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Original article

Specific bioelectrical vectors pattern in individuals with sarcopenic obesity

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SUMMARY

Background: Sarcopenic obesity is a common condition in the elderly associated with excessive adiposity and low muscle mass and strength.
Aims: This study aims to establish a method for detecting bioelectrical characteristics in individuals with sarcopenic obesity through specific Bioelectrical Impedance Vector Analysis (*specific* BIVA), while considering the characteristics of individuals with healthy, sarcopenic, and obese conditions.
Methods: The sample was composed by 915 Italian adults over 50 years of age (men: 74.6 ± 8.8 y; women:76.3 ± 8.8 y) living in Sardinia (Italy). A dataset of 1590 US adults aged 21 – 49 years retrieved from the 2003 – 2004 National Health and Nutrition Examination Survey was also considered in a final step of the study. Anthropometric (stature, weight, waist, arm, and calf circumferences) and whole-body bioelectrical variables were taken. In the Italian sample, bioelectrical impedance was applied to estimate the relative content of fat mass and skeletal muscle mass. Groups with healthy body composition (NS-NO), or consistent with sarcopenia (S), sarcopenic obesity (S-O), and obesity (O) were defined based on the cut-offs suggested by European expert guidelines (EWGSOP2 and ESPEN-EASO). *Specific* BIVA was applied to compare groups and to identify the area for sarcopenic obesity within young-adults tolerance ellipses. The position of the specific vector of US individuals with S-O, selected on the basis of DXA measurements, was also considered.
Results: In both sexes of the Italian sample, the bioelectrical characteristics of the four groups were different ($p < 0.001$). The differences were mainly related to vector length, indicative of higher fat mass, which was longer in the O and S-O groups, and phase angle, a proxy of intracellular/extracellular water and muscle mass, lower in the sarcopenic groups. Bioelectrical vectors of the S-O group fell in the right quadrant, outside of the 95 % tolerance ellipses of young adults. The mean vector of the US sample with S-O fell in the same area. Within the S-O area, women had similar bioelectrical values, while men showed phase angle variability, which was related to the severity of the condition.
Conclusions: *Specific* BIVA detects body composition peculiarities of individuals with sarcopenic obesity, thus allowing their diagnosis when associated with low handgrip strength values.

1. Introduction

Sarcopenia and sarcopenic obesity are common and progressive diseases associated with body composition abnormalities and muscle failure. Sarcopenia is characterised by low muscle mass and function, leading to physical disability, frailty, increased risk of adverse health outcomes, including an elevated risk of falls and fractures, and mortality [1,2]. Sarcopenic obesity is a distinct condition characterised by the presence of sarcopenia in the context of excess adiposity [3]. Individuals with sarcopenic obesity suffer from the synergistic effect of sarcopenia, obesity, and their negative physiological and clinical interactions [4,5]. These health problems affect the quality of life of individuals and have economic and social impacts by increasing healthcare costs and the burden on social support systems [6].

Both conditions are mostly reported in older people, where they affect between 10 % and 16 % of the elders around the world [7,8]. Indeed, age-related physiological and behavioral changes imply

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muscle loss and fat accumulation [9]. However, they can also begin earlier in life and be due to the presence of acute or chronic diseases [1,10].

Prevention and treatment are possible through a combination of lifestyle measures related to physical activity, diet, and medical treatment, and are more effective when started early [11,12].

Despite the recognized adverse health outcomes of sarcopenia and sarcopenic obesity, the widespread prevalence, and the potential for therapeutic intervention, their screening and diagnosis are often overlooked in routine care [1,13]. To raise awareness and propose consensus definitions, expert panels recommended measures and cut-off points for case-finding, diagnosis, and severity determination of sarcopenia and sarcopenic obesity, useable in clinical practice and in research populations [1,10,14].

The European Working Group on Sarcopenia in Older People 2 (EWGSOP2) [1] proposed the Find-Assess-Confirm-Severity pathway based on four criteria: a) patient self-report to find possible cases; b) low muscle strength to detect probable sarcopenia; c) low muscle quantity (total body or appendicular skeletal muscle mass) or quality to confirm the diagnosis; d) low physical performance to diagnose severe disease.

The European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO) launched the Sarcopenic Obesity Global Leadership Initiative (SOGLI) and defined diagnostic criteria for sarcopenic obesity [10,14]. Screening is based on the presence of a high body mass index (BMI) or waist circumference along with clinical symptoms, the presence of risk factors, or validated questionnaires. Diagnosis is divided into two steps: an initial assessment of muscle function to identify potential cases and an assessment of body composition to evaluate the presence of excessive adiposity and low skeletal muscle mass to confirm the diagnosis [10].

An accurate evaluation of body composition is therefore a critical step in the diagnostic process for both sarcopenia and sarcopenic obesity. EWGSOP2 and ESPEN-EASO indicated magnetic resonance imaging, computed tomography, and the more widely available dual-energy x-ray absorptiometry (DXA) as preferable techniques [1,10]. However, these methods require high equipment costs and highly trained personnel, and cannot be used in community, in patients with disabilities, and for routine applications. In these contexts, bioelectrical impedance analysis (BIA), particularly single-frequency BIA, is a suggested alternative because of its wide availability, affordability, and portability [1,10]. The consensus also recommended the use of regression equations calibrated to populations with similar age, sex, and geographic ancestry [1]. EWGSOP2 and ESPEN-EASO also consider the use of phase angle (PhA), a variable based on raw bioelectrical data and therefore not requiring the use of equations and assumptions about body hydration. Indeed, PhA has shown a strong relationship with body cell mass [15] and extracellular to intracellular water ratio (ECW/ICW) [16,17] and is considered a proxy of muscle quantity and quality [18]. An expanding body of literature has underscored the association between a low PhA and sarcopenia or sarcopenic obesity [19–25].

