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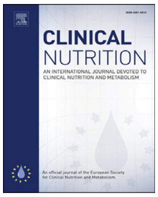

Q4

Segmental body composition estimated by *specific* BIVA and dual-energy X-ray absorptiometry

Q3

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SUMMARY

Aims: The aim of this study was to analyse the association between *specific* bioelectric impedance vector analysis (BIVA) and dual-energy X-ray absorptiometry (DXA) to assess segmental body composition using DXA as the reference technique.

Methods: The sample comprised 50 young active students who practised or played different sports (25 men, age: 24.37 ± 4.79 y; 25 women, age: 24.32 ± 4.43 y) from the National Institute of Physical Education of Catalonia (INEFC). Anthropometric data (height, weight, arm, waist, and calf circumferences) and bioelectrical measurements (R, ohm; Xc, ohm) were recorded. Body composition was analysed with *specific* BIVA. DXA was used as the reference method to assess body composition of the whole-body, the trunk, and the limbs. The percentage of fat mass ($\%FM_{DXA}$) and fat-free mass index ($FFMI_{DXA} = FFM/length^2$) were calculated. The agreement between *specific* BIVA and DXA was evaluated by a depth–depth analysis, two-way ANOVA, and Pearson's correlations.

Results: The depth–depth analysis showed a good agreement between DXA and BIVA ($F = 14.89$, $p < 0.001$) in both sexes and all body segments. *Specific* vector length (Zsp; i.e. indicative of %FM) was correlated with $\%FM_{DXA}$ in the whole body and all body segments, and the phase angle was correlated with $FFMI_{DXA}$, with he trunk in women as the only exception. *Specific* BIVA demonstrated to balance the effect of body size on bioelectrical measurements in both whole and segmental approaches.

Conclusions: Segmental *specific* BIVA and DXA provided a consistent evaluation of body composition in both sexes, of the whole body and each body segment. The indices %FM and FFMI obtained with DXA were correlated to vector length and phase angle in each segment, respectively. *Specific* BIVA represents a promising technique for monitoring segmental body composition changes in sport science and clinical applications.

1. Introduction

The evaluation of body composition is relevant during the whole life cycle because of its relationship with health conditions and diseases [1]. The analysis assumes particular interest when it is used to monitor age-related variations or changes associated with lifestyles, such as training effects or dietary interventions.

Although body composition is mostly applied to the whole body, the definition of variations at a segmental level, i.e. in different body segments (limbs, trunk), is growing in interest. Most studies have been directed at using segmental bioelectrical impedance measurements to predict whole-body composition [2]. However, segmental body composition is also useful to provide selective information about the risk of some diseases (e.g. trunk adiposity for

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type 2 diabetes [3]), in diagnostic investigation (e.g. limb FFM in sarcopenia; [4]), for analysing the effect of medicaments (e.g. arm hydration in lymphedema; [5]), in the evaluation of training effects [6], and for studying body asymmetry (e.g. in athletes; [7,8]). Furthermore, in some experimental conditions, such as in the elderly where total body measurements may not be convenient, the information on limbs can be used as an alternative to total body composition [9,10]. Indeed, the association between the whole body and segmental approaches has been observed in various experimental contexts [11–13].

Presently, several techniques are available for body composition analysis, each with different advantages and disadvantages [14]. Dual-energy X-ray absorptiometry (DXA) is considered the reference technique that provides an assessment of fat mass (FM), fat-free mass (FFM) and bone mineral content, of both the total body and body segments [15].

Bioelectrical impedance analysis (BIA) is a non-invasive, rapid and economical technique that allows quantitative estimates of body composition to be obtained [16]. Phase-sensitive BIA devices provide two components: resistance (R), negatively correlated with total body water (TBW) and FFM, and reactance (Xc), positively correlated with body cell mass. Traditional BIA analysis is based on population-specific regression equations. However, this approach can lead to errors when applied to samples with different characteristics from the ones used for the equation's validation [17]. The use of highly specialised equations reduces the possibility of generalisation and comparison.

These problems can be avoided using alternative approaches to analyse raw bioelectrical data (R, Xc, or their derivates: phase angle [$PA = \text{arctn } Xc/R\ 180/\pi$] and vector length [$(R^2 + Xc^2)^{0.5}$, Ω cm]) that were proposed for body composition estimation. Phase angle depends on the quantity and quality of cells' membranes and is related to the distribution of body fluids [18]. As shown by Gonzalez et al. [19], the major determinants of PA variation are age, the extracellular to intracellular water (ECW/ICW) ratio, FFM, height and population. The association between PA and ECW/ICW has been confirmed by Marini et al. [20]. A growing body of research is considering the PA indicative of muscle mass and functional status, a marker of nutritional status and a prognostic index of morbidity and mortality.

