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Bioimpedance analysis as an indicator of muscle mass and strength in a group of elderly subjects

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ABSTRACT

Objective: To assess the association between whole-body and calf impedance vectors and muscle mass and strength in a group of elderly individuals.
Material and methods: We carried out a cross-sectional observational study on a sample of 113 elderly people. Anthropometric parameters (weight, height and body circumferences) were determined. Body composition was evaluated using conventional bioimpedance analysis (BIA) and vector bioimpedance analysis (BIVA) (whole-body and calf BIVAs), and muscle strength was determined (manual dynamometry). The results were analyzed using the Student *t*-test or the Mann-Whitney *U*, and the correlations using the Pearson or Spearman test. To compare BIVA results among the subgroups established, the Mahalanobis distance (dM) was calculated and the Hotelling T^2 statistic was used. Statistical significance was set to $p < 0.05$.
Results: Nearly half the sample was overweight. Based on waist circumference, 66.7% of the males and 94.9% of the females showed risk of metabolic complications; calf circumference indicated no risk of disability or skeletal muscle mass depletion. However, BIA and dynamometry detected risk of sarcopenia in more than half the subjects. Whole-body BIVA results agreed with those of the BIA, given that most impedance vectors in both sexes were to the right of major axis of the tolerance ellipses. This shows cell mass depletion. While the whole-body BIVA distinguished the subjects having loss of muscle mass and strength, the specific BIVA (calf) only did so in individuals with muscle mass loss.
Conclusions: Whole-body BIVA detects loss of muscle mass and strength, while calf BIVA only distinguishes subjects having muscle mass loss. The localized BIVA might be an alternative to conventional BIA or whole-body BIVA to assess body composition in the elderly.

1. Introduction

During the last decades, developed societies have undergone demographic aging because of the increase in life expectancy (WHO, 2015). The elderly are vulnerable to nutritional alterations that can negatively affect the development of certain diseases and geriatric syndromes prevalent in this age group, such as sarcopenia, osteoporosis, malnutrition and fragility, among others (Abajo-del-Álamo et al., 2008).

One of the most important biological changes produced with advancing age is the loss of muscle mass, which leads to reduced muscle strength (Vianna et al., 2007; Hairi et al., 2010; Ribeiro and Kehayias, 2014). In 2009 the European Working Group on Sarcopenia in Older People (EWGSOP) defined sarcopenia as a geriatric syndrome characterized by a progressive, generalized loss of skeletal muscle mass and strength, with risk of adverse health results, such as functional limitations, physical disability, problems carrying out basic daily life activities, poor quality of life, and even death (Cruz-Jentoft et al., 2010). This group support using dynamometry to assess muscle strength, and considers bioimpedance analysis monofrequency at 50 kHz, with a tetrapolar electrode configurations (BIA), as a valid alternative to dual X-ray absorptiometry (DXA) for estimating skeletal muscle mass. Both are used to diagnose sarcopenia (Cruz-Jentoft et al., 2010).

Incorporating the handgrip test in nutritional assessment for the

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Abbreviations: BIA, bioelectrical impedance analysis; BIVA, bioelectrical impedance vector analysis; CP, calf circumference; EWGSOP, European Working Group on Sarcopenia in Older People; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; GS, handgrip strength; H, height; R, resistance; SMM, skeletal muscle mass; WC, waist circumference; Xc, reactance; Z, impedance

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elderly may be useful as an early screening tool to link grip strength, functional autonomy, and risk of falls in older adults (Hairi et al., 2010; Sallinen et al., 2010). It is also used as an indicator of fragility (García et al., 2013).

Determining body composition by BIA at 50 kHz uses multiple regression models. The method assumes a percentage of constant hydration and lack of corporal morphologic alterations. Neither assumption is often fulfilled in the elderly (Norman et al., 2007). Several studies have shown that bioimpedance vector analysis (BIVA) is a valid technique for evaluating cell mass and hydration status (Camina-Martín et al., 2014a, 2014b; Camina-Martín et al., 2015) in the elderly because it does not require fulfillment of the assumptions mentioned before. In BIVA impedance vectors are directly interpreted using the BIA-graph (Norman et al., 2007): vector length provides information on tissue hydration, while the length indicates the content of the soft tissue cell mass (Piccoli et al., 1994).

Both conventional (BIA) and vector bioimpedance (BIVA) are normally performed in single-frequency mode (50 kHz) at the level of the entire body with tetrapolar electrodes (hand-foot) (Lukaski, 1991). However, in the geriatric population it is sometimes impossible to perform a whole-body BIA because many individuals present structural alterations, amputations, metal prosthesis, or pacemakers.

