects, who are characterized by peculiar body composition and hydration characteristics, and by a great individual variability.[2,12]

Alternative techniques, that use directly bioelectrical variables without referring to predictive equations and/or assumptions on body composition, can overcome this problem.

Bioelectrical impedance vector analysis (BIVA)[13] is based on the analysis of bioelectrical values (resistance, R; reactance, Xc), standardized for body height to remove the effect of conductor length. Bioelectrical vectors can be analyzed in relation to reference values (tolerance ellipses) or for intergroup comparisons (confidence ellipses).[13]

BIVA has demonstrated to be correlated to indicators of nutritional status and capable of evaluating hydration status and has been applied in several populations, in all life-cycle stages, in athletes, in healthy as well as in diseased individuals (see reviews by Barbosa-Silva and Barros,[14] Buffa *et al*.,[15] Kyle *et al*.[16] and Norman *et al*.[17]). However, its efficacy for assessing body composition in term of fat and fat-free mass has not been reviewed yet.

Specific BIVA[18,19] is a technique recently proposed as an extension of the procedure conceived by Piccoli *et al*.,[13] that differs from classic BIVA in that it standardizes bioelectrical values for height and transverse areas, rather than just body height. The theoretical basis is the Ohm's law, according to which resistance is directly proportional to the conductor's length and inversely proportional to its cross-section. Specific values are expected to be more sensitive to the tissues' properties, and hence to body composition, because the influence of body size and shape is counterbalanced.

In this review, we discussed the suitability of bioelectrical impedance vector analysis in the elderly. In particular, the

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addressed question centered on the definition of the efficacy of the classic and specific approaches for assessing two-compartment body composition.

MATERIALS AND METHODS

The analysis was realized following the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' PRISMA guidelines.[20]

Eligibility criteria

The review included methodological and empirical studies on body composition comparing the results of bioelectrical impedance vector analysis with those of other techniques. Papers analyzing bioelectrical vectors of individuals classified in one of the following four categories of body composition were also included: cachexia, obesity, athletics and lean.

Search strategy

The search was focused on studies using classic or specific BIVA for analyzing body composition. The studies were identified by searches using Medline (up to 12 February 2014).

The following search term was used:

(BIVA OR 'bioelectrical impedance vector analysis' OR 'vector analysis')

AND

('body composition' OR 'fat mass' OR 'fat-free mass' OR 'lean mass' OR 'lean body mass')

Moreover, the list of papers citing the first description of BIVA[13] or that of specific BIVA,[18,19] obtained from SCOPUS database (12 February 2014), was compared and integrated with the results of the search of MEDLINE.

Study selection

All abstracts from the electronic searches (MEDLINE and SCOPUS) were screened independently by all authors to select articles meeting eligibility criteria, upon discussion. The full texts of selected articles were obtained and checked to better consider the fit with eligibility criteria. References of selected articles were also screened, to obtain further studies not previously identified.

Data collection and analysis

Each selected article was analyzed to extract details on: bibliographic characteristics (authors, year and journal of publication), sample characteristics (population, age range, health status, athletic discipline); comparative technique (other indicators used to assess body composition); BIVA approach (classic or specific).

RESULTS

We reviewed 333 abstracts: 183 resulting from MEDLINE search and additional 150 identified, after duplicates exclusion, from the list of 218 papers citing the first description of classic or specific BIVA, retrieved by SCOPUS. Thirty-six full-text articles were first selected and, upon detailed review, seven of them were removed for not fulfilling the eligibility criteria. With the addition of one record identified through citation checking, a total of 30 articles using classic or specific BIVA for assessing body composition were included in the review (Figure 1). Table 1 summarizes the general characteristics of selected articles.

Bibliographic characteristics

The articles included in the review were published from 1994,[13] but the majority of them (73%) appeared in 2007 or later (Table 1).

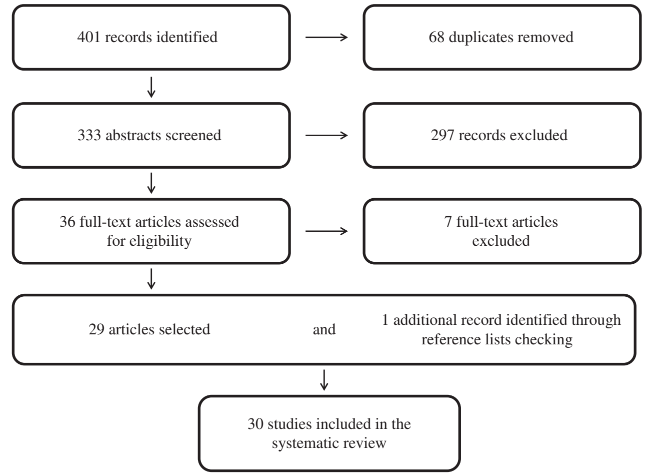

Figure 1. Flow chart of study identification for the systematic review.