Analysis of the phase angle alone, however, can lead to interpretation errors since it does not consider the information provided by the vector length. Groups of individuals characterised by very similar phase angles, but with different vector lengths, may show different body fluids or %FM [21,22].

Bioelectrical impedance vector analysis (classic BIVA, [21]; and *specific* BIVA, [23,24]) considers phase angle and vector length simultaneously. The classic and *specific* BIVA approaches differ from each other for the standardisation of resistance and reactance. In classic BIVA, adjustments are made for height to reduce the effect of conductor length, while in *specific* BIVA, adjustments are made for height and cross-sectional areas, thus obtaining resistivity and reactivity, to reduce the effect of body volume.

Specific BIVA has been validated in a large sample of adults using DXA as the reference technique [23] and proved to be significantly more accurate than classic BIVA in measuring total body composition. These results are consistent with those obtained in a sample of older adults [24] and young athletes [20], where it was also found that both techniques are sensitive to ECW/ICW, and that classic BIVA is highly accurate in estimating TBW. In addition, the associations between resistivity and %FM in different body segments have been observed by Biggs et al. [10] and Fuller et al. [25], even not under a BIVA approach.

Specific BIVA has been applied in several contexts [26–28], while the segmental approach has been introduced more recently [9,29]. At the present day, no studies have evaluated the performance of *specific* BIVA at the segmental level.

The present research aims to analyse the relationship between *specific* BIVA and DXA, used as the reference technique, for segmental body composition, and to analyse comparatively the information retrieved from different body segments and the whole body.

2. Methods

2.1. Study participants

Fifty active students (25 women, 25 men) from the National Institute of Physical Education of Catalonia (INEFC) volunteered for this research. Sample size was determined by fixing the type I error at 5% while minimizing the type II error at less than 5% and by using standard formulas for comparing independent normal populations. The average age of the volunteers was 24.37 (±4.79) years for men and 24.32 (±4.43) years for women. The sample includes students involved in different sports: swimming, football, running, tennis, cycling, padel, badminton, skiing, dancing, water polo, basketball, climbing, taekwondo, rugby, gymnastics, callisthenics and weightlifting.

Before the measurements, each participant was informed about the aims of the project and the type of measurements. The following exclusion criteria were adopted: electronic medical implants such as a pacemaker, diuretic therapy, pregnancy, alcohol or drug abuse, a physical disability that might interfere with body composition measurement and the use of contraceptives. Each participant provided his or her consent before the examination. The experimental protocols were approved by the Ethics Committee for Clinical Research of the Catalan Sports Council (24/CEICGC/2020).

2.2. Protocol

Subjects were asked to come to the laboratory after at least 3 h of fasting and no previous exercise. For the evaluation, volunteers were asked to wear light, casual clothing, and remove all metal jewellery. The experimental protocol was performed following a precise order of measurement steps. First, anthropometrical measurements were recorded. Then, the densitometric analysis was conducted. Finally, the total and segmental bioimpedance analysis was performed. The data registration procedure was done between 9:00 and 14:00.

Anthropometric measurements were obtained by an ISAK-certified technician following an international standardised protocol [30]. Body mass was measured with a scale (Seca 700®, Seca Corp©, Hamburg, DE) to the nearest 0.01 kg and height was measured to the nearest 0.1 cm with a stadiometer (Holtain stadiometer®, Holtain Limited®, Crymych, UK).

Circumferences of the relaxed right arm, right calf and waist were taken. Also, lengths were measured for the right arm, right leg and trunk. Arm length was measured as the distance between the acromion and the stylion, leg length as the distance between the trochanter and the malleolus and trunk length as the distance between injector electrodes.

The technical error of intra-observer measurement (TEM) and TEM% were calculated in a sample of ten subjects (height: TEM = 0.04 cm, TEM% = 0.02; weight: TEM = 0.04 kg, TEM% = 0.07; arm circumference: TEM = 0.16 cm, TEM% = 0.22; waist circumference: TEM = 0.14 cm, TEM% = 0.53; calf circumference: TEM = 0.10 cm, TEM% = 0.29).

