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Segmental fat-free mass and lean soft mass: a comparative study with dual X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA) and anthropometry and development of anthropometric prediction models

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ABSTRACT

Background: Although dual X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), and anthropometry (ANT) are commonly used to evaluate body composition, evidence on their agreement at the segmental level remains limited. This study aimed to compare intra-subject differences in DXA, BIA, and ANT for estimating segmental weight (SW), fat-free mass (FFM), and lean soft mass (LSM) and to examines sex-related influences, and to develop anthropometric prediction equations using DXA as the reference.
Methods: A cross-sectional study was conducted on 258 young adults (157 males, 101 females). Participants were assessed using DXA, BIA, and ANT. SW, FFM, and LSM were estimated in kilograms and percentages for the upper limbs, trunk, and lower limbs using DXA and BIA. FFM was also estimated using anthropometry (ANT).
Results: Significant intra-subject differences were observed between methods across most body segments ($p \leq 0.049$), except for SW in the right upper limb ($p = 0.328$) and LSM in the trunk ($p = 0.186$) for females. Sex covariable showed a significant influence on the differences found in these comparisons ($p \leq 0.032$). Females exhibited lower values of SW, FFM, and LSM in the upper limbs, while males showed higher values of FFM and LSM specifically in the trunk and lower limbs. Bland – Altman analysis revealed a general lack of agreement between DXA and both BIA and ANT, except for BIA when estimating SW in the right upper limb in females ($p = 0.167$). The new anthropometric equations demonstrated high predictive accuracy ($R^2 > 0.750$), with slightly lower values in the upper limbs of females for FFM and LSM ($R^2 = 0.688$–0.723). Key predictors included body mass, corrected girths, and segmental lengths.
Conclusions: DXA, BIA, and ANT showed significant differences in estimating SW, FFM, and LSM, highlighting their lack of interchangeability. Sex was a significant factor, indicating its importance in body composition estimation. The new anthropometric equations showed good comparability with DXA, although their predictive performance was slightly lower in the upper limbs of females for FFM and LSM.

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Segmental body composition; DEXA; bioimpedance; kinanthropometry; regional lean mass; prediction equations

1. Introduction

The body composition of athletes has been described primarily in terms of total body composition, which is useful for identifying desirable weights for competition, monitoring the effects of nutrition, and tracking training progress and performance [1]. More specifically, one of the components most analyzed for its influence on athletic performance is muscularity. However, before addressing this issue, it is important to consider that different terminologies have been used to assess this component, such as fat-free mass (FFM) or lean body mass, which must be clarified. In this regard, it has been noted that both terms are equivalent, as they represent body compartments without including essential fat. However, it is recommended to use

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"FFM" due to its conceptual precision and greater acceptance in recent scientific literature, thereby facilitating scientific communication and the replicability of future studies [2].

Muscle mass assessment has traditionally been addressed globally, and this approach provides little information on regional mass distribution. Therefore, evaluating total body segmental weight (SW), along with the regional distribution of FFM and lean soft mass (LSM), becomes particularly relevant in sports with unilateral demands or predominant use of either the upper or lower limbs. These disciplines may generate substantial asymmetries in segmental mass distribution [3,4], potentially compromising performance and increasing injury risk due to altered load management and motor patterns [5,6].

In sports, performance relies heavily on strength and power generation in any of its manifestations, so the ability of a specific body segment to produce force is crucial [7]. The mass of a limb directly impacts its force-generating capacity in dynamic actions in which an active translation of the body segment is produced [8]. Assessing SW allows coaches and athletes to optimize training by adjusting limb mass to enhance performance [3]. Moreover, asymmetric mass distribution can affect balance and movement efficiency, which is especially important in sports requiring unilateral actions [9]. This may be specifically relevant when segmental mass increases due to soft tissue variation, and more specifically of the FFM or LSM [10,11], as the amount of muscle mass is directly related to the ability to exert force and power [10–12]. Therefore, measuring SW, and the regional distribution of FFM and LSM provides valuable information on diet, exercise, and aging [13,14].