Previous studies by our group (Redondo del Río et al., 2015) in a young population demonstrated a link between muscle strength and the electric parameters of the whole-body BIA and specific BIA of the calf. Consequently, the objective of this study was to ascertain whether there was an association between whole-body vectors and the calf and muscle mass and strength in a group of elderly subjects.

2. Material and methods

2.1. Study design and participants

This was a cross-sectional observational study on a group of 113 elderly people living in the community and another group of institutionalized elderly in healthcare centers in Castilla y León (Spain). Excluded were subjects that had prostheses or metal implants, presented an acute condition, had lost $> 5\%$ of their weight, presented a body mass index (BMI) of $> 34\ \text{kg/m}^2$ or $< 17\ \text{kg/m}^2$, or clinical signs of dehydration (skin folds) and/or edemas.

Written informed consent was obtained from all participants. This study was conducted in accordance with the Declaration of Helsinki and all procedures involving human participants were approved by the Clinical Research Ethics Committee (CEIC) East Valladolid Healthcare Area.

Body weight (W; kg) was measured to the nearest 100 g using a SECA scale (Hamburg, Germany); height (H; m) was measured to the nearest 0.1 cm using a SECA stadiometer (Hamburg, Germany); and body circumferences were measured with a flexible, inelastic measuring tape to the nearest 0.1 cm.

Whole body impedance measurements were made using a standard protocol (Lukaski, 1991). A 50-kHz, tetra-polar phase-sensitive BIA (BIA-101; AKERN-Srl, Florence, Italy) introduced a sinusoidal, alternating current of 400 μA to measure resistance (R) and reactance (Xc).

Fat-free mass (FFM) and skeletal muscle mass (SMM) (kg) were estimated with the BIA equations developed by Kyle et al. (2001) and by Janssen et al. (2004). Fat mass (FM; kg) was calculated as W – FFM. Then, FM, FFM, and SMM indices (FFMI, FMI and SMI, respectively) were calculated as $\text{FMI (kg/m}^2) = \text{FM/H}^2$; $\text{FFMI (kg/m}^2) = \text{FFM/H}^2$; and $\text{SMI (kg/m}^2) = \text{SMM/H}^2$. Finally, FMI, FFMI, and SMI were converted to age- and sex-specific standard deviation (SD) scores (Z-scores) in all subjects using the reference body composition data for Caucasians (Schutz et al., 2002; Janssen et al., 2004).

For BIVA data, R and Xc values of all individuals were normalized by subject height (R/H and Xc/H, Ohm/m). The reference bivariate tolerance ellipses (50%, 75%, and 95% of the distribution of the values in general population) for the adult and older men (Piccoli et al., 1995) were used for the qualitative and semiquantitative assessment of body composition and hydration status in each individual.

For the calf bioimpedance, two measuring (ES1 and ES2) and two injecting electrodes (EI1 and EI2) were placed on the lateral side of the right leg. The ES1 electrode was placed at maximum circumference of the calf; ES2 was placed 10 cm distal to ES1. Injecting electrode EI1 was placed 5 cm proximal to ES1, and EI2 was placed 5 cm distal to ES2 (Sawant et al., 2013).

Handgrip strength (GS) was measured using a Jamar Hand Dynamometer following the protocol of the 2009 American Society of Hand Therapists (ASHT) (Mathiowetz et al., 1984). The test was repeated by three attempts with each hand within 30 s and the highest value of the three measurements was recorded.

2.2. Statistical analysis

All data are presented as mean (SD) or median (25th–75th percentiles). The normality of the distribution of the variables was checked by the Kolmogorov Smirnov or the Shapiro-Wilk tests. A *t*-test or Mann-Whitney *U* test was used for pairwise comparisons, and correlation analyses were performed with Pearson or Spearman correlation tests. Vector analyses were performed with BIVA software developed by Piccoli and Pastori (2002). Statistically significant differences between the mean vectors were assessed with the Hotelling's T^2 test for vector analysis, and distance between groups with the Mahalanobis distance. The level of significance was set at $p < 0.05$. Statistical analysis was performed with SPSS® version 19.0 (SPSS, Chicago, IL, USA).