DXA analysis was performed using a whole-body DXA scan (Lunar Prodigy Advance model with an enCORE v18 software platform, from GE Medical Systems Madison, Wisconsin, USA). The scanning method involves a narrow fan beam (4.5° angle) with an intelligent fan and MVIR. X-ray characteristics include a constant potential source at 76 kV, K-edge filter at efficient dose, tube current: 0.15–3.00 mA. DXA quality control calibration procedures were performed using dedicated circuit (120 VAC 50–60 Hz 20 A or 230–240 VAC 50–60 Hz 10 A; ± 10%). Ambient requirements were a temperature between 18°C-27 °C and humidity between 20% and 80%. A specialised technician positioned the subjects in a supine position within the edges outlined on the scan table. Each full-body scan took about 7 min. DXA measurements included whole-body and segmental measurements of %FM, FM (kg) and FFM (kg).

FFM indexes were calculated for total and body segments using the formula: FFMItotalbody = FFM/height^2 (kg/m^2) or FFMI-segmental = FFM/segment length^2 (kg/m^2).

A total and segmental bioelectrical impedance analysis was performed on the right side of the body, using a single-frequency phase-sensitive impedance device (BIA 101 Anniversary Sport Edition, Akern, Firenze, Italy; 50 kHz and 400 μA). The BIA device and cables were checked for each session with a test circuit. Subjects were measured lying on a non-conductive bed. The positioning of the electrodes (BIATRODES, Akern, Firenze, Italy) for the entire body followed the standard hand-to-foot position [16]. For segmental body composition, to ease the procedure and to optimise the representation of different body segments, an ad hoc protocol was defined. As suggested by Chumlea et al. [31], on the arm, a pair of electrodes were placed on the shoulder and the hand. On the leg, the procedure indicated by Fuller and Elia [32], at the level of the iliac crest and the foot was preferred, that was considered less affected by measurement error. On the trunk, the same pair of electrodes that were placed on the shoulder and the iliac crest were used. The difference between the sum of raw bioelectrical values measured in the arm, the trunk and the leg, and the value of the total body was below the threshold of biological significance ($R = 2.7$; $Xc = -0.5$).

Specific BIVA was applied for the estimation of body composition [23,24]. The resistance (R) and reactance (Xc) values were adjusted for a correction factor (A/L). For the whole body, A was estimated as 0.45 arm area +0.10 trunk area +0.45 calf area (cm^2); the arm, trunk and calf areas were calculated as $C^2 4\pi$, where C (cm) is the circumference of each segment. The length was calculated as $L = 1.1H$, where H is the height in cm. The correction factors for the arm, the leg and the trunk were calculated using the cross-sections (A) and the length (L) of the arm, the calf and the trunk, respectively.

Specific impedance (Zsp) was calculated using the formula $(Rsp^2 + Xcsp^2)^{0.5}$ (Ω cm) and phase angle with the formula arctan $Xc/R180/\pi$ (degree).Bioelectrical values were projected on the R/Xc graph and analysed with tolerance ellipses, where the major axis refers to variations in FM% (higher values towards the upper pole). The minor axis refers to the variations in body cell mass, skeletal muscle mass in particular, and ECW/ICW ratio (lower values on the left side).

3. Statistical analysis

Descriptive analyses of the total and segmental bioelectrical and DXA variables were performed.

The distribution of bioelectrical specific vectors was evaluated with tolerance ellipses representing the Italo-Spanish reference population.

According to Shapiro–Wilk, all the variables were normally distributed. The comparison between sexes was made using the Student's t-test.

Pearson's correlation was used to estimate the correlation between specific bioelectrical variables (Rsp, Xcsp, Zsp), phase angle and %FM, FM, FFM and FFMI for total and segmental body composition.

The general agreement between *specific* BIVA and DXA was evaluated with a depth–depth analysis [33,34] ANOVA. The depth statistics measures the compatibility of a single multivariate observation with the rest of the sample. The more the depth, the less different is the sample. In particular, we considered the measures of FM% and FFMI obtained in each subject with DXA and compared them with the measures for Zsp and phase measured with BIVA. The two sets of measures lead to two corresponding unknown multivariate distributions and, thus, to two sets of depth measures. In this case, we used the so-called Zonoid depth, which is suitable for small sample sizes that provide low information regarding the two unknown multivariate distributions [34]. The two sets of depths from the two techniques were compared using ANOVA. If the subjects measured with *specific* BIVA and DXA

Table 1
Subject characteristics, including the bioelectrical variables of total and segmental specific BIVA and the comparison between the sexes.