Although many studies have addressed the various components of body composition, confusion still persists in the scientific literature about the terminology used to refer to these components. FFM is defined as total body weight minus nonessential fat, encompassing water, protein, minerals, glycogen and essential lipids, and is crucial for physical functionality and basal metabolism [15–17]. LSM, on the other hand, takes the totality of molecules, excluding both non-essential fat mass and bone mineral content (BMC) [17,18]. This differentiation is crucial, as in the literature, these terms have been used as synonymously, when they are not [17,19–21].

Several techniques are used to estimate FFM and LSM segmentally, with the most common being dual X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), and anthropometry (ANT) [22–25]. DXA is considered the gold standard technique for BMC estimation due to its high accuracy and replicability [22,26]. BIA can operate with either single or multiple frequencies to measure the bioelectrical properties of the body [27,28]. This is especially important, given that previous research has shown that multi-frequency and single-frequency BIA are not interchangeable [28,29]. The multi-frequency approach is particularly advantageous, as it allows for a more precise assessment of intra- and extracellular spaces, differentiating between the different molecules that make up the body according to their ability to conduct electrical current [17,18,27–29]. This capability enhances the accuracy of body composition assessments, especially when assessing appendicular skeletal muscle [28]. The validity of BIA may depend on the position used to assess the subject and the processing of the results it provides [22,30,31]. Finally, ANT uses regression equations to predict different body components based on measurements of basic body measurements such as skinfolds, girths, breaths, height, lengths, and depths [32–35].

ANT is one of the most deeply rooted methods in body composition assessment due to its affordability and practical application [22,32,36]. Research has highlighted its robustness against external factors such as prior food and fluid intake, as well as hydration status [37,38]. However, the absence of reliable formulas for SW estimation, particularly in younger populations [39], limits its applicability. This gap constrains its use in clinical and sports settings, where more precise, segmental assessments are required.

The scientific literature has documented the advantages and limitations of each of these techniques [22]. DXA provides accurate measurements of segmental body composition, although access may be limited due to cost and availability [22,40,41]. BIA has been valued for its practicality, but some studies point out discrepancies of its estimates with DXA for the body in general, and that its results can be affected by the hydration levels of those assessed [18,35,38,42]. In ANT, the measurement of SW is based on regression equations derived from a small sample of six cadavers, five of whom were older adults and one adolescent [39]. While these foundational studies used cadaver dissection – considered the gold standard for comparison [39], the limited and specific sample makes it difficult to generalize these equations to broader populations [35], particularly healthy, physically active adults. As a result, the segmental equations have limited applicability. Furthermore, various equations have been proposed for the estimation of FFM,

although these proposals have measured only one side of the body, often assuming body symmetry [21,39,43–47] and do not declare the protocols used, which makes it impossible to replicate their results [19,20,43,48]. Other studies have used older protocols currently in disuse or they have been designed for a very specific population [21,43]. In the case of LSM, it is surprising that no study has documented a strategy for its estimation by body segments using ANT.

The absence of consensus on how to assess segmental body composition across different methods highlights the relevance of conducting intra-subject comparisons to better understand both the magnitude and direction of discrepancies. Recent studies have adopted this within-subject approach to compare DXA, BIA, and ANT, aiming to clarify their agreement and practical applicability. Evaluating the outcomes of different techniques within the same individual offers valuable insights that would likely be obscured by inter-individual variability [33,35,49,50].

Furthermore, to the best of our knowledge, we have not found studies that compare the resulting values between DXA, BIA, and ANT in the estimation of SW and segmental FFM and LSM. While previous research has compared segmental results between DXA and BIA and included ANT, it did not estimate SW or FFM, nor did it assess LSM. Additionally, it focused solely on mid-thigh segments and did not account for gender differences, and a small sample size of only 16 participants was utilized [51]. In view of these limitations, it is essential to evaluate the differences between methods and formulas in the estimation of SW, FFM, and LSM, and in the case of ANT, to develop new equations that overcome the limitations of the above formulas. In addition, previous studies have suggested that sex could be a determining factor in body composition estimation and comparability between methods [33,35,36,52], although this issue has not been considered or analyzed for SW and segmental FFM and LSM.