Participants and methodologies

Researches were focused on healthy (46.7%) as well as diseased (53.3%) individuals. Only six studies concerned athletic subjects. The age range of studied samples included children, adults and elderly.

Most of the researches were based in Europe (76.7%), especially in Italy (60%) and five (16.7%) were conducted in the United States, Central or South-America (Table 1).

Of the 30 studies analyzed, 26 (86.7%) used the classic BIVA and 4 (13.3%) the specific approach (Table 1). Reviewed studies included methodological (53.3%) and empirical (46.7%) researches, and were mainly based on the comparison with anthropometry (43.4%), BIA (3.3%) or both (20%), whereas those based on DXA (13.3%) or other techniques (clinical evaluation, somatotype, handgrip strength), were few (20%) (Table 1).

Classic BIVA: theoretical principles and procedure

The first description of BIVA was published by Piccoli *et al.*[13] This new approach was based on the analysis of the bivariate distribution of the impedance vector, defined by its length and phase, on the RXc graph. The sex-specific 50, 75 and 95% tolerance ellipses of the reference population allow the simultaneous analysis of direction (phase) and length of the impedance vector, that are indicative of hydration and nutritional status. Variations of the bioelectrical vectors along the major axis of the ellipses indicate changes in tissue hydration (dehydration towards the upper pole, fluid overload towards the lower pole). Variations along the minor axis indicate differences in the content of body cell mass in soft tissues (more cell mass on the left side). On the left side of the ellipses, athletic individuals are characterized by similar phases but longer vectors than obese ones; on the right side, cachectic individuals show similar phases but shorter vectors than lean ones.

The efficacy of BIVA in assessing variation of hydration status (variations of vector length, along the major axis) and of nutritional status (variations of phase, along the minor axis) has been verified by numerous studies and has been discussed in some reviews.[14–17]

Efficacy of classic BIVA for assessing two-compartment body composition

This review showed that the accuracy in evaluating two-compartment body composition has been mainly evaluated by means of the comparison with indirect techniques, such as anthropometry (particularly BMI, but also somatotype, arm muscular area, growth indicators), or conventional BIA (Table 1).