ESPEN-EASO experts also mentioned specific bioelectrical impedance vector analysis (*specific* BIVA) [26] as a potential diagnostic tool for sarcopenic obesity [10]. Similar to the phase angle, BIVA analyses raw data, thereby avoiding potential errors introduced by equation applications. Furthermore, the vectorial approach offers valuable insights into body composition by enabling the contextual analysis of both phase angle and vector length [27]. Classic BIVA [28] is appropriate to study body hydration, whereas *specific* BIVA has demonstrated remarkable accuracy (ROC areas: 0.84 – 0.92) in estimating the relative content of fat mass (FM%), with overweight or obesity conditions characterized by longer vectors [26]. Thus, *specific* BIVA enables the contextual analysis of fat mass (primarily associated with vector length) and muscle quantity and quality (primarily associated with the phase angle) and could serve as a single tool for screening body composition characteristics typical of sarcopenic obesity while providing information on both obesity and sarcopenia. Indeed, previous studies on the BIVA application in sarcopenia and/or sarcopenic obesity have yielded promising results [23–25].

The present study aims to analyse the suitability of *specific* BIVA in assessing body composition characteristics of sarcopenic obesity, compared to sarcopenia and obesity, with the ultimate goal of incorporating this analysis into the diagnostic process of sarcopenic obesity.

1.1. The sample

A cross-sectional, observational study on 915 Italian volunteers (396 men and 519 women) over 50 years of age (men: 74.6 ± 8.8; women: 76.3 ± 8.8) was recruited on a voluntary basis. The following exclusion criteria were considered: use of any implanted electrical devices, diuretic therapy, alcohol or drug abuse, and physical disabilities that might interfere with body composition measurement. In accordance with the Helsinki Declaration [29], all volunteers were informed about the aims and methods of the investigation before giving written informed consent to participate. All procedures were approved by the ethics committee of the University of Cagliari.

In addition, to compare the results on S-O in individuals of different ancestry and age and with body composition assessed by DXA, a sample of 1590 US adults (836 men and 754 women, aged 21 – 49 years) from the 2003 – 2004 National Health and Nutrition Examination Survey (NHANES) was also analysed. The NHANES data survey is approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board, and written informed consent is a first step in the experimental procedures. The NHANES 2003 – 2004 open access datasets were selected because they include anthropometric (weight, standing height, body mass index, arm, waist, calf circumferences), bioelectrical (R and Xc at 50 kHz) and DXA data (percent fat, lean mass excluded bone mineral content of the four limbs), as well as demographic information (age, sex). A more detailed description of the dataset can be found in Buffa et al. [26].

2. Methods

2.1. Anthropometry

Italian volunteers were instructed to avoid any food or beverage for the previous 4 h, as well as intensive exercise or alcohol intake for the previous 12 h before the test. The participants were also asked to wear light, casual clothing, and remove all metal jewellery. Measurements were taken by experienced operators following standard international criteria [30].

Body weight was measured with a scale (Seca, Hamburg, Germany), without shoes and wearing minimal clothes, to the nearest 0.01 kg. Height was measured to the nearest 0.1 cm with a stadiometer (Seca, Hamburg, Germany). Circumferences of the relaxed right arm, right calf and waist were measured by using an anthropometric tape (Seca, Hamburg, Germany).

The protocol used for the 2003 – 2004 National Health and Nutrition Examination Survey for anthropometric measurements is detailed on the CDC website [31]. Measurements were taken using a Toledo electronic weight scale, a Seca electronic stadiometer, and a steel tape.

Body mass index (BMI) was calculated as weight/height^2 (kg/m^2).

2.2. Conventional BIA and DXA

In the Italian sample, resistance (R, ohm) and reactance (Xc, ohm) were measured using a single-frequency impedance analyzer (BIA 101, Akern, Florence, Italy). Prior to each test, the analyzer was checked with the calibration tester (R = 380 Ω, Xc = 47 Ω; 2 % error). Impedance measurements were obtained using the standard positions for the outer and inner electrodes (Biatrodes Akern Srl, Florence, Italy) on the right hand and foot under controlled conditions [32].

The regression equations for calculating body compartments were selected considering similarities in geographic ancestry and age. The appendicular skeletal muscle mass (ASM) was quantified using the equations proposed by Sergi et al. [33], which have been validated against dual X-ray absorptiometry (DXA) in a sample of European subjects over 60 years of age. This is one of the two equations proposed by EWGSOP2 [1] to detect low muscle quantity and was also used in a recent application of the ESPEN-EASO criteria [13]. The relative content of fat mass (FM%) was estimated using equations proposed by Lohman [34] for elderly subjects.

In the US sample, bioelectrical measurements were taken with a HYDRA ECF/ICF Bio-Impedance Spectrum Analyzer (Model 4200; Xitron Technologies, Inc, San Diego, California, USA) and whole body DXA scans with a Hologic QDR-4500A fan-beam densitometer (Hologic, Inc., Bedford, Massachusetts). The protocol is detailed on the CDC website [35].

ASM and FM% values were calculated from DXA measurements.