Therefore, the objectives of the present study were: 1) to analyze the intra-subject differences in the values obtained through the use of DXA, BIA, and ANT, in the estimation of SW, FFM, and LSM for the right upper limb, left upper limb, trunk, right lower limb, and left lower limb, and to determine whether these differences are influenced by the sex factor; 2) to examine the agreement between BIA and ANT in comparison with DXA for the estimation of SW, FFM, and LSM across body segments; and 3) to develop prediction equations using ANT to estimate SW, FFM, and LSM in kg and percentages, based on the results obtained through the use of DXA as a gold standard.

2. Materials and methods

2.1. Experimental design

A descriptive cross-sectional study was carried out following the STROBE recommendations [53]. The sample was selected through non-probabilistic sampling. The data collection protocol was submitted for review and approval by the Institutional Ethics Committee of the Catholic University of Murcia (code: CE072103). The research was aligned with the guidelines of the World Medical Association and complied with the ethical principles of the Declaration of Helsinki. The participants were informed about the procedure and signed an informed consent before starting the study.

The sample size was calculated using Rstudio 3.15.0 software, specifically the R power [library(pwr)] package (Rstudio Inc., Boston, MA, USA). A significance level of $\alpha = 0.05$ was established. The standard deviation (SD) was based on the percentage of skeletal muscle mass (SMM) from previous studies (SD = 1.58) [54,55]. With a margin of error (d) of 0.19% in the percentage of SMM, it was determined that 258 subjects were needed as the total sample. In addition, the required sample size of males and females, respectively, was calculated. The SD was based on the percentage of skeletal muscle mass (SMM) from previous studies (SD = 1.58) [54,55]. With a d of 0.31% in the percentage of SMM, it was determined that 101 subjects were needed for each group.

2.2. Participants

A total of 258 adults participated in the study. Figure 1 shows the flow chart of the sample selection. The inclusion criteria were: (1) age between 18 and 35 years. The exclusion criteria were: (1) failure to complete all body composition assessments; (2) having an injury at the time of the assessment; (3) being under hormonal