3. Results

The study sample was composed of 113 subjects, 59 (52.2%) females and 54 (47.8%) males, with an average age of 79.8 years (range: 52.3 to 98.0 years). Most subjects (99, 87.6%) lived institutionalized in a geriatric healthcare center, while only 14 elderly individuals (12.4%) lived in the community. Nearly half of the sample were overweight (Table 1), and the BMI of the females was significantly higher [$28.4\ \text{kg/m}^2$ (4.6)] than that of the males [$26.1\ \text{kg/m}^2$ (3.8)]. The majority of the subjects were at risk of metabolic complications according to waist circumference [males: 98.7 cm (10.4), females: 99.5 cm (12.6)] (Table 1). The calf perimeter value was similar in both sexes [33.6 cm (2.5) in males and 33.5 cm (3.3) in females], and few subjects showed risk of disability and loss of skeletal muscle mass based on this indicator (Table 1).

The BIA-estimated body composition of the females differed significantly from that of the males: females had a higher proportion of body fat and, consequently, a lower proportion of fat-free and skeletal muscle mass. The indices for fat mass, fat-free mass and skeletal muscle mass were also different (Table 2). As for skeletal muscle mass, 53.7% of the males and 52.5% of the females presented criteria for Class I sarcopenia according to the European Sarcopenia Group, while 13% of the males and 16.9% of the females fulfilled criteria for Class II sarcopenia. As expected, the females showed significantly less grip strength than the males [19.3 kg (6.0) vs. 30.0 kg (9.2)]. Based on sarcopenia

Table 1
Sample cataloging according to the anthropometric characteristics.

Sample characteristics		Males (n = 54) n (%)	Females (n = 59) n (%)
BMI	Risk of malnutrition	8 (14.8)	3 (5.1)
	Overweight/obesity	13 (24.1); 10 (18.5)	12 (20.3); 21 (35.6)
WC	Metabolic risk	36 (66.7)	56 (94.9)
CP	Risk of SMM loss	5 (9.3)	10 (16.9)

BMI: body mass index (kg/m^2); CP: calf circumference (cm); SMM: skeletal muscle mass; WC: waist circumference (cm).

Table 2
Body composition of the study participants.

Variables	Male mean (SD) (n = 54)	Female mean (SD) (n = 59)
FFM (%)	72.1 (5.7)	60.2 (5.7)*
FFMI (kg/m^2)	18.7 (1.78)	16.89 (1.6)*
Z-FFMI	−0.21 (1.20)	0.49 (1.01)
FM (%)	27.9 (5.7)	39.8 (5.7)*
FMI (kg/m^2)	7.47 (2.4)	11.50 (3.4)*
Z-FMI	0.62 (1.18)	0.82 (1.19)
SMM (%)	35.9 (4.4)	25.6 (4.2)*
SMMI (kg/m^2)	9.27 (1.0)	7.16 (0.95)*
Z-SMMI	−0.50 (0.84)	0.11 (0.85)

FFM: fat-free mass; FFMI: fat-free mass index; FM: fat mass; FMI: fat mass index; SMM: skeletal muscle mass; SMMI: skeletal muscle mass index; Z-FFMI: normalized Z-score of the fat-free mass index; Z-FMI: normalized Z-score of the fat mass index; Z-SMMI: normalized Z-score of the skeletal muscle mass index.

* $p < 0.05$ males vs. females.

risk assessed using handgrip strength, more than half of the subjects presented values lower than the reference values (53.7% of the males and 57.6% of the females). They were consequently considered at risk of sarcopenia.

Possible associations between the bioelectric variables obtained using whole-body BIA and those from using calf BIA were analyzed. Although significant correlation coefficients were obtained for all the bioelectric variables in the total sample, the best association was found with the Resistance [R = 0.731 ($p < 0.001$)] and its derived variable [resistance/height (R/H): coefficient R = 0.780 ($p < 0.001$)]. Results were similar in both males and females.

There were several significant associations between maximum grip strength and some bioelectric variables from whole-body BIA [reactance (Xc), phase angle, resistance/height (RH), reactance/height (XcH), impedance/height (ZH)]. However, the highest correlation coefficient value was obtained for phase angle (R = 0.612; $p < 0.001$). Analysis of calf impedance revealed weaker associations than those for whole-body BIA. The best correlation coefficient was obtained for phase angle as well (R = 0.513; $p < 0.001$).

Fig. 1 (tolerance ellipses) shows the distribution of the impedance vectors (BIVA) of the males and females studied. In both groups, most of the impedance vectors were located to the right of major axis of the tolerance ellipses, which indicates cell mass loss. This was more notable in the males. In the female group, 7 (11.9%) vectors were found outside normal range (> 75%), while there were 13 (24.1%) in the males.