2.3. Groups definition

Individuals with body composition characteristics of sarcopenic obesity (S-O group) were selected based on the reference ranges suggested by ESPEN-EASO [10]. Taking into account the similarities in terms of age and geographic ancestry, the cut-points provided by Levine and Crimmins [36] were used for appendicular skeletal muscle mass normalized by body weight (ASM/W*100 < 25.72 % and < 19.43 % for men and women) and those provided by Gallagher et al. [37] for FM% (> 43 % for females and > 31 % for males). The same cut-points for FM% were used to identify individuals with obesity (O group).

Individuals with body composition characteristics of sarcopenia (S group) were selected using the cut-points proposed by Gould et al. [38] (ASM/H^2 < 7 kg/m^2 for men and < 5.5 kg/m^2 for women), in agreement with the EWGSOP2 criteria [1].

Individuals without both obesity and sarcopenia (NS-NO group) were defined based on cut-points used for diagnosing sarcopenia (EWGSOP2) and obesity (ESPEN-EASO).

Table 1 summarises the criteria and cut-points used to define the groups.

2.4. Specific BIVA

In both the Italian and US samples, bioelectrical values were also analysed using *specific* BIVA [26]. This semiquantitative procedure follows the methods proposed by Piccoli et al. [28] and analyses the variability of bioelectrical vectors, defined by their module (impedivity) and inclination (phase angle). According to BIVA methodology, bioelectrical vectors variability can be interpreted by means of graphical and statistical approaches based on confidence and tolerance ellipses in the Cartesian plane [28]. Confidence ellipses represent the area where the average of the population falls with a probability of 95 %, and allow the statistical comparison among samples, with significant differences indicated by not overlapping ellipses and significant values of the Hotelling's T^2 test. Concentric tolerance ellipses represent the variability of the reference population (50 %, 75 %, and 95 % of cases) and allow the evaluation of body composition based on the position of individual or mean vectors within the graph.

Specific BIVA standardises bioelectrical values by a correction factor A/L, where A represents an estimate of the transverse area of the body (0.45 arm area +0.10 waist area +0.45 calf area, based on relaxed arm, minimum waist, maximum calf circumferences) and L the distance between electrodes (height *1.1) [26]. This correction aims to reduce the influence of body size and shape on bioelectrical variables, thus obtaining values (specific resistance and specific reactance) solely determined by body composition. In fact, according to Ohm's law, R is directly proportional to the conductor's length (L) and inversely proportional to its cross-section (A) ($R = \rho * L/A$). The coefficient ρ represents the resistivity, or specific resistance (Rsp), and characterises materials depending on their ability to conduct electric currents, that is, in humans, depending on body composition.

Impedivity (Zsp) can be calculated as the square root of sum of squares of resistivity and reactivity $(Rsp^2 + Xcsp^2)^{0.5}$. Phase angle is the arctangent Xc/R * 180/π (degrees) and is not influenced by the correction.

The major axis of specific tolerance ellipses, which is mainly related to Rsp and Zsp variability, gives indications on the relative content of FM (higher values toward the upper pole); the minor

Table 1
Criteria and cut points used to define the groups.

Condition	Acronym	Index	cut-points	Reference	Recommended by
Sarcopenia	S	Appendicular skeletal muscle mass normalized by stature (ASM/H^2)	<7 kg/m^2 M <5.5 kg/m^2 W	Gould et al. (2014) [38]	EWGSOP2 (Cruz-Jenthof et al., 2019) [1]
Sarcopenic obesity	S-O	ASM normalized by body weight (ASM/W) Percent fat mass (FM%)	<25.72 % M <19.43 % W >31 % M >43 % W	Levine and Crimmins (2012) [36] Gallagher et al. (2000) [37]	ESPEN-EASO (Cappellari et al., 2023) [10]
Obesity	O	FM%	>31 % M >43 % W	Gallagher et al. (2000) [37]	Based on ESPEN-EASO
Non sarcopenia non obesity	NS-NO	ASM/H^2 FM%	≥7 kg/m^2 M ≥5.5 kg/m^2 W ≤31 % M ≤43 % W	Gould et al. (2014) [38] Gallagher et al. (2000) [37]	Hybrid, based on both EWGSOP2 and ESPEN-EASO

ASM calculated using the equations proposed by Sergi et al. [33]. ASM = −3.964 + (0.227 * RI) + (0.095 * weight) + (1.384 * sex) + (0.064 * Xc); RI = resistance normalized for stature; Women = 0, Men = 1.
FM (weight - FFM) calculated using the equations proposed by Lohman [34]. FFM men: 0.600 * (stature^2/R) + 0.186 * weight + 0,226 * Xc - 10.9; FFM women: 0.474 * (stature^2/R) + 0.180 * weight + 7.3.

axis, which is mainly related to Xcsp and phase angle variability, is indicative of body cell mass and quality, especially muscle mass, and ICW/ECW ratio (with the higher values toward the left side) (Fig. 1) [26].

2.5. Statistical analysis

In the Italian sample, for all outcome variables, descriptive statistics of the S, S-O, O, and NS-NO groups were calculated, and normality was evaluated using Shapiro–Wilk test. Due to the violation of the assumption of normality and homoscedasticity, group comparisons were performed by a Kruskal Wallis test. Post hoc comparisons among the four groups were conducted using the Dwass-Steel-Crichtlow-Fligner test.