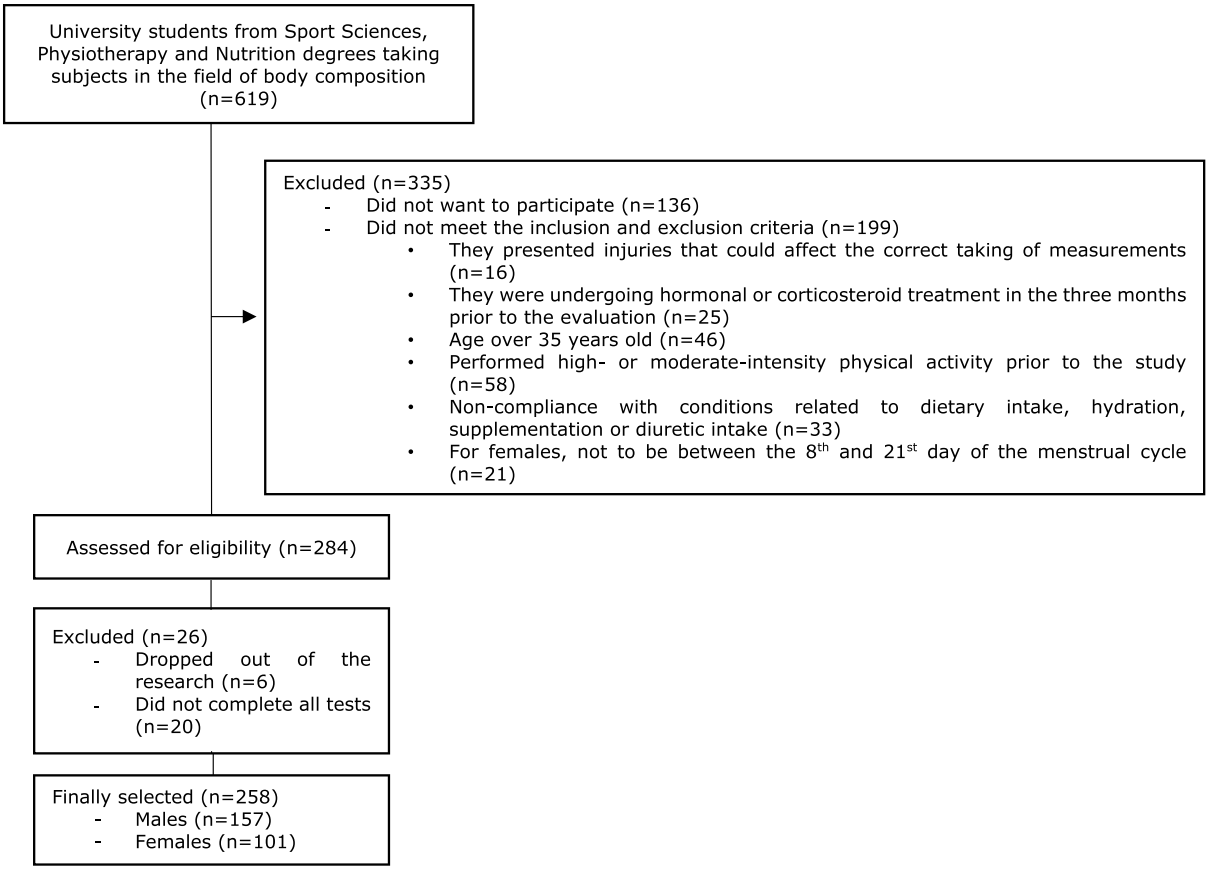

Figure 1. Participants' flow chart.

or corticosteroid treatment in the three months prior to the assessment (with the exception of hormonal treatments to regulate the menstrual cycle); (4) in the case of females, not being between the 8th and 21st day of the menstrual cycle, in order to avoid the influences that estrogen and luteinizing hormone variation may have on body water retention and distribution [56], which could affect the accuracy of both methods, particularly BIA, which is sensitive to hydration levels [37,38]; (5) performing intense physical activity 24 hours prior to the measurement, moderate physical activity 12 hours before, or any type of exercise on the day of the measurement; (6) having eaten a large meal the day before or not having fasted from food for at least 8 hours since the evening of the previous day; (7) not being well hydrated [57]; (8) consumption of products with diuretics effects with the 72 hours prior to the assessment, as these can affect hydration status [58,59]; (9) consumption of sports supplements that may affect body composition, specifically creatine, within four weeks, as its impact on water retention and muscle mass can persist for several weeks post-consumption [60–62]; and (10) suffering from diseases that may influence the accumulation of FFM or LSM (Figure 1).

2.3. Protocol

Students from the Catholic University of Murcia enrolled in Medicine, Nutrition, Physiotherapy and Sports Sciences, were contacted through digital advertisements (social networks, e-mail, and websites), and face-to-face events (information stands and presentations). As an incentive, they were offered a report of their body composition. Students interested in participating completed a questionnaire with basic information, and subsequently, those who met the inclusion criteria were contacted to provide additional instructions. Prior to participation, informed consent was obtained from each volunteer, and the process consisted of two distinct phases: first, data collection through an initial screening, and second, scheduling appointments for the measurements, considering the menstrual cycle in the case of females. They were asked to maintain their

normal food and fluid intake in the 24 hours prior to the measurements, according to previous studies [38,63].

Each volunteer was assigned an appointment to be evaluated. All measurements were performed at the same location, with a standardized humidity of 60% and a temperature of 24 °C, between 9:00 am and 2:00 pm, and were carried out by the same investigators. Participants independently completed the ad hoc questionnaire, supervised by an experienced researcher, who was available to resolve any doubts. They also completed a urine test to assess hydration status. A laterality test was performed to confirm the dominant side of both the upper and lower limbs of the subjects [64]. Subsequently, evaluations by DXA, BIA, and ANT were performed counterbalance randomly. The measurements were taken after a 10-minute rest period, during which the participants rested in a supine position, to minimize any influence of changes in posture [65,66]. The same evaluators performed all measurements in each session to eliminate technical errors of measurement between evaluators.

2.4. Instruments

2.4.1. Questionnaires

An ad hoc questionnaire was used to collect information on sociodemographic aspects. Date of birth, ethnicity and sex, possible pathologies that could influence the accumulation or distribution of SW, FFM, and LSM of the segments, injuries at the time of evaluation, hormonal treatments or administration of corticosteroids, and consumption of diuretics were recorded. The date of their last menstrual period and the time elapsed since then were noted for female participants. Information on dietary intake on the day prior to the measurements was collected using a 24-hour dietary recall, based on previous studies [67–69]. Participants were asked about their habitual consumption of sports supplements [70], and their physical activity was documented by means of a 48-hour exercise reminder, following previous studies [67].