Figs. 2 and 3 are diagrams of the mean impedance vector in the whole-body and calf BIAs, respectively, in males (left) and females (right) by maximum grip strength (confidence ellipses). In the whole-body BIA, significant differences were seen in the mean impedance vector in both groups based on grip strength ($p < 0.001$ in both cases). However, such differences were not found in the calf BIA (Fig. 3). The whole-body (Fig. 4) and calf (Fig. 5) BIAs by skeletal muscle mass index showed statistically significant ($p < 0.0001$) differences in the mean vectors in both cases, and for the two sexes.

4. Discussion

In this study the association between whole-body and calf impedance vectors and muscle mass and strength in a group of elderly individuals has been assessed. Based on BMI, almost half of the sample was overweight. However, coinciding with other studies, the mean female BMI was significantly higher (Camina-Martín et al., 2015; Slee et al., 2015; Wanden-Berghe, 2007). The BMI is an anthropometric parameter that is correlated with body fat; however, in the elderly the level of adiposity can be underestimated, given age-associated changes in body composition, or overestimated, due to height loss produced by vertebra compression (Chumlea et al., 1985). Neither does BMI consider body fat distribution (Alberti et al., 2005). In contrast to BMI, older-adult waist circumference correlates better with total body fat and la intra-abdominal fat, and it is used as an adverse effect, mainly cardiometobolic complications (Pérez León and Díaz-Perera, 2002). Most of the elderly individuals in our sample (81.4%) had waist circumferences indicating abdominal obesity (≥94 cm in males and ≥80 cm in females) and, consequently, cardiometabolic risk. There are studies that have shown that females have, as they age, larger waist circumference than males of the same race and age (Kuk et al., 2009). This is confirmed in our study. However, the risk may be overestimated, given that the classification of this parameter used cut-off points established for adult populations because no specific geriatric standards are available.

Another anthropometric indicator assessed has been calf circumference, which is a sensitive anthropometric parameter proposed as a marker of muscle loss since it correlates better with nutritional status than arm circumference (López Lirola et al., 2016). Calf circumference correlates positively with muscle mass, and it is recommended as alternative measure for early identifications of sarcopenia in clinical practice (Safer et al., 2015). Also, for years it has been used to determine the cut-off points of decreased muscle mass in the elderly population (Rolland et al., 2003). This is important in evaluating the risk of malnutrition in the elderly. Most of our subjects (both males and females), showed a calf circumference of > 31 cm. Consequently, based

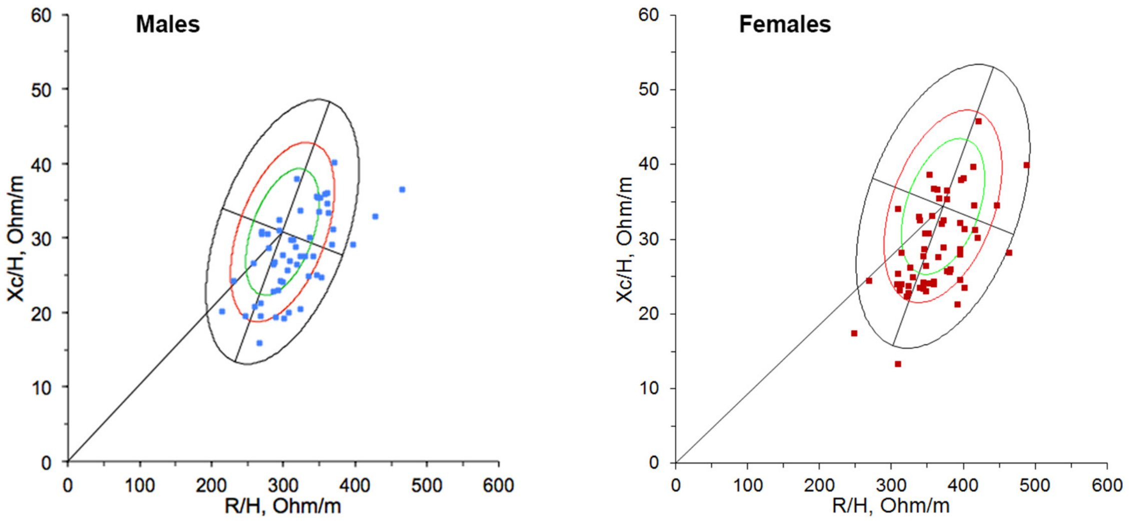

Fig. 1. Tolerance ellipses showing the impedance vectors for the study participant mapping. H: height; R: resistance; Xc: reactance.