TOTAL	Men (n = 25)		Women (n = 25)		t-test
	Mean	s.d.	Mean	s.d.	*p*
Weight (kg)	72.4	7.9	57.1	7.6	0.000
Height (cm)	175.7	7.0	163.0	7.4	0.000
BMI (kg/m^2)	23.5	2.4	21.5	2.0	0.000
FFM (kg)	60.4	7.4	43.1	6.6	0.000
FM (kg)	12.0	3.6	14.0	3.4	0.046
%FM	16.5	4.2	24.5	5.5	0.000
FFMI (kg/m^2)	19.6	2.2	16.2	1.6	0.000
Rtot (ohm)	460.9	55.7	559.5	58.7	0.000
Xctot (ohm)	65.9	7.3	69.1	5.5	0.091
Rsptot (ohm·cm)	306.5	19.6	324.6	30.3	0.017
Xcsptot (ohm·cm)	44.2	4.0	40.3	4.9	0.004
Zsptot (ohm·cm)	309.7	19.7	327.1	30.5	0.022
Phase angle (°)	8.2	0.7	7.1	0.6	0.000
ARM					
Arm C. (cm)	30.9	3.1	26.9	2.2	0.000
FFM (kg)	3.8	0.7	2.2	0.5	0.000
FM (kg)	0.6	0.8	0.8	0.2	0.003
%FM	14.0	4.1	26.4	7.4	0.000
FFMI (kg/m^2)	11.0	2.3	7.7	1.1	0.000
R (ohm)	195.6	34.7	257.6	34.8	0.000
Xc (ohm)	25.7	3.6	29.0	3.0	0.001
Rsp (ohm·cm)	247.2	29.0	274.4	39.1	0.007
Xcsp (ohm·cm)	32.8	4.8	31.1	5.1	0.241
Zsp (ohm·cm)	249.4	29.2	276.2	39.3	0.009
Phase angle (°)	7.6	0.8	6.5	0.8	0.000
LEG					
Calf C. (cm)	36.7	1.9	34.3	1.9	0.000
FFM (kg)	10.3	1.5	7.2	1.1	0.000
FM (kg)	2.4	0.7	3.0	0.7	0.002
%FM	18.1	4.7	29.5	5.1	0.000
FFMI (kg/m^2)	14.2	1.7	11.4	1.3	0.000
R (ohm)	223.7	23.6	250.9	24.3	0.000
Xc (ohm)	33.6	4.2	33.6	3.2	0.976
Rsp (ohm·cm)	280.2	13.6	293.7	23.5	0.017
Xcsp (ohm·cm)	42.1	3.9	39.4	4.4	0.024
Zsp (ohm·cm)	283.4	13.8	296.4	23.7	0.022
Phase angle (°)	8.6	0.7	7.6	0.6	0.000
TRUNK					
Waist C. (cm)	77.3	4.8	67.4	3.9	0.000
FFM (kg)	28.5	3.3	20.9	3.4	0.000
FM (kg)	5.2	2.1	5.6	1.9	0.453
% FM	15.2	4.2	21.2	7.0	0.001
FFMI (kg/m^2)	70.6	11.5	58.5	7.9	0.000
R (ohm)	39.0	5.5	48.1	6.7	0.000
Xc (ohm)	7.3	0.8	7.0	0.9	0.250
Rsp (ohm·cm)	287.0	41.4	290.7	39.9	0.754
Xcsp (ohm·cm)	54.0	7.9	42.1	5.1	0.000
Zsp (ohm·cm)	292.1	28.8	293.8	38.9	0.888
Phase angle (°)	10.7	1.2	8.3	1.1	0.000