The mean bioelectrical vectors of the S, S-O, O, and NS-NO groups were compared by means of confidence ellipses. Because of the use of different criteria for diagnosing sarcopenia, obesity and sarcopenic obesity, some overlap of the cases was unavoidable. Furthermore, to identify the area on the tolerance ellipses corresponding to sarcopenic obesity, the mean vectors were projected on the ellipses of the reference population. In agreement with experts' recommendations [1,39] suggesting a reference composed of healthy young adults, an Italo-Spanish sample (Rsp - men: 332.70 ± 41.70, women: 388.60 ± 60; Xcsp - men: 44.40 ± 6.80, women: 43.70 ± 7.50) aged 18 − 30 years was selected as reference [40]. The mean vector of US individuals with S-O was also projected on the tolerance ellipses, to compare the position of a different sample, whose body composition was based on DXA measurements. In addition, to better analyse internal S-O variability, individual vectors of the more numerous Italian male S-O group were projected onto the tolerance ellipses.

A p-value threshold of <0.001 was used to determine statistical significance, with a few exceptions, as detailed in Table 2.

Data were analyzed with IBM SPSS Statistics version 29 (IBM, Chicago, IL, USA) and the specific BIVA software (www.specificbiva.com).

3. Results

According to the recommendations for the diagnosis of sarcopenia and sarcopenic obesity of EWGSOP2 and ESPEN-EASO, in the Italian sample, 43 subjects (36 men and 7 women; 9.1 % and 1.3 %, respectively, of the total sample within the same sexes) were assigned to group S-O, 111 subjects (65 men and 46 women; 16.4 % and 8.9 %, respectively) to group S, and 324 individuals (217 men and 107 women; 54.8 % and 20.6 %, respectively) to group O.

The anthropometric, bioelectrical, and body composition values of groups S, S-O, O, and NS-NO differed significantly from each other when compared by Kruskal Wallis test. In more detail, the groups with obesity (S-O and O) had higher BMI, WC, FM, FM%, ASM values than the groups NS-NO and S (except for the mostly not significant comparison of ASM with NS-NO) (Table 2). The S-O group differed from the O group in higher FM% values in both sexes, higher BMI, WC and FM in men and lower ASM in women. The S group had lower BMI, WC, ASM, and FFM in all comparison. ASM/W showed lower values in the S-O group compared to O, and,

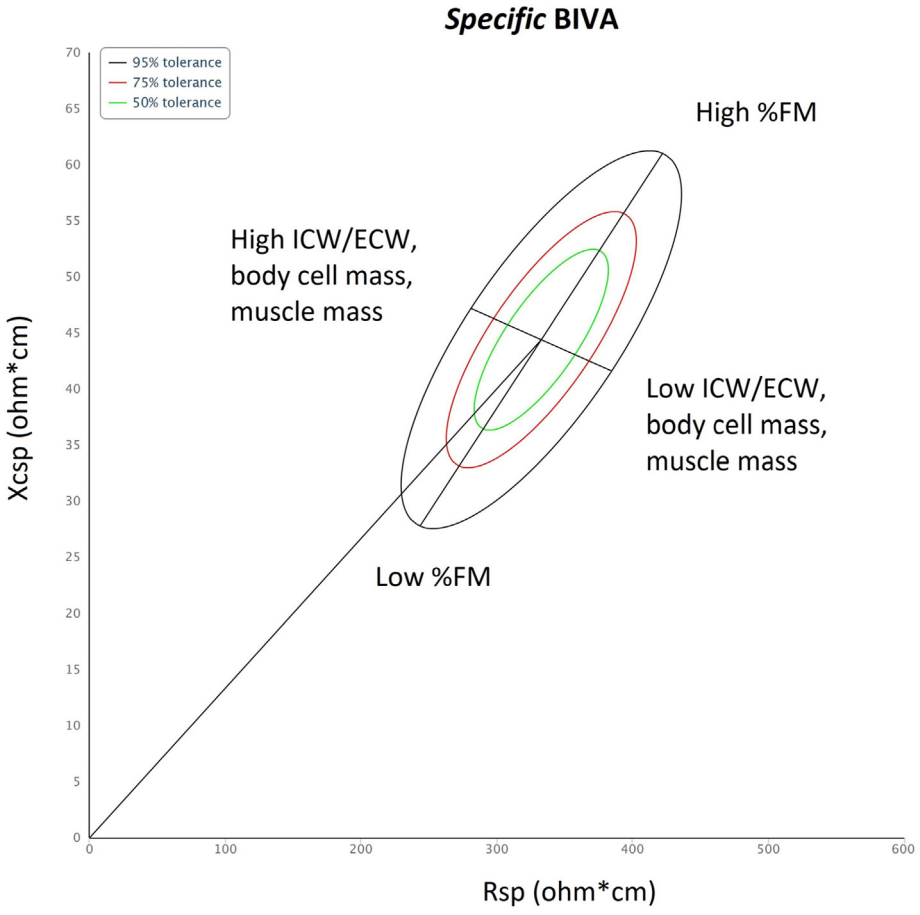

Fig. 1. Specific tolerance ellipses with interpretation of axes in terms of body composition. Rsp = specific resistance; Xcsp = specific reactance; FM = fat mass; ICW = intracellular water; ECW = extracellular water.

Table 2
Descriptive statistics and post-hoc comparisons of the healthy group (NS-NO) and the groups with possible sarcopenia (S), sarcopenic obesity (S-O) and obesity (O) in the Italian sample.