2.4.2. Hydration status analysis

To measure hydration status, a urine sample was collected from each participant. Subjects were provided with a sterile, clean, and sealed jar and instructed to urinate into it [71]. The urine specific gravity (USG) was then measured using a MASTER-URC/Nα model refractometer (Atago, Japan), yielding an average of 1.020 ± 0.008 Specific Gravity. Hydration status was classified as well-hydrated (USG:≤1.020), moderately dehydrated (USG:1.021–1.024), or significantly dehydrated (USG: > 1.024) [57]. Participants who were not classified as well-hydrated were excluded from the study.

2.4.3. Laterality assessment

To assess lateral dominance, a series of established tests were performed, focusing on both upper and lower limbs. For the upper limbs, the participants completed five tasks, including identifying hand and foot prints, pointing to body parts, aiming a ball at a target, performing a throwing task, and executing a precision test with a specific apparatus [64]. The performance in these tasks was recorded, allowing for the determination of lateral dominance based on the side that produced superior results [64]. For the lower limbs, assessments included maintaining balance on one foot, stepping up and down from a platform, and performing a single-leg horizontal jump (forward lunge) [64]. The participants' results were evaluated to identify the dominant side based on their performance metrics [64]. These procedures adhered to protocols established in previous studies, ensuring the reliability and validity of the assessments [64].

2.5. Dual X-ray absorptiometry (DXA)

Each participant underwent SW, FFM, and LSM measurements by DXA. The Hologic Horizon model scanner (Hologic Inc., USA) was used, and the evaluation was performed by an experienced technician. To ensure uniformity of measurements, all participants wore specific sports clothing, and the protocols described in previous research were followed [72]. Prior to assessment, metal objects were removed from the subjects. In addition, participants were asked to urinate within 30 minutes prior to the measurements to minimize potentially confounding variables [73]. During the scan, subjects were positioned with their hands at their sides and both feet in an internal alignment of 15° [72].

The results obtained were analyzed using Hologic APEX 13.6.0.5:5 software (Hologic Inc., USA). The SW, FFM, and LSM values in kg and percentage, as reported by the system, were recorded. The strategies used in the estimation of SW, FFM, and LSM by DXA are detailed in Table 3.

2.6. Bioelectrical impedance analysis (BIA)

Each participant underwent BIA evaluation using the TANITA MC-780-MA model scale (Tanita Cooperation, Japan). This device employs a multi-frequency segmental system with electrodes configured for specific measurement frequencies (5 kHz/50 kHz/250 kHz) [74]. The electrodes used were touch-type, placed on the hand and foot platforms according to the manufacturer's guidelines [75]. Throughout the evaluation process, the manufacturer's guidelines and protocols established in previous research were strictly followed [65,66,75]. Before the measurements, the participants' skin was prepared by cleaning with wipes, as recommended in the device's manual [75]. Participants remained barefoot and made direct contact with the hand and foot electrodes [65,66]. Participants were instructed to urinate within 30 minutes prior to measurements, and information was collected on water intake and dietary factors that could influence body water levels, seeking to minimize potential sources of variability [63]. Each of the participants wore tight-fitting sports clothing and removed all metallic objects before the evaluation. The upper limbs were positioned at 30° to the trunk, and the lower limbs at 45° during the analysis, with the correct placement of the electrodes carefully checked before each measurement [31]. After taking the measurements, the TANITA MC-780-MA system software (Tanita Cooperation, Japan) was used to calculate the kg and percentage of SW, FFM, and LSM (Table 3).