Table 1. General characteristics of selected articles

Reference	Sample description	Age range	Health status	Comparative technique	BIVA approach
Baldwin et al.[45]	Australia (N = 29)	Adults	Critically ill, survivors	BIA	Classic
Barufaldi et al.[21]	Brazil (N = 3204)	Children	Healthy	BMI	Classic
Bronhara et al.[46]	Italy (N = 179)	Adults, elderly	Different conditions[a]	Clinical evaluation	Classic
Buffa et al.[42]	Italy (N = 201) (97 m, 104 f)	Elderly	Sarcopenia	BMI	Classic
Buffa et al.[18]	USA (N = 1590)	Adults	Healthy	BMI, DXA	Specific
Buffa et al.[34]	Italy (N = 353) (60 m, 84 f)	Adults, elderly	Type 2 diabetes	BMI, AMA	Classic
Castillo-Martinez et al.[39]	USA (N = 519) (233 m, 286f)	Adults	Different conditions[b]	BMI, HG	Classic
Colin-Ramirez et al.[41]	Mexico (N = 405)	Adults	Heart failure	BMI, HG	Classic
Gatterer et al.[35]	Austria-Italy (N = 14 m)	Adults	Healthy (football)	BMI	Classic
Guida et al.[22]	Italy (N = 315 m)	Adults, elderly	Healthy	BMI, BIA	Classic
Guida et al.[31]	Italy (N = 464)	Children	Healthy	BMI, BIA	Classic
Haas et al.[23]	Germany (N = 57 f)	Adults	Anorexia nervosa	BMI, BIA	Classic
Kim et al.[24]	Korea (N = 21)	Adults	Healthy (gymnastics)	BMI, somatotype	Classic
Marini et al.[25]	Venezuela—Amerindians (N = 101) (40 m, 61 f)	Children, adults, elderly	Healthy	BMI	Classic
Marini et al.[26]	Italy (N = 207) (75 m, 132 f)	Elderly	Healthy	BMI, DXA	Classic Specific
Marini et al.[19]	Italy (N = 207) (75 m, 132 f)	Elderly	Healthy	BMI, DXA	Classic Specific
Micheli et al.[27]	Italy (N = 893 m)	Adults	Healthy (soccer)	BMI	Classic
Nescolarde et al.[36]	Spain (N = 14)	Adults	Healthy (football, basketball)	BMI	Classic
Norman et al.[28]	Germany (N = 242)	Adults	Gastrointestinal disease	BMI, HG	Classic
Norman et al.[40]	Germany Denmark (N = 363) (172 m, 191 f)	Adults, elderly	Hospitalized patients	HG	Classic
Piccoli et al.[13]	Italy (N = 217)	Adults	Different conditions[c]	BMI	Classic
Piccoli et al.[37]	Italy (N = 7 m)	Adults	Healthy (climbing)	BMI	Classic
Piccoli et al.[29]	Italy (N = 1316) (548 m, 768 f)	Adults, elderly	Healthy, obesity, nephropathy	BMI, BIA	Classic
Piccoli et al.[43]	Italy (N = 74 f)	Adults	Anorexia nervosa	BMI, BIA	Classic
Piccoli et al.[38]	Italy (N = 30 m)	Adults	Healthy (body building)	BMI	Classic
Saragat et al.[44]	Italy (N = 174) (66 m, 108 f)	Elderly	Alzheimer's disease, healthy	BMI, AMA	Classic
Saragat et al.[49]	Italy (N = 560) (265 m, 295 f)	Elderly	Healthy	DXA	Specific
Savastano et al.[32]	Italy (N = 110) (25 m, 85 f)	Adults	Severe obesity	BMI, BIA	Classic
Savastano et al.[33]	Italy (N = 45)	Adults	Severe obesity	BMI[d]	Classic
Scalfi et al.[30]	Italy (N = 38 f)	Adults	Anorexia nervosa	BMI	Classic

Abbreviations: AMA, arm muscle area; BIA, bioelectrical impedance analysis; BIVA, bioelectrical impedance vector analysis; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; f, females; HG, handgrip strength; m, males. [a]Cachexia, obesity, dehydration, anasarca. [b]Cachexia, chronic heart failure, anorexia, dyspnea, edema, orthopnea. [c]Healthy, obesity, chronic renal failure, idiopathic syndrome. [d]DXA and BIA were used, but not compared with BIVA.

Other information come from the analysis of samples characterized by means of their muscle function (handgrip strength), by a clinical diagnosis, or for being athletes. Only two studies used a gold standard (DXA) as a reference technique (Table 1).

In general, the results of BIVA and BMI showed a good agreement (Table 2): BMI was positively related to phase angle[13,18,21–30] and negatively related to vector length.[13,18,21,22,26–31] As supposed according to classic BIVA,[13] bioelectrical vectors of obese individuals, diagnosed on the basis of their BMI, were located on the lower left quadrant of the tolerance ellipses, being characterized by short vector length and high phase[13,19,22,29,31–33] (Tables 2 and 3). A similar pattern has been observed in obese patients with type-2 diabetes.[34]

The information on bioelectrical vectors of athletes are fewer and less consistent in findings[24,27,35–38] (Tables 2 and 3). Bioelectrical vectors of athletic individuals were located on the left side of the ellipses. This result is coherent with the already-mentioned positive correlation between phase and BMI, and with the association between phase and indirect indicators of muscle mass and strength, such as the mesomorphic component of somatotype[24] and handgrip strength.[28,39–41] On the contrary, the impedance vector length, that is, the location on the left upper or left lower quadrant of the ellipse, was dishomogeneous in different sports. Moreover, in the case of football players,[35] basketball players,[36] climbers[37] and body-builders,[38] the mean bioelectrical vector was within the 'obesity' area, even if near the minor axis (Table 2).