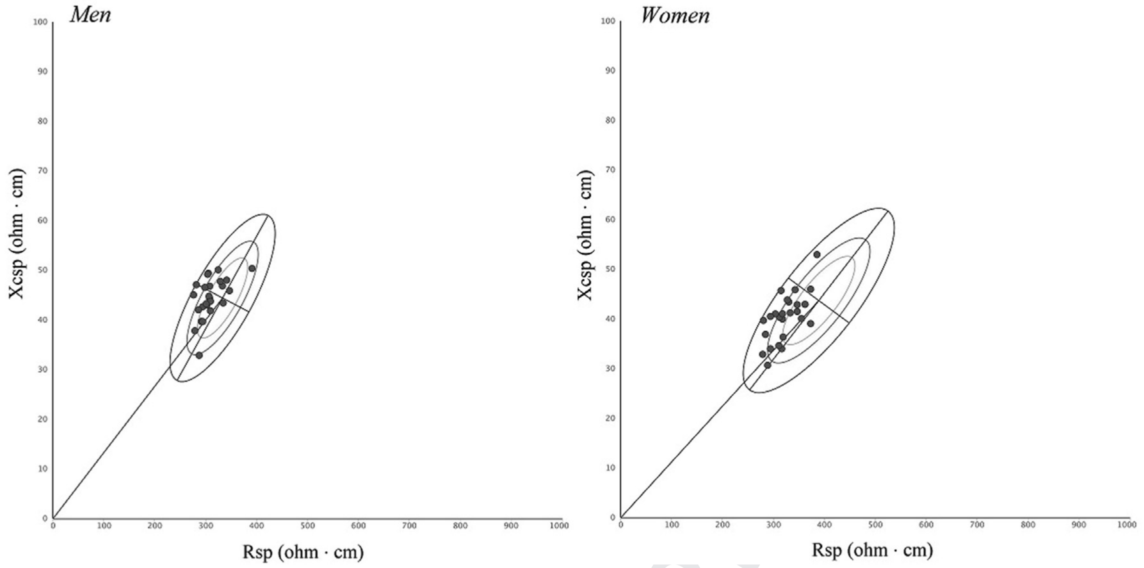

Fig. 1. Distribution of bioelectrical vectors of subjects on the sex-specific bivariate tolerance ellipses.

Table 2
Total and segmental correlations between bioelectrical and body composition variables.

	Pearson's correlations							
	Men (n = 25)				Women (n = 25)			
TOTAL	*%FM*	*FM*	*FFM*	*FFMI*	*%FM*	*FM*	*FFM*	*FFMI*
Rsp	0.755[a]	0.788[a]	−0.077	−0.206	0.782[a]	0.765[a]	−0.240	−0.096
Xcsp	0.231	0.376	0.313	0.282	0.331	0.528[a]	0.218	0.503[b]
Zsp	0.751[a]	0.787[a]	−0.070	−0.197	0.778[a]	0.765[a]	−0.233	−0.084
Phase	−0.447[b]	−0.315	0.420[b]	0.528[a]	−0.350	−0.077	0.532[a]	0.769[a]
ARM	*%FM*	*FM*	*FFM*	*FFMI*	*%FM*	*FM*	*FFM*	*FFMI*
Rsp	0.486[b]	0.089	0.134	0.292	0.754[a]	0.734[a]	−0.281	−0.147
Xcsp	−0.067	0.127	0.493[b]	0.692[a]	0.304	0.537[a]	0.250	0.399[a]
Zsp	0.478[b]	0.090	0.143	0.303	0.750[a]	0.734[a]	−0.274	−0.140
Phase	−0.591[a]	0.030	0.526[a]	0.639[a]	−0.453[b]	−0.109	0.680[a]	0.719[a]
LEG	*%FM*	*FM*	*FFM*	*FFMI*	*%FM*	*FM*	*FFM*	*FFMI*
Rsp	0.611[a]	0.695[a]	0.018	0.029	0.589[a]	0.441[b]	−0.193	0.146
Xcsp	−0.032	0.093	0.275	0.365	0.319	0.372	0.086	0.403[b]
Zsp	0.596[a]	0.684[a]	0.029	0.044	0.587[a]	0.443[b]	−0.188	0.153
Phase	−0.386	−0.287	0.310	0.409[b]	−0.143	0.062	0.292	0.404[b]
TRUNK	*%FM*	*FM*	*FFM*	*FFMI*	*%FM*	*FM*	*FFM*	*FFMI*
Rsp	0.626[a]	0.686[a]	0.047	0.070	0.832[a]	0.796[a]	−0.452[b]	−0.440[b]
Xcsp	0.008	0.152	0.494[b]	0.475[b]	0.077	0.209	0.221	−0.087
Zsp	0.612[a]	0.676[a]	0.063	0.085	0.826[a]	0.794[a]	−0.443[b]	−0.438[b]
Phase	−0.669[a]	−0.554[a]	0.547[a]	0.502[b]	−0.731[a]	−0.583[a]	0.628[a]	0.339

[a] The correlation is significant at 0.01 level.
[b] The correlation is significant at 0.05 level.

received similar depths, the two techniques provided similar information on their body composition.

Statistical analyses were performed using the free software R (http://www.R-project.org) with the MASS library and *specific* BIVA (www.specificbiva.unica.it).