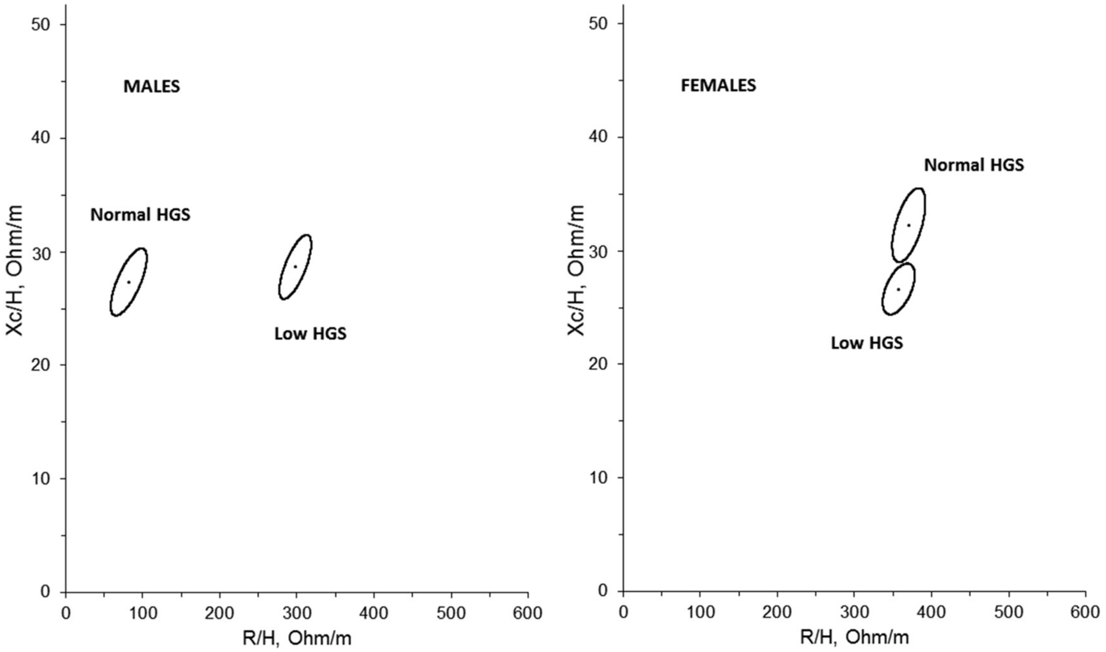

Fig. 2. Male and female confidence ellipses (whole-body bioelectrical impedance vector analysis) based on maximum grip strength mapping. H: height; HGS: handgrip strength; R: resistance; Xc: reactance.

on this parameter, they were not at risk of disability or SMM loss. This is not always true, given that in many cases calf circumference is < 31 cm and there are significant differences by sex (Cuervo et al., 2009).

Considering the anthropometric parameters globally, nearly half of our sample were overweight. In > 80% of the cases, the subject had increased abdominal fat, although apparently (based on calf circumference) no risk of SMM loss was seen. Bearing in mind the limitations of anthropometric parameters in nutritional assessment of the elderly patient, these data confirm the need to perform a complete body composition analysis in these subjects.

Coinciding with other studies (Gómez-Cabello et al., 2012) using conventional bioimpedance analysis (BIA), we have found significant differences in the body compartments by sex in our study. Although the females presented a greater fat percentage and lower skeletal muscle mass than the males, their normalized scores (Z-score) showed similar fat mass values (Z-FM = 0.62 and 0.82 in males and females, respectively). Our female SMM resembled that of the population of reference (Z-FFMI: 0.49; Z-SMM: 0.11). However, the males presented greater