2.7. Anthropometry (ANT)

The evaluation of anthropometric variables was performed following the full protocol established by the International Society for the Advancement of Kinanthropometry (ISAK) [76]. Measurements were performed by two anthropometrists with a current level 3 certification issued by the ISAK, one of whom took the measurements on the right side and the other on the left side. Each measurement was performed twice, randomly starting on either the right or left side, and the protocol applied to the left side was based on the ISAK protocol. In case of a difference of more than 5% in skinfolds and 1% in the rest of the variables between measurements, a third evaluation was performed. The final value used for data analysis was the mean when two measurements were taken, or the median for variables for which three measurements were taken. The intra- and inter-evaluator technical error of measurement (TEM) was calculated in a sub-sample ($n = 20$). The intra-evaluator TEM was found to be 0.01% for basic measurements, 0.70% for skinfolds, 0.30% for girths, 0.38% for lengths, 0.27% for heights, and 0.21% for breaths.

A total of 43 anthropometric variables were measured, corresponding to the complete profile established by the ISAK. All measurements were taken according to ISAK guidelines [76]. All measured variables and the site on which they were measured can be found in Table 1.

A TANITA MC-780-MA scale (Tanita Cooperation, Japan) with an accuracy of 0.1 kg was used to measure body mass, while height was measured with a SECA 213 stadiometer (SECA, Germany) with an accuracy of 0.1 cm. Arm span was measured with a Smartmet arm span segmometer (Smartmet, Mexico). Skinfolds were assessed using a Harpenden skinfold caliper (Harpenden, London, UK), accurate to 0.2 mm. Girths were measured with a Lufkin W606 PM inextensible millimeter tape measure (Lufkin, USA) with an accuracy of 0.1 cm. Lengths and heights were measured with a Cescorf segmometer (Cescorf, Brazil), large breadths and depths were measured with a RealMet large sliding caliper (RealMet Institute, Spain). Small breadths were evaluated with a RealMet small sliding caliper (RealMet Institute, Spain). All the instruments used were pre-calibrated to ensure accuracy and minimize the d in the measurements.

After the evaluations, the girths were adjusted for skinfold thickness using the formula: girth (cm) – (pi number, π) × skinfold (cm)) to arrive at the corrected girth (cm), a common procedure in ANT to more accurately estimate FFM or muscle mass [22–24,52,53]. This correction method is consistent with previous protocols and studies using similar anthropometric approaches, such as those by Scafoglieri et al. [44], which apply the full skinfold value (in cm) multiplied by π to estimate the subcutaneous fat contribution to the

Table 1. Anthropometric variables measured according to ISAK guidelines.

Type of variable	Variable	Variables taken generally for the whole body	Variables taken on both sides (right and left)
Basic measurements	Body mass	X	
	Stretch stature	X	
	Sitting height	X	
	Arm Span	X	
Skinfolds	Triceps		X
	Subscapular		X
	Biceps		X
	Iliac crest		X
	Supraspinale		X
	Abdominal		X
	Thigh		X
	Calf		X
Girths	Head	X	
	Neck	X	
	Arm relaxed		X
	Arm flexed and tensed		X
	Forearm		X
	Wrist		X
	Chest	X	
	Waist	X	
	Hips	X	
	Thigh 1 cm gluteal		X
	Thigh middle		X
	Calf		X
	Ankle		X
Lengths and Height	Acromiale-radiale		X
	Radiale-stylion		X
	Midstylion-dactylion		X
	Iliospinale height		X
	Trochanterion-tibiale laterale		X
	Tibiale laterale height		X
	Foot		X
	Tibiale mediale-sphyrion tibiale		X
Breadths and Depths	Biacromial	X	
	Antero-posterior abdominal depth	X	
	Biiliocristal	X	
	Transverse chest	X	
	Antero-posterior chest depth	X	
	Humerus		X
	Bi-styloid		X
	Femur		X
	Bimalleolar		X

measured girth. This supports the rationale of using the full skinfold value without dividing by two, in line with ISAK protocol recommendations [76].

Each corrected girth, along with the specific variables used in its calculation and the specific formula, is detailed in Table 2.

FFM values in kg were calculated according to the equations by Scafoglieri et al. [44] for the right and left upper limbs, and the right and left lower limbs, and Ritchie et al. [45] for the trunk, right and left upper limbs, and right and left lower limbs. The equations used in the estimations of FFM by segments in ANT can be found in Table 3.

Table 2. Corrected girths and variables used in the calculation and formula.