	Men								Women							
	S-O (N = 36)		S (N = 65)		O (N = 217)		NS-NO (N = 147)		S-O (N = 7)		S (N = 46)		O (N = 107)		NS-NO (N = 366)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMI (kg/m^2)	32.5	3.7^{b,c,d}	22.9	2.4^{a,c,d}	28.9	3.8^{a,b,d}	26.2	2.3^{a,b,c}	37.7	2.6^{b,d}	20.7	2.3^{a,c,d}	34.9	3.7^{b,d}	27.0	3.5^{a,b,c}
Waist Circ. (cm)	110.5	9.5^{b,c,d}	88.9	7.8^{a,c,d}	100.9	9.3^{a,b,d}	93.2	7.3^{a,b,c}	103.8	8.5^{b,d}	79.0	8.1^{a,c,d}	104.9	11.4^{b,d}	88.2	9.8^{a,b,c}
FFM (kg)	48.8	8.4^{b}	40.4	5.4^{a,c,d}	47.7	7.6^{b,d}	50.7	5.9^{b,c}	37.5	3.6^{b}	30.7	2.9^{a,c,d}	41.5	5.1^{b,d}	37.9	4.9^{b,c}
FM (kg)	36.8	6.5^{b,c,d}	19.3	5.9^{a,c}	27.2	6.4^{a,b,d}	18.2	4.0^{a,c}	39.0	5.3^{b,d}	13.0	4.4^{a,c,d}	36.0	5.5^{b,d}	21.7	5.7^{a,b,c}
FM%	43.0	2.3^{b,c,d}	32.0	6.8^{a,c,d}	36.2	3.9^{a,b,d}	26.2	3.8^{a,b,c}	50.9	2.8^{b,c,d}	29.0	6.6^{a,c,d}	46.4	2.5^{a,b,d}	35.9	5.0^{a,b,c}
ASM (kg)	21.1	3.6^{b}	17.2	2.2^{a,c,d}	20.4	3.2^{b,d}	21.2	2.4^{b,c}	14.4	1.5^{b,c}	11.0	1.2^{a,c,d}	16.7	2.3^{a,b,d}	14.9	2.3^{b,c}
ASM/W (%)	24.7	0.8^{b,c,d}	29.0	2.5^{a,c,d}	27.3	1.5^{a,b,d}	30.9	1.4^{a,b,c}	18.8	0.6^{b,c,d}	25.3	2.5^{a,c}	21.6	1.4^{a,b,d}	25.1	2.1^{a,c}
ASM/H^2 (kg/m^2)	8.0	0.9^{b}	6.6	0.4^{c,d}	7.9	0.9^{b,d}	8.1	0.6^{b,c}	7.1	0.4^{b}	5.2	0.2^{a,c,d}	7.5	0.7^{b,d}	6.7	0.8^{b,c}
Rsp (ohm*cm)	481.6	35.5^{b,c,d}	372.9	57.2^{a,c}	409.2	52.4^{a,b,d}	347.9	40.4^{a,c}	617.3	60.6^{b,c,d}	402.8	65.5^{a,c,d}	551.9	73.8^{a,b,d}	425.6	56.7^{a,b,c}
Xcsp (ohm*cm)	46.9	9.3^{b}	34.0	7.9^{a,c,d}	43.0	10.4^{b}	43.9	10.7^{b}	51.7	8.5^{b}	32.2	6.7^{a,c,d}	59.1	11.6^{b,d}	45.7	10.8^{b,c}
Zsp (ohm*cm)	484.0	35.8^{b,c,d}	374.5	57.4^{a,c}	411.5	52.7^{a,b,d}	350.7	41.1^{a,c}	619.5	60.9^{b,c,d}	404.2	65.7^{a,c,d}	555.2	74.0^{a,b,d}	428.2	57.0^{a,b,c}
PhA (°)	5.6	1.0^{d}	5.2	0.9^{c,d}	6.0	1.2^{b,d}	7.2	1.2^{a,b,c}	4.8	0.55^{c,d}	4.6	0.6^{c,d}	6.1	1.1^{a,b}	6.2	1.3^{a,b}

The letters indicate significant comparisons with groups: a = S-O; b = S; c = O; d = NS-NO.
BMI = body mass index; FFM = fat free mass; FM = fat mass; ASM = appendicular skeletal muscle mass; W = weight; H = height; Rsp = specific resistance; Xcsp = specific reactance; Zsp = specific impedance; PhA = phase angle.

especially, to S and NS-NO groups, whereas ASM/H^2 showed the lower values in the S group and similar values in the other three groups.

Mean bioelectrical vectors differed significantly between groups S, S-O, O, and NS-NO (Fig. 2). Consistent with the results of conventional BIA, in both sexes the groups with obesity (S-O and O) were characterised by longer vectors (indicative of greater FM%) and the groups with sarcopenia (S and S-O) by lower phase angles (indicative of lower muscle mass and quality) (Fig. 2, Table 2).

For both men and women, the position of the mean vectors of the healthy subjects was within the 50 % tolerance ellipses (Fig. 3). Conversely, the mean vectors of the S-O group were in the middle-upper right quadrant, outside the 95th percentile, partially overlapping with the overweight-obesity area (high FM% values) defined by the *specific* BIVA, but shifted to the right and in a lower position, with lower phase angle, that is towards the position where falls the mean vector of the S group (Fig. 3). The vectors of the NHANES dataset selected for the sarcopenic obesity group (SO_{DXA}; 13 men and 7 women; 1.6 % and 0.9 % of the whole sample of the same sex, respectively; Table 3) fell within the same area.

Within the S-O area, women had similar values for phase angle and vector length, whereas the wider sample of S-O men showed specific reactance and phase angle variability (Fig. 4). This variability was associated with the severity of sarcopenic obesity. Men with lower phase angles, whose vectors were in the lowest-right quadrant of the S-O area, exhibited the lowest values of ASM/W ($F = 4.69$; $p = 0.016$) and the highest values of FM% ($F = 8.46$; $p = 0.001$), indicating worse conditions.