On the other side, the vectors of individuals classified as underweight on the basis of their BMI or by means of a clinical evaluation were on the right half of the ellipse (Table 2). In particular, vectors of cachectic individuals fell toward the lower pole,[39,41] whereas those of anorexic and sarcopenic ones toward the upper pole.[13,23,26,42,43] A peculiar case is that of patients with Alzheimer's disease, whose vectors were characterized by low phase and high impedance, hence located in the region of lean individuals (upper right quadrant of the RXc graph), despite

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Table 2. Comparison between BIVA and BMI

Comparison	*Result*	*Characteristics of the sample*	*Reference*
Association between BMI and vector length	Negative	Healthy group	Piccoli *et al.*,[13] Piccoli *et al.*,[29] Guida *et al.*,[22] Guida *et al.*,[31] Barufaldi *et al.*,[21] Buffa *et al.*,[18] Marini *et al.*[19]
		Gastrointestinal disease	Norman *et al.*[28]
		Sarcopenia	Marini *et al.*[26]
		Anorexia	Scalfi *et al.*[30]
		Athletes: football	Micheli *et al.*[27]
		Morbid obesity	Savastano *et al.*[33]
Association between BMI and phase angle	Positive	Healthy group	Piccoli *et al.*,[13] Piccoli *et al.*,[29] Guida *et al.*,[22] Barufaldi *et al.*,[21] Marini *et al.*,[25] Marini *et al.*,[19] Buffa *et al.*,[18] Saragat *et al.*[49]
		Gastrointestinal disease	Norman *et al.*[28]
		Anorexia	Scalfi *et al.*,[30] Hass *et al.*[23]
		Sarcopenia	Marini *et al.*[26]
		Athletes: football	Micheli *et al.*[27]
		Athletes: gymnastic, dance	Kim *et al.*[24]
Location of vectors of obese individuals on the RXc graph	Lower left quadrant	Healthy group	Piccoli *et al.*,[13] Piccoli *et al.*,[29] Guida *et al.*,[22] Guida *et al.*,[31] Marini *et al.*[19]
		Morbid obesity	Savastano *et al.*[32]
		Morbid obesity	Savastano *et al.*[33]
		Type 2 diabetes	Buffa *et al.*[34]
Location of vectors of athletes individuals on the RXc graph	Upper left quadrant	Athletes	Piccoli *et al.*[13]
		Athletes: football	Nescolarde *et al.*,[36] Micheli *et al.*[27]
	Lower left quadrant (near the minor axis)	Athletes: football	Gatterer *et al.*[35]
		Athletes: basketball	Nescolarde *et al.*[36]
		Athletes: climbing	Piccoli *et al.*[37]
		Athletes: body building	Piccoli *et al.*[38]
Location of vectors of lean individuals on the RXc graph	Upper right quadrant	Healthy group (elderly)	Buffa *et al.*[42]
		Anorexia	Piccoli *et al.*,[13] Piccoli *et al.*,[43] Haas *et al.*[23]
		Sarcopenia	Marini *et al.*[26]
Location of vectors of patients on the RXc graph	Upper right quadrant	Alzheimer's disease	Saragat *et al.*[44]
	Lower right quadrant	Cachexia	Colin-Ramirez *et al.*,[41] Castillo-Martinez *et al.*[39]

Abbreviations: BIVA, bioelectrical impedance vector analysis; BMI, body mass index. [a]A short vector length was observed also in nephropathic patients with edema, who were characterized for having a lower phase angle than obese individuals. [b]Using the BMI-for-age $> +2$ *z*-score and the 95% tolerance ellipse as cutoff points for overweight, differences between classifications were observed.

Table 3. Comparison between BIVA and other indicators of body composition

Comparative technique	*Relationship*	*Characteristics of the sample*	*Reference*
Somatotype	Positive association between phase angle and mesomorphy	Athletes	Kim *et al.*[24]
AMA	Positive association with phase angle	Alzheimer's disease	Saragat *et al.*[44]
	Negative association with phase angle	Type 2 diabetes	Buffa *et al.*[34]
HG	Positive association with phase angle	Gastrointestinal disease	Norman *et al.*[28]
		Hospitalized individuals	Norman *et al.*[40]
		cachexia	Colín-Ramírez *et al.*,[41] Castillo-Martínez *et al.*[39]
Clinical evaluation	Agreement	Healthy group cachexia	Bronhara *et al.*[46]

Abbreviations: AMA, arm muscular area; BIVA, bioelectrical impedance vector analysis; HG, handgrip strength.

showing a BMI similar to that of age-matched controls (possibly related to a relatively high proportion of fat mass).[44]

The association between BIA and BIVA findings was not always evident (Table 4). Some studies revealed an agreement between BIA estimates of body components (BCM, FFM, FM) and the BIVA pattern, with individuals characterized by more soft tissue mass showing higher phase.[22,27,31,32] On the other hand, other researches, focused on clinical issues, found only a tendency to agreement,[23,45] or inconsistent results.[29,43]

A recent analysis on the efficacy of BIVA in estimating body composition by applying fuzzy linguistic models[46] does not add much information to the results of this review (Table 3). In fact, although authors obtained a good agreement between BIVA and clinical diagnoses of body composition, the result was mainly due to the correct identification of hydration status, while obese and athletic individuals were poorly checked.