4. Results

The sample of young students practising physical exercise showed that both sexes had normal weight, as indicated by their BMI, and low %FM values (Table 1). Considering the whole body, the majority of specific vectors among men (84%) and women (92%) fell on the left side of tolerance ellipses, indicating high values of cell mass, muscle mass in particular, and ICW/ECW (Fig. 1).

A normal pattern of sexual dimorphism was detected in the total body and different body segments. Compared with women, men showed higher anthropometric values, FFM, FFMI, and phase angle, and lower values of %FM, and, in most cases, of Rsp and Zsp (Table 1).

The bivariate depth–depth analysis showed good agreement between the results of DXA on FFMI and %FM and those of *specific* BIVA based on the phase angle and vector length ($F = 14.89$, $p < 0.001$). The relationship was similar in men and women, as the

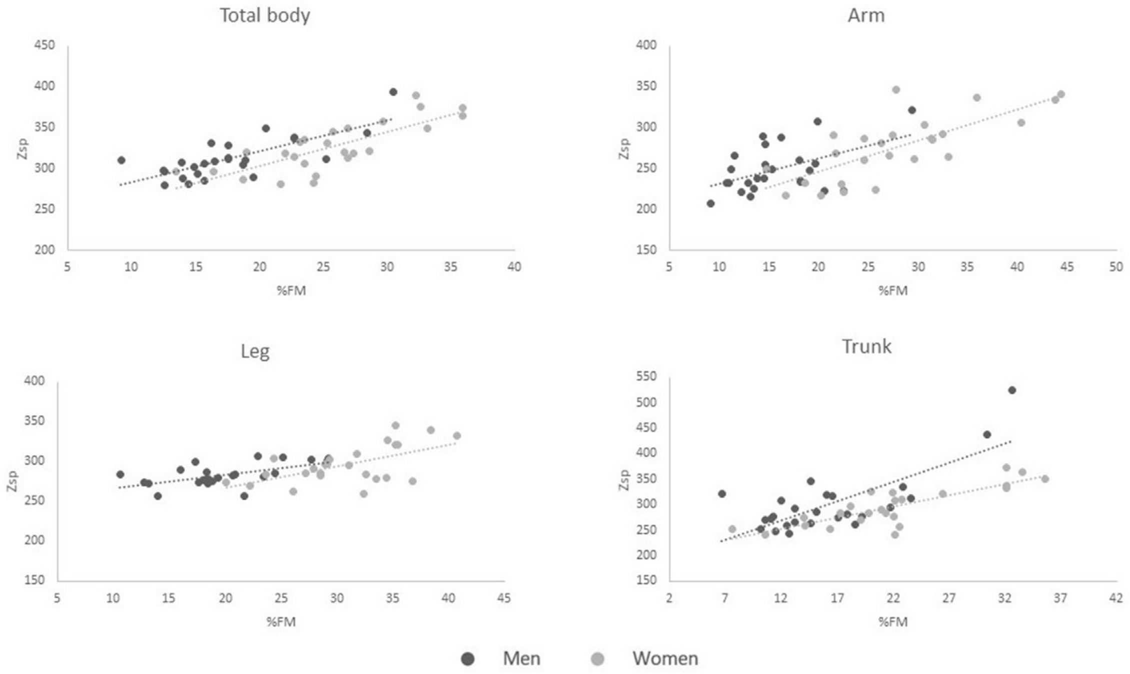

Fig. 2. Correlation between specific impedance vectors and %FM of the whole body and body segments.