4. Discussion

This study showed that, in a large sample of adults and older people, *specific* BIVA allows the evaluation of body composition features associated with sarcopenic obesity (S-O), distinguishing them from those of sarcopenic (S), obese (O), or healthy (NS-NO) conditions, as defined by the diagnostic criteria of expert panels

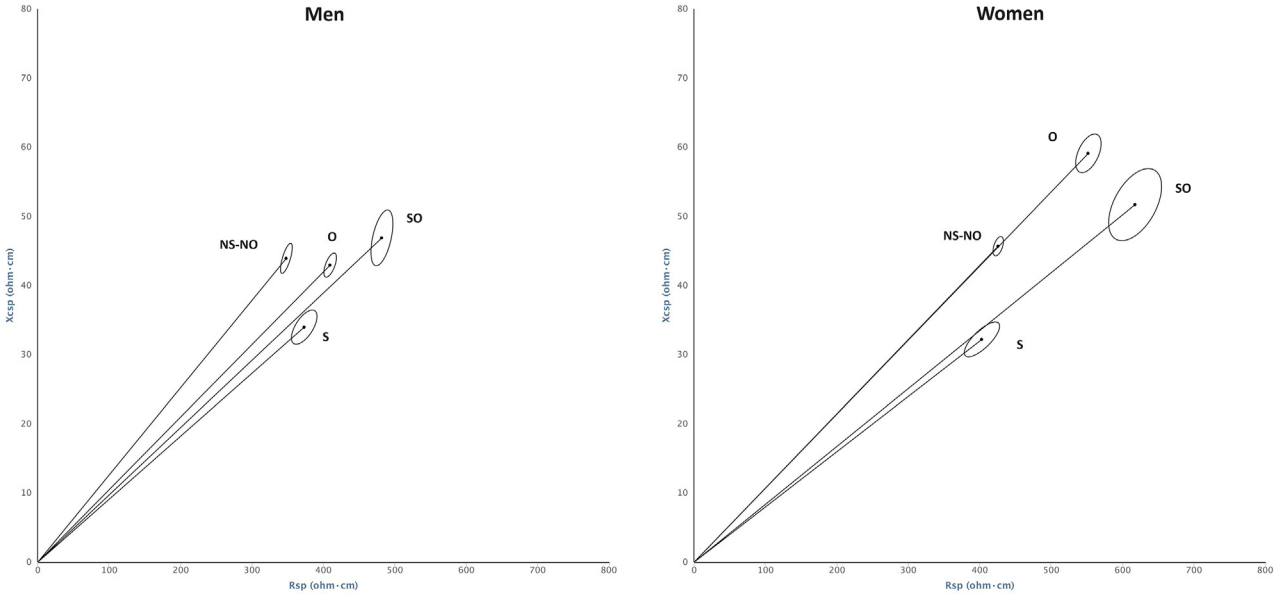

Fig. 2. Mean bioelectrical vectors of the healthy group (NS-NO) and the groups with possible sarcopenia (S), sarcopenic obesity (SO), and obesity (O). Rsp = specific resistance; Xcsp = specific reactance.

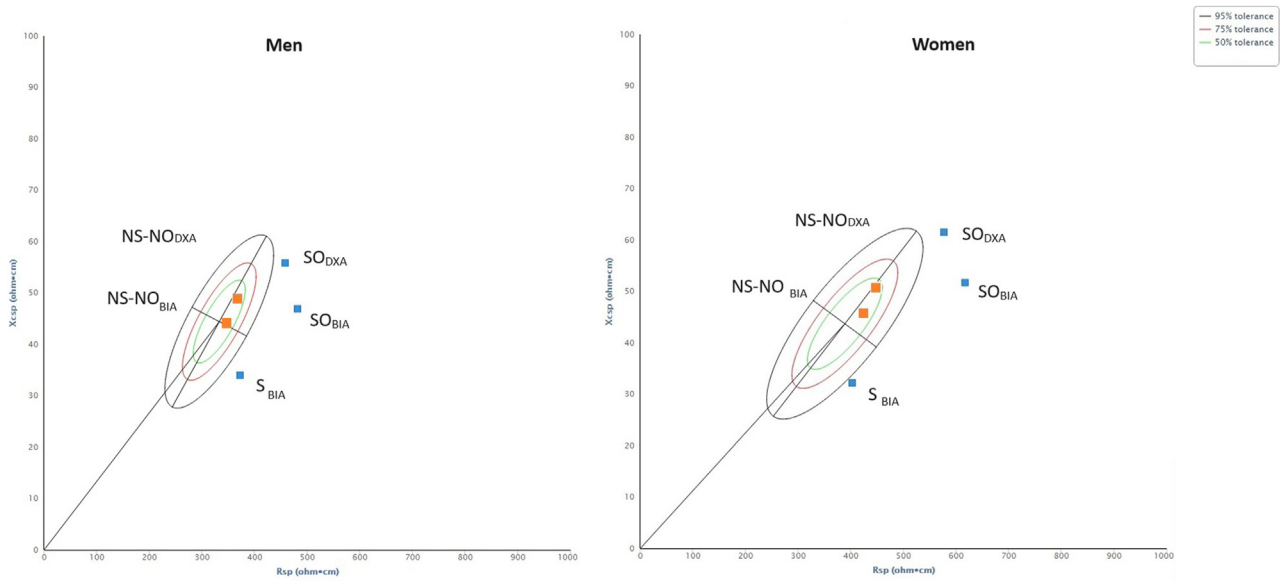

Fig. 3. Position of the mean vectors of the healthy group (NS-NO$_{BIA}$, NS-NO$_{DXA}$) and the groups with possible sarcopenia (S$_{BIA}$), sarcopenic obesity by BIA (SO$_{BIA}$) and by DXA (SO$_{DXA}$) within the 50 % tolerance ellipses of healthy young-adults. Rsp = specific resistance; Xcsp = specific reactance.