Researches using DXA as the reference technique showed a weak capability of classic BIVA to evaluate body composition, that is,

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Table 4. Comparison between BIVA and BIA

Relationship	Body component	Characteristics of the sample	Reference
Agreement between BIVA and BIA	FM	Healthy group	Guida *et al.*,[22] Guida *et al.*[31]
		Anorexia	Haas *et al.*[23]
	FFM	Healthy group	Guida *et al.*,[22] Guida *et al.*[31]
		Critically ill patients	Baldwin *et al.*[45]
	BCM	Healthy group	Guida *et al.*,[22] Guida *et al.*[31]
		Morbid obesity	Savastano *et al.*[32]
Disagreement between BIA and BIVA	FM	Anorexia	Piccoli *et al.*[43]
		Renal disease	Piccoli *et al.*[29]
	FFM	Renal disease	Piccoli *et al.*[29]
		Anorexia	Piccoli *et al.*[43]
	BCM	Anorexia	Haas *et al.*[23]

Abbreviations: BCM, body cell mass; BIA, bioelectrical impedance analysis; BIVA, bioelectrical impedance vector analysis; ECF, extracellular fluid; FFM, fat-free mass; FM, fat mass; ICF, intracellular fluid; TBW, total body water. [a]A very large variability of body composition estimates by conventional BIA was observed. [b]A reduction of FFM, TBW, ECF and ICF, but not of phase and impedance was observed in repeated testing.

Table 5. Comparison between classic or specific BIVA and DXA

	Body component	Kind of relationship	Characteristics of the sample	Reference
Classic BIVA	BCM	Agreement	Healthy group	Marini *et al.*,[26] Buffa *et al.*,[18] Marini *et al.*[19]
	FM%	Disagreement	Healthy group	Marini *et al.*,[26] Buffa *et al.*,[18] Marini *et al.*[19]
Specific BIVA	BCM	Agreement	Healthy group	Marini *et al.*,[26] Buffa *et al.*,[18] Marini *et al.*,[19] Saragat *et al.*[49]
	SMI	Agreement	Healthy group	Marini *et al.*,[26] Buffa *et al.*[18]
	FM%	Agreement	Healthy group	Marini *et al.*,[26] Buffa *et al.*,[18] Marini *et al.*,[19] Saragat *et al.*[49]

Abbreviations: BCM, body cell mass; BIVA, bioelectrical impedance vector analysis; DXA, dual-energy X-ray absorptiometry; FM%, fat mass percentage; SMI, skeletal muscle index.

the relative quantity of mass (Table 5).[18,19] In a sample of 207 elderly Italians, the differences between groups whose vectors lay in the two left-hand quadrants of the ellipses (the supposed position of 'athletic' and obese individuals) were not significant.[19] Moreover, classic BIVA was not capable of recognizing bioelectrical differences between groups selected for having different quantities of FM%.[19] Similar results were obtained in a sample of 1590 US adults.[18] Even if in this large sample, classic BIVA recognized significant differences between bioelectrical values of groups with different quantities of FM%, the accuracy of classification analysis was slightly better than random, as indicated by receiver operating characteristic curves. In fact, the vectors distribution of individuals with extremely low and high values of FM% largely overlapped within the normal region represented by the 50th percentile.

Specific BIVA: theoretical principles and procedure

The specific BIVA approach[18,19] uses the same vectorial approach of classic BIVA[13] but differs from the classic procedure, in that the specific bioelectrical values are standardized for a correction factor A/L, considering the effect of cross-sectional area (A = 0.45 arm area+0.10 waist area+0.45 calf area) besides than the 'conductor' length (L = 1.1 H). This correction, which is inherent to the Ohm's law, is intended to reduce the influence of body size and shape, and to increase the sensitivity of specific values (resistivity, reactivity and impedivity) to the tissues' properties. Phase angle is unaffected by the correction. The procedure of specific BIVA is well detailed in Buffa *et al.*[18] (for the calculation of correction factor, see Appendix S1 and Supplementary Figure S1 therein).