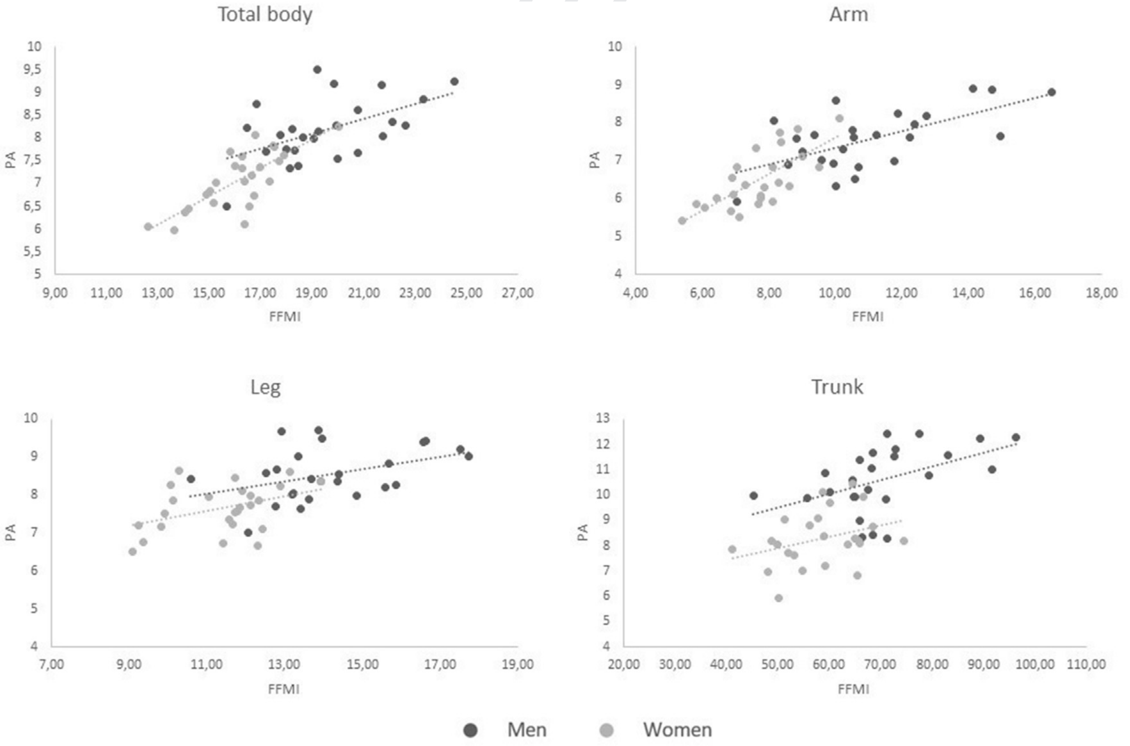

Fig. 3. Correlation between phase angle and FFMI of the whole body and body segments.

effect of sex was not significant (F = 0.27, $p = 0.84$), in different body segments (F = 0.77, $p = 0.51$), without interactions (sex * body segment, F = 1.39, $p = 0.25$).

In both sexes, in the total and the segmental approach, vector length was positively correlated with %FM (Table 2, Fig. 2), and in some cases with FM (Table 2). Among women, a negative correlation between the vector length and FFMI was also detected at the trunk level (Table 2, Fig. 3).

Phase angle was positively correlated with total body FFMI in both sexes and all segments, with the only exception of the trunk

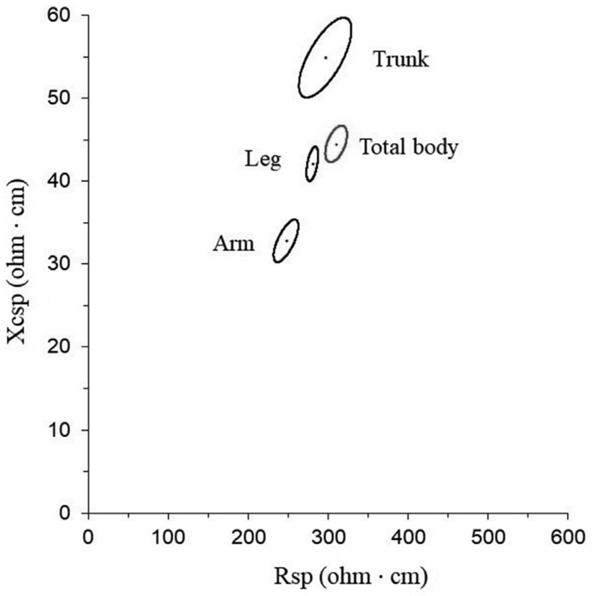

Fig. 4. Confidence ellipses representing the whole body and body segments.

among women (Table 2, Fig. 3). It was also negatively associated with %FM in the total body in men, and in the arm and trunk in both sexes (Table 2, Fig. 2).

5. Discussion

This research showed that body composition evaluation performed with *specific* BIVA agrees well with that of DXA. The analysis showed a similar association in both sexes, in the total body and the trunk, arms and legs. These results are consistent with previous research on total body composition, where *specific* BIVA was compared with DXA in different samples [20,23,24]. However, this research study is the first to demonstrate that such an association has also been detected at the segmental level.