Corrected girth	Girth	Skinfold	Formula
Right arm	Right arm relaxed	Right triceps	Right arm relaxed girth − (π × right triceps skinfold)
Left arm	Left arm relaxed	Left triceps	Left arm relaxed girth − (π × left triceps skinfold)
Right chest	Chest	Right subscapular	Chest girth − (π × right subscapular skinfold)
Left chest	Chest	Left subscapular	Chest girth − (π × left subscapular skinfold)
Right waist	Waist	Right abdominal	Waist girth − (π × right abdominal skinfold)
Left waist	Waist	Left abdominal	Waist girth − (π × left abdominal skinfold)
Right thigh	Right thigh middle	Right thigh	Right thigh middle girth − (π × right thigh skinfold)
Left thigh	Left thigh middle	Left thigh	Left thigh middle girth − (π × left thigh skinfold)
Right calf	Right Calf	Right calf	Right calf girth − (π × right calf skinfold)
Left calf	Left Calf	Left calf	Left calf girth − (π × left calf skinfold)

* π: pi number.

Table 3. Methods of analysis by body segments with the equations used and their corresponding possible estimates, units and segments.

Method	Equation	Estimation	Units	Segments
DXA	Hologic Horizon software	SW	kg	Trunk
		FFM	%	Right upper limb
		LSM		Left upper limb
				Right lower limb
				Left lower limb
BIA	TANITA MC-780-MA software	SW	kg	Trunk
		FFM	%	Right upper limb
		LSM		Left upper limb
				Right lower limb
				Left lower limb
ANT	Ritchie et al.	FFM	kg	Trunk
				Right upper limb
				Left upper limb
				Right lower limb
				Left lower limb
	Scafoglieri et al.	FFM	kg	Right upper limb
				Left upper limb
				Right lower limb
				Left lower limb

* DXA: Dual X-ray absorptiometry; BIA: bioelectrical impedance analysis; ANT: anthropometry; SW: Segmental weight; FFM: Fat free Mass; LSM: Lean Soft Mass; kg: kilograms; %: percentages.

2.8. Statistical analysis

Statistical tests were applied to verify the normality and homogeneity of the variables, using the Kolmogorov-Smirnov test for distribution normality, and Levene's test for homogeneity. The results showed that all the variables exhibited a platykurtic distribution, confirming their normality and homogeneity, which allowed the application of parametric tests. Afterward, the descriptive analysis of all the variables studied was performed. Differences between SW, FFM, and LSM results, depending on the method used for their measurement, were evaluated by a repeated-measures one-way analysis of variance (ANOVA). The use of this statistical test answers to the aim of exploring the intra-individual differences in the results obtained with the different methods, is it has been done in previous researches with similar objectives [33,36,49,50]. In addition, an analysis of covariance (ANCOVA) was performed considering the covariate "sex" to explore its influence. The observed power was calculated in both the ANOVA and ANCOVA analyses to assess the statistical power of the tests. According to O'Keefe [77], a power value of > 0.8 indicates a sufficient power to detect differences, suggesting that the results are reliable, while values between 0.5 and 0.8 indicate moderate power, indicating that the study may still have detected significant effects but should be interpreted with caution due to the potential for errors. Values < 0.5 indicate low power, suggesting underpowered results and the need for a larger sample size. Student's t-test was used to determine the specific differences in SW, FFM as a percentage, and LSM, between the BIA and DXA methods when the sample was divided according to sex. Cohen's d was calculated to interpret the effect size of the differences observed in the Student's t-test, with values categorized as small (0.2), medium (0.5), or large (0.8) [78]. A post-hoc Bonferroni adjustment was applied to explore differences between equations and specific methods for FFM in kg. Effect size was assessed using the partial Eta squared coefficient (η^2 p), supplemented with 95% confidence intervals (CI). The agreement in kg between BIA and ANT with DXA for SW, FFM, and LSM was assessed using a Bland-Altman analysis, with DXA as the reference method. This technique was applied to evaluate each body segment analyzed, including right and left upper limbs, trunk, and right and left lower limbs. The limits of agreement and mean differences between methods were calculated to provide a comprehensive assessment of agreement. The regression equation for the model was also derived to complement the agreement analysis. Correlations between anthropometric variables and segmental mass estimates by DXA were assessed by Pearson's correlation test in the complete sample, and in the sample divided by sex groups. A forward stepwise multiple linear regression was then performed with the variables that had shown significant correlations, to discover which variables could predict segmental mass estimates by DXA. The significance level was set a priori at $p < 0.05$. The software used to perform the Bland-Altman test was MedCalc Statistical Software v.20.106 (Mariakerke, Belgium). The remaining statistical analyses were performed using SPSS version 27 (IBM, Endicott, NY, USA).