When compared with DXA, specific BIVA proved effective to distinguish between individuals with different amounts of fat and fat-free mass in both US adults[18] and Italian elderly samples.[19]

Consistently with electrophysiological assumption on body conductivity, specific bioelectrical values showed a positive relation with FM% assessed by DXA (Table 5). In both the elderly Italian sample[19] and in the US adults one,[18] the major axis of specific tolerance ellipses refers to variations of the relative quantity of fat mass (FM%), with higher values towards the upper right pole.

As in classic BIVA, the minor axis refers to variations associated with changes of phase angle, indicative of body cell mass (left side: more cell mass; right side: less cell mass). The minor axis is also related to variations of extracellular/intracellular water ratio (ECW/ICW), with high values, indicative of low body cell mass[47] and muscle mass in particular,[48] toward the right lower area.[18] Accordingly, specific bioelectrical values of adults with different skeletal muscle mass (SMI) (men: SMI $> 9.51\ kg/m^2$ versus SMI $< 7.39\ kg/m^2$; women: SMI $> 7.93\ kg/m^2$ versus SMI $< 5.66\ kg/m^2$) were significantly different, with lean individuals characterized by a lower phase angle and vector length.[18] Moreover, Marini *et al.* [26] showed that sarcopenia is associated with a reduction of phase angle, with bioelectrical values of sarcopenic elders toward the right lower area of the RXc graph and those of sarcopenic obese ones toward the right upper (higher values of specific resistance). Further, Saragat *et al.*[49] showed that the mean impedance vectors for elderly men with a 'low body weight, low FFM and low FM', as assessed by DXA, were located near the position of sarcopenic individuals, while men with a 'normal body weight, low FFM and high FM' approached the 'sarcopenic obese area'. Authors also showed an age-related trend of bioelectrical variations, mainly due to a reduction in Xc *sp* and phase angle, that corresponds to a decrease in skeletal muscle mass.[49]

Specific bioelectrical impedance vector reference values for the US American adults[18] and the healthy elderly Italian population[49] have been published.

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MAJOR FINDINGS AND CONCLUSIVE REMARKS

The results of this review showed that the accuracy of classic BIVA for assessing two-compartment body composition has been evaluated by means of indirect techniques (anthropometry and conventional BIA), and that when a reference method was used for comparison, a weak association was observed.

The results of the comparison with anthropometry confirmed that the migration of bioelectrical impedance vector along the minor axis of the tolerance ellipses (that is, variations of the phase angle) is indicative of body cell mass and BMI changes. Accordingly, groups with a high body mass, such as obese and athletes, show a high phase angle, whereas cachectic, anorexic and sarcopenic individuals are characterized by low values. Moreover, phase was associated with indirect indicators of muscle mass and function, such as the mesomorphic component of somatotype and handgrip strength.

On the other hand, the variations of the impedance vector along the major axis of the tolerance ellipses seems to be less informative in terms of two-compartment body composition.

The negative relationship observed between impedance vector length and body mass index, and the short vector of obese individuals justify the characterization of the lower left quadrant of the ellipses as the obesity area. However, even if BMI is a commonly used indicator of obesity,[50] it is not sensitive to variations of body composition: a high BMI could correspond to high quantities of muscle as well as fat mass. The relationship is probably related to the effect of body geometry—cross-sectional areas in particular—on bioelectrical parameters. In fact, according to the Ohm's law, the large transverse dimensions of obese individuals could reduce the opposition to the flow of electrical current. On the other side, because of the lower conductivity of fat with respect to fat-free mass, athletic individuals should be characterized by relatively shorter impedance vector than obese subjects. As a matter of fact, the identification of the 'athlete' area in the upper right pole of the ellipses has been scarcely investigated and it appears controversial. In fact, impedance vectors of athletic individuals were scattered throughout the left side of the ellipses, in some cases overlapping the 'obesity' area.

The analysis of studies using conventional BIA do not show a clear and informative picture of the relation with BIVA. The results appear inconsistent when diseased individuals are considered, suggesting that in these cases BIVA performs better than BIA.

In conclusion, although classic BIVA is capable of discriminating nutritional status (variations along the minor axis) and hydration status differences (variations along the major axis), this review showed that it should be used with caution for assessing two-compartment body composition.

Specific BIVA proved effective for identifying changes of fat and fat-free mass in adult and elderly samples. This variant of classic BIVA could represent an interesting tool for monitoring fat and lean mass changes, with potential for application in nutritional, sport and geriatric medicine, where body composition variations can be undetected by commonly used techniques, such as BIA or anthropometry.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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