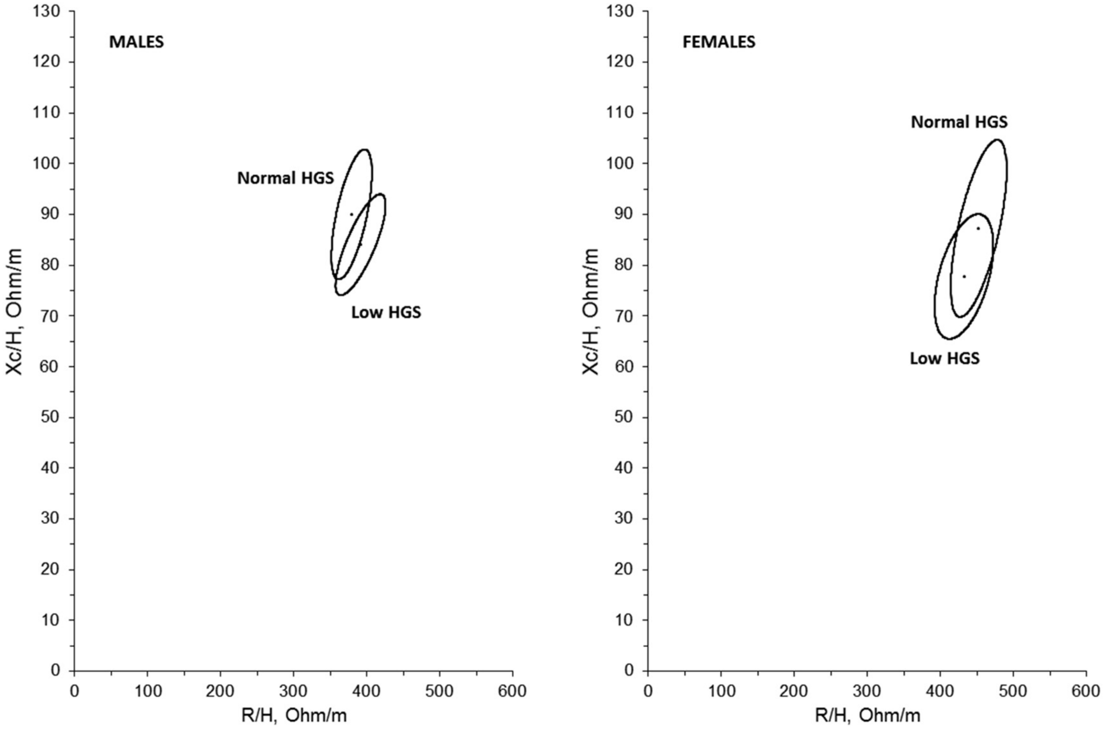

Fig. 3. Confidence ellipses for the male and female calf bioelectrical impedance vector analyses based on maximum grip strength mapping. H: height; HGS: handgrip strength; R: resistance; Xc: reactance.

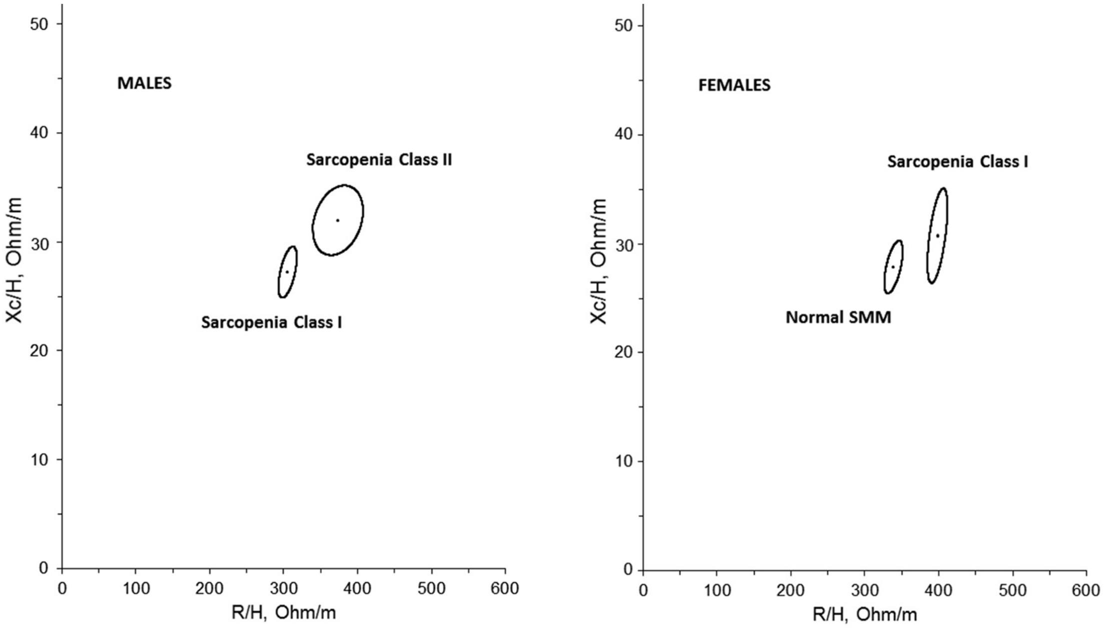

Fig. 4. Male and female confidence ellipses (whole-body bioelectrical impedance vector analysis) based on skeletal muscle mass mapping. H: height; R: resistance; SMM: skeletal muscle mass; Xc: reactance.