BIVA is based on the joint analysis of variables that are correlated (R and Xc, or phase angle and vector length) and provides information on variables also related to each other, such as those describing body composition (e.g. FM and FFM). Thus, the bivariate statistical approach used in this study to analyse the performance of BIVA regarding DXA is very appropriate. The analysis of body composition based on single variables may not be fully informative, and it may furnish the wrong information. As shown by Mereu et al. [22], for example, individuals with the same phase angle but different specific vector length, can be characterised by %FM differences as high as 60%.

However, it is undeniable that the vector components are influenced differently by different body compartments. The specific vector length is positively related to %FM, as clearly indicated by the results of this research (whole body and all body segments) and those of previous studies (whole body: [10,20,23,24]; body districts: [25]). Phase angle shows a positive association with FFMI (this research, except the trunk among women), with skeletal muscle mass index [35] or with FFM (this research, except in the legs; [19,36]). Phase angle also shows a less clear tendency to be negatively related with %FM (whole body, arm and trunk in men, arm and trunk in women: this research; men only: [23]; women only: [20]; men: [37]), or with FM (trunk: this research; [19]). In contrast, the association between vector length and FFMI or FFM is rarely significant and inconsistent among studies (negative, only in the trunk among women: this research; positive, in the legs and arms among men: [25]; positive, whole body among men: [20]). When the composition of different body segments was considered comparatively, the trunk's higher FFM content with respect to the limbs was detected by both *specific* BIVA and DXA, consistently with the results of other studies in athletes [38] and the general population [39]. However, the Zsp values of the trunk were indicative of %FM values tendentially higher than expected on the basis of DXA, whereas recent research based on traditional BIA have shown an underestimation of fat mass at the trunk level [40,41]. Also, the literature and our results on raw R and Xc data show that the Z of the trunk accounts for only about 10% of the total impedance, whereas the trunk represents 45% of body mass [25]. This difference has been attributed to the composition and shape of this segment [10,17,25,32]. The trunk includes internal organs, visceral and subcutaneous fat with variable density and distribution, and empty spaces, such as the air volume included in the lungs (that overemphasises the trunk volume). Furthermore, the trunk is characterised by a wider cross-sectional area concerning the limbs, whereas the length is similar. Hence, based on Ohm's law, the current passage in the trunk is easier, and the resistance is consequently lower.

The volume effect problem is overwhelmed by the *specific* BIVA approach, where the bioelectrical values are adjusted by A/L, i.e. by an estimate of body cross-sectional areas and length.

This study also showed that the information provided by *specific* BIVA for the body segments is aligned with the results of the whole-body approach, confirming the correctness of the analytical procedure. In fact, the confidence ellipses of the whole body are located in an intermediate position with respect to those of different body segments (Fig. 4).

This study has some limitations, mainly related to the sample size and characteristics. In fact, the lack of individuals with different ages and expressions of body composition, particularly overweight individuals, reduces the potential generalisation of the results, that should be verified in different and larger samples. Moreover, it was not possible to carry out the analysis on body water, for which the classic BIVA would have been appropriate because there are no reference methods to estimate body fluids at the segmental level.

However, this study has the strength of being the first research to analyse the relationship between *specific* BIVA and DXA and demonstrate that the consistency between two approaches is appreciable the sexes and different segments. Furthermore, a new protocol regarding electrode position was used in this study, selecting and integrating previous research contributions. This method has proven to be adequate, as the sum of raw bioelectrical values at the segmental level corresponded to those of the whole body. Hence, the criticism highlighted by Ward [2] about the imprecision in locating electrodes in the segmental approach does not apply to our case. Furthermore, the adequacy of the analytical approach used in *specific* BIVA for the whole body, that weights the contribution of different body segments differently, was confirmed to be correct.

6. Conclusions

Specific BIVA has shown to be associated with DXA in both sexes and the whole body and all body segments. The indices %FM and FFMI obtained with DXA were correlated to vector length and phase angle in each segment, respectively.

From a methodological point of view, the new protocol proposed for segmental analysis proved to be effective. The comparative analysis of different body segments indirectly confirmed that *specific* BIVA effectively overwhelmed the effect of body size in both the whole and segmental approaches. *Specific* BIVA represents a promising technique for monitoring segmental body composition changes in sport science and clinical applications.

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Author contributions

Conceptualization: E.M., S.S, A.I.; Data curation: S.S., A.I., M.C.M., J.R.R.; Formal analysis: S.S., E.M., S.C.; Methodology: all authors; Supervision: E.M., A.I.; Visualization: S.S.; Writing - original draft: S.S., E.M; Writing - review & editing: all authors.

Conflict of interest

The authors have no competing interests to declare.

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