Table 3
Descriptive statistics of the healthy group (NS-NO) and the group with possible sarcopenic obesity (S-O) in the US sample.

	Men (N = 823)		Men S-O (N = 747)		Women (N = 13)		Women S-O (N = 7)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (y)	34.3	8.6	35.5	8.4	35.4	8.4	38.9	9.21
BMI (kg/m^2)	27.2	4.8	28.2	6.9	28.3	6.9	38.5	5.10
%FM	26.3	5.5	38.7	6.4	38.7	6.4	50.4	2.62
ASM/W (%)	31.1	5.1	24.6	3.2	24.2	4.8	18.7	0.62
Rsp (ohm*cm)	372.8	51.1	454.5	83.5	455.9	84.1	577.5	60.49
Xcsp (ohm*cm)	48.7	8.4	51.2	11.0	51.5	12.0	61.5	10.30
Zsp (ohm*cm)	376.0	51.5	457.4	84.1	458.9	84.7	580.8	61.12
PhA (°)	7.5	0.8	6.5	0.7	6.5	0.8	6.1	0.53

BMI = body mass index; FM = fat mass; ASM = appendicular skeletal muscle mass; W = weight; Rsp = specific resistance; Xcsp = specific reactance; Zsp = specific impedance; PhA = phase angle.

[1,10]. The groups with possible sarcopenic conditions (S and S-O) were characterised by lower mean phase angles, while the groups with obesity (O and S-O) exhibited longer vectors. The NS-NO group exhibited values close to the mean of a young adult healthy population with similar ancestry [40]. The area distinctive of sarcopenic obesity (S-O area) corresponded to the right side of the specific tolerance ellipses, exceeding the 95th percentile. This threshold defines a probability range close to the range corresponding to cut-off points set at 2 standard deviations [41] and is thus consistent with the criteria suggested for the diagnosis of sarcopenia [1,39]. It is not surprising, given the partially shared physiological conditions and diagnostic criteria, that the S-O area falls in an intermediate position and partly overlaps with the areas of obesity, as defined based on *specific* BIVA paradigm, and sarcopenia, as expected based on the literature results. Indeed, the upper and upper-right poles of the tolerance ellipses represent the area of high FM% values, that is where the vectors of individuals with obesity are situated [26] (Fig. 1). The variability along the minor axis of the tolerance ellipses is closely associated with phase angle variations, which reflect cell mass and quality and are related to muscle mass [15,18], showing the lower values on the right side. As highlighted by recent reviews, a substantial body of literature, irrespective of the samples analysed, the diagnostic criteria employed, or the devices used, has recognised an association between low phase angles and sarcopenia [19–22]. Accordingly, bioelectrical impedance vectors of sarcopenic individuals were placed on the right side of the reference ellipses [23–25].

However, as already pointed out by other authors [21], a low phase angle is not exclusively due to sarcopenia but can also be related to other diseases, or to the physiological age-related trend, that appears similar in different populations [42,43]. Indeed, further investigation is necessary to clarify the interpretation of a low phase angle as an indicator of diminished muscle mass, reduced muscle quality, or a combination of both. Together with other factors, such as the use of different bioimpedance approaches and devices, this challenge currently impedes the establishment of a definitive phase angle cut-off value for diagnosing sarcopenia.

In relation to sarcopenic obesity, Marini et al. [23] observed results that closely overlap with the findings of the present study. They analysed a distinct sample of 200 older individuals diagnosed with sarcopenic obesity using DXA, different cutoffs, and a different reference group. The mean vectors of individuals with potential sarcopenic obesity (low skeletal muscle mass index and high FM% value) had low phase angles and long vectors, that fell into the same position within the RXc graph as observed in this study. Other authors have also observed a low phase angle in sarcopenic obese individuals [22]. In the present study, it is noteworthy that the position of the vector is shared by the Italian and US samples, regardless of the diagnostic procedure (BIA or DXA), age and geographic ancestry of the sample (young adult US and middle-aged-older Italians). Interestingly, the mean vector of the healthy US group falls within the 50 % ellipse. These results point to the strength of *specific* BIVA in the detection of body composition peculiarities in individuals with sarcopenic obesity. However, the use of the procedure in non-European populations requires further ad hoc research to select the appropriate tolerance ellipses.

Furthermore, in the S-O area of men, we also observed a pattern of variability in body composition. The variation was mainly related to the phase angle, while the vector module remained consistently long. The position of the individual vectors on the RXc graph was associated with different patterns of body composition and the