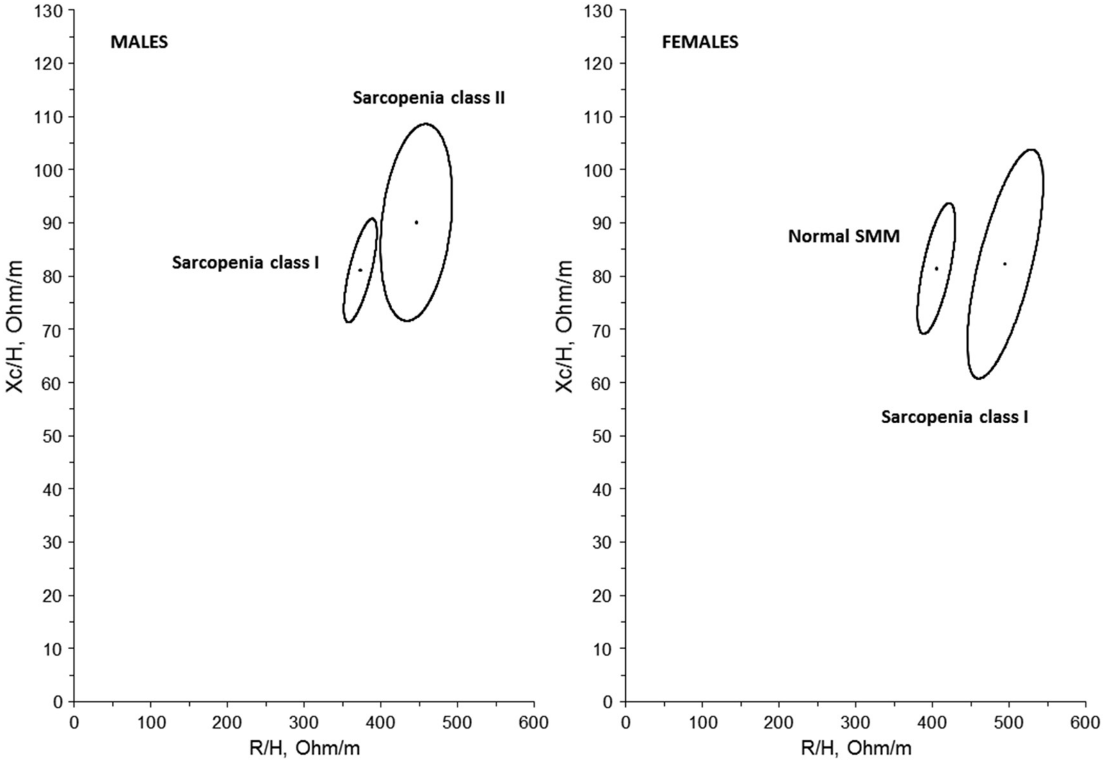

Fig. 5. Confidence ellipses for the male and female calf bioelectrical impedance vector analyses based on skeletal muscle mass mapping. H: height; R: resistance; SMM: skeletal muscle mass; Xc: reactance.

muscle mass loss (Z-FFMI: −0.21; Z-SMM: −0.50) compared with their population of reference. This suggests a possible mild sarcopenic obesity in the males.

According the European Sarcopenia Group criteria (Cruz-Jentoft et al., 2010), in our sample approximately half of the males and of the females presented moderate sarcopenia and around 15%, severe sarcopenia; and only a third of the subjects had a normal SMM. It has been shown that an individual's skeletal muscle begins to decrease from approximately 45 years of age. Due to the loss of muscle mass, a reduction of strength is produced, which can lead to physical disability and functional deterioration in severe cases. Especially in females, the increase in risk of physical disability and functional deterioration can also stem from increased fat mass, even though the skeletal muscle mass is conserved (Janssen et al., 2004).

Another parameter used to assess functional deterioration is grip strength. Its reduction tends to lead to functional limitations and disability (Bohannon et al., 2006). In many cases it is also accompanied by loss of joint mobility or reduced movement speed, which is directly linked to skeletal muscle mass loss (García et al., 2013). Using dynamometry we have found significant differences in handgrip strength by sex (29 vs. 19.3 kg in males and females, respectively) in our study. The hand dynamometer measures the maximum static muscle strength, it reflects the component lean, the mineral content of bones and serves as an estimator of the physical condition and nutritional status of an individual (García López et al., 2017). The handgrip strength reports about the overall muscular strength, also it correlates with the muscle function and it is used in the clinical setting (Norman et al., 2011). Our results, agree with other studies, that have shown that grip strength decreases with age and differs between males and females (García et al., 2013; Bohannon et al., 2006). As in the case of SMM, using the European Sarcopenia Group criteria (Cruz-Jentoft et al., 2010), handgrip strength makes it possible to detect the risk of sarcopenia. Based on our data, more than half of the subjects (55.8%) presented this risk, but no significant differences were found by sex.

Loss of muscle mass is known to be accompanied by a loss of muscle strength, which has a negative effect on physical functioning and general health (Hairi et al., 2010). Several studies suggest that males may be at greater risk of the loss of FFM and, consequently, of muscle mass, than females (Ribeiro and Kehayias, 2014). It is also accepted that muscle strength is lost more quickly than muscle mass. This mismatch between muscle mass and muscle strength suggests a progressive deterioration of muscle quality, a fact that probably makes muscle adapt to the environment worse with age (Barbat-Artigas et al., 2013). Therefore, mainly by the dependence of muscle strength with age and muscle quality, the results obtained in young people cannot be compared with those of the elderly.

Bioimpedance vector analysis (BIVA) is useful in older adults because it permits identifying subjects that are hyper-hydrated or dehydrated, and obese, thin, or cachectic, by displaying them with tolerance ellipses specific for this population. In contrast to conventional bioimpedance analysis (BIA), with BIVA no predictive models are used to transform the electric data into body composition, variables, nor is it necessary for the subjects to be metabolically stable, without rapid changes in fluid and electrolyte content (Camina-Martín et al., 2014a, 2014b). These premises are unnecessary to apply the vector modality, so the analysis results are free from the limitations normally associated with conventional bioimpedance analysis. In addition, the measurements directly reflect the changes in resistance and in reactance associated with changes in body compartment composition (hydration and cell mass).

It should be pointed out that, in the whole-body BIVA (in both males and females) in our study, most of the impedance vectors were to the right of major axis of tolerance ellipses. This indicates a trend towards cell mass loss, more striking in the males. These results are consistent with those obtained using conventional BIA (Z-score results). Various studies have demonstrated that, as individual ages, a loss of cell mass occurs. This is reflected in the migration of the individual impedance vectors in both sexes towards the right of the major axis in the R-Xc diagram. Even so, these studies contend that the loss of skeletal muscle mass is greater in males than in females (Camina-Martín et al., 2015; Buffa et al., 2003; Redondo-del-Río et al., 2016); this has also been observed in our study.

We chose the calf to perform the localized BIA due to the correlation between the muscle mass and the calf circumference and considering that this surrogate marker is an alternative measure for early identifications of sarcopenia in clinical practice. As for the association of the whole-body and calf impedance vectors and muscle strength, the whole-body confidence ellipses distinguish the subjects with reduced muscle strength from those having normal strength. This is not seen with the calf BIVA. However, the calf BIVA does indeed pinpoint the subjects with reduced SMM, just as the whole-body BIVA does. This suggests that localized BIVA might be an appropriate method to use with elderly individuals whose skeletal muscle mass is impossible to assess using conventional BIA or whole-body BIVA. This is the case, for example, with dehydrated elderly adults, individuals having edemas, and people that have lost a limb or have bilateral metallic prostheses or pacemakers.

All these changes in body composition in the elderly affect their nutritional status negatively and put their functional independence at risk. Early detection is therefore crucial. It seems evident that body composition analysis using bioelectric impedance in one of its modalities need to be included routinely in nutritional status assessments. This would make early detection possible for sarcopenia, obesity or sarcopenic obesity, so prevalent in the elderly with these characteristics, to improve their quality of life and health.

In previous studies, our group suggested that specific BIVA is more effective than classic BIVA in identifying bioelectrical changes associated with psycho-functional and nutritional indicators (Camina-Martín et al., 2015). However, the sample was small, all the subjects were institutionalized elderly with dementia, and we do not study muscle mass or muscle strength. In the present work, the sample size is larger and it includes both institutionalized elderly and elderly people living in the community. Moreover, some works that study the effects of resistance exercise in the elderly do not allow identify a preferred method, classic or specific BIVA (Fukuda et al., 2016).

We agree that specific BIVA is an alternative to classic BIVA for assessing nutritional status in geriatrics. Our purpose is to continue this line of work and then study the applications of specific BIVA approach and other BIA modalities, such as BIA located and BIA segmental.

5. Conclusions

Whole-body BIVA detects loss of muscle mass and strength, while calf BIVA only distinguishes subjects with loss of muscle mass. Using BIVA to determine variations in cell mass and hydration is the most widely accepted alternative to conventional BIA, because the latter can lead to substantial predictive errors, especially in older adults, due to their changes in body composition.

Conflicts of interest

None.

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