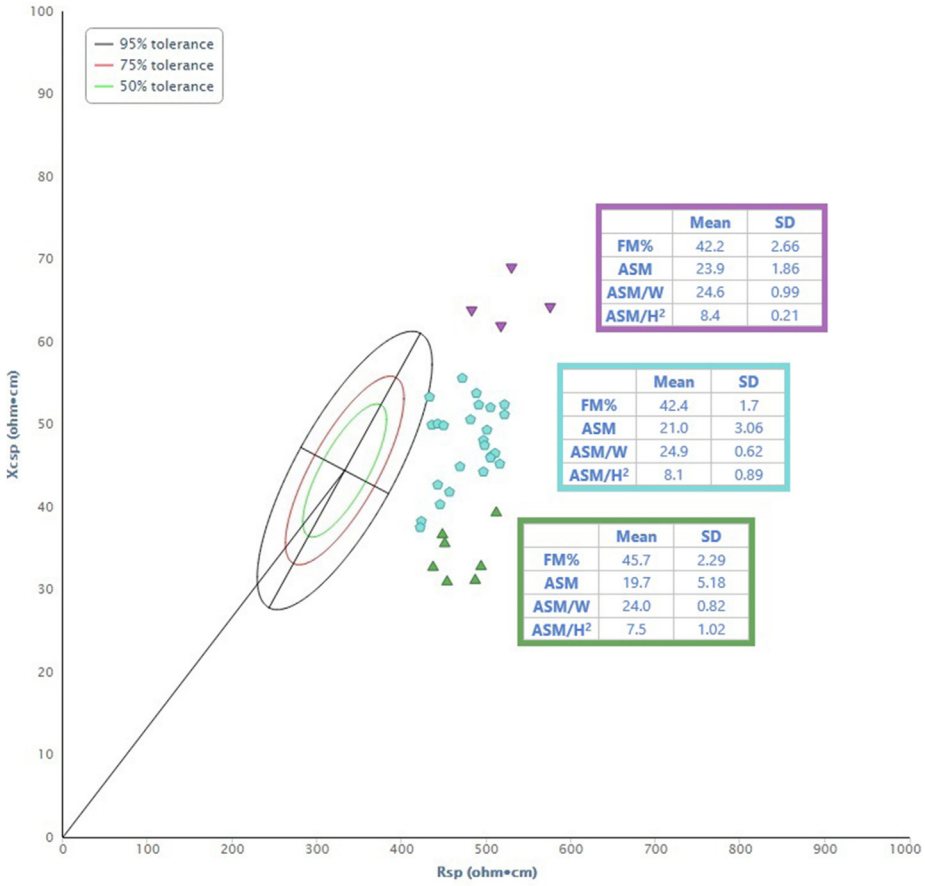

Fig. 4. Variability of bioelectrical vectors within the sarcopenic obesity (S-O) area in men. Rsp = specific resistance; Xcsp = specific reactance; FM = fat mass; ASM = appendicular skeletal muscle mass; W = weight; H = height.

corresponding severity of sarcopenic obesity. Individuals whose vectors fell in the lower-right part of the graph, i.e. with lower phase angles, had lower ASM/W and higher FM% values; they were thus characterised by more severe conditions. Conversely, higher phase angles were associated with higher ASM/W values and lower FM%. Such a relationship between PhA and fat mass could have been expected based on the literature results. Indeed, PhA shows a decreasing trend in individuals with high size (BMI values above 40 kg/m^2 [44,45]), high FM% [20,46], or large silhouettes [47].

Interestingly, the S-O subgroup with higher phase angles had mean values of ASM and ASM/H^2 that were above the threshold for sarcopenia according to EWGSOP2 criteria. In other words, S-O individuals with higher phase angles were characterised by a relative reduction in skeletal muscle mass (as indicated by ASM/W) related to their high body fat percentage, without an absolute loss of skeletal muscle (as indicated by ASM), even when standardised by body height (ASM/H^2). This body composition condition may have significant and peculiar clinical and functional implications [14].

The comparison of cut-points recommended by the EWGSOP2 and ESPEN-EASO is far from the objectives of the present study. However, our results show how the choice of measurements and operational definitions influences the results on the prevalence of sarcopenia and sarcopenic obesity conditions, as already pointed out by other authors [48,49]. In particular, they show that individuals with high fat mass may be not recognised as sarcopenic according to the EWGSOP2 criteria, as already noted by Scott and colleagues [48]. As shown in this study, in these individuals, normalising ASM to body weight (ASM/W) better accounts than normalising by height (ASM/H^2) for the greater absolute lean mass (ASM) associated with higher body mass. *Specific* BIVA could be useful in such cases by providing detailed information on the variable expression of body composition in sarcopenic obesity.

This study has both strengths and limitations. Notably, it benefits from an extensive sample size encompassing both adult and older individuals and employs updated criteria from expert panels to define sarcopenia and sarcopenic obesity. On the other hand, a major limitation is the challenge of generalising the results to populations without European ancestry. Although the consistency of results in different populations is suggested by the position of the mean specific vector of healthy and sarcopenic obese US individuals, the reference group used in this study is exclusively applicable to the European population. The establishment of references for diverse populations, or ideally for the global population, is imperative and aligns with the objectives of ongoing studies and projects, such as the International BIA dataset project [50].

5. Conclusions

Specific BIVA allows a straightforward evaluation of body composition features associated with sarcopenic obesity. When combined with tailored questionnaires and muscle strength estimates, it could be incorporated into a comprehensive diagnostic procedure that simultaneously considers both body fat and muscle mass, enabling the diagnosis of sarcopenic obesity and providing insights into its varying severity levels, as well as offering valuable information regarding sarcopenia and obesity. In the clinical setting, the possibility to use a single, simple, and

freely available method for obtaining reliable data on body composition may be very beneficial, particularly in routine use, or in resource-constrained settings. The ease of conducting the analysis and the comprehensibility of the graphical representation of results make this approach particularly valuable for personalised monitoring of disease progression, assessing the effectiveness of preventive strategies, and evaluating the outcomes of therapeutic interventions.

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Conflict of interest

The authors have no competing interests to declare.

Author contributions

Conceptualization (EM, SSt); Data curation and visualization (SSt, SSu); Formal analysis (SSt, SSu); Writing (EM); review & editing (all the authors).

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