3. Results

3.1. Descriptive analysis

A total of 258 adults (mean age = 22.37 ± 3.41 years; mean body mass = 71.21 ± 13.60 kg; mean height = 172.27 ± 9.38 cm; mean BMI = 23.85 ± 3.30 kg/m^2) participated in the study. Of these, 157 were males (mean age = 22.84 ± 3.44 years; mean body mass = 77.88 ± 10.97 kg; mean height = 177.67 ± 6.73 cm; mean BMI = 24.64 ± 3.01 kg/m^2), and 101 were females (mean age = 21.65 ± 3.24 years; mean body mass = 60.85 ± 10.44 kg; mean height = 163.88 ± 6.22 cm; mean BMI = 22.61 ± 3.37 kg/m^2). All participants were Caucasian. Regarding hand dominance, 240 participants were right-handed, 16 were left-handed, and 2 were ambidextrous. For leg dominance, 213 were right-footed, 41 were left-footed, and 4 were ambidextrous.

Table 4 shows the results of the descriptive statistical analysis performed to estimate SW, FFM, and LSM by DXA, BIA, and ANT in kg and percentages in the overall sample, including means and SD.

3.2. Intra-subject differences between methods of estimating body composition in segmental analysis and the influence of sex

The results of the analysis of intra-subject differences across methods and the effect of sex on differences are included in Table 4. *In most cases, significant differences were observed between methods ($p \leq 0.049$). However, some exceptions were identified, such as SW (kg) in the left upper limb ($p = 0.328$) and LSM (kg) in the right lower limb ($p = 0.082$).*

Sex also showed a significant influence on the comparability of results ($p \leq 0.032$) for the majority of variables, although no effect was detected in SW (kg) of the left and right lower limbs ($p > 0.200$), FFM (%) of the left lower limb ($p = 0.425$), and LSM (kg) of the left upper limb and right lower limb ($p > 0.076$).

The analysis of observed power (OP) across the variables confirms that in most cases, the power was between moderate and high (OP = 0.756–1.000). However, in cases where no significant differences were observed, such as SW of the right lower limb ($p = 0.200$, OP = 0.249), LSM in kg of the right lower limb ($p = 0.171$, OP = 0.278), and FFM in percentage of the left lower limb ($p = 0.425$, OP = 0.533), the observed power was low.

3.3. Pairwise comparisons

To examine differences between both DXA and BIA for SW (kg), FFM (%), and LSM (kg and %), pairwise comparisons were conducted using Student's t-tests, with the analysis stratified (Table 5). Statistically significant differences were found in all segments ($p < 0.001$), except in LSM (%) in the trunk among females ($p = 0.186$).

However, to evaluate differences between DXA, BIA and ANT in FFM (kg) estimations, post hoc pairwise comparisons were performed using Bonferroni adjustment (Table 6). The analysis showed significant differences between all methods and estimation formulae ($p < 0.001$), except for DXA and BIA in the right lower limb in the female group ($p = 0.154$).

3.4. Agreement and concordance with a reference method (DXA)

The Bland-Altman analysis was used to assess the agreement between BIA and the two anthropometric equations with DXA when measuring SW (kg), FFM (kg) and LSM (kg) for the overall sample and by sex, as shown in Table 7. In the overall sample, neither BIA nor the anthropometric equations demonstrated an agreement with DXA ($p < 0.001$). This lack of agreement was also observed when the sample was divided by sex ($p \leq 0.026$), with the exception of BIA when estimating SW (kg) in the right upper limb in females, which showed a certain agreement ($p = 0.167$).

Using DXA as a reference, BIA consistently showed a tendency to overestimate SW in the trunk and upper limbs (r = 0.897-r = 0.971; $p < 0.001$), and to underestimate it in the lower limbs (r = 0.876-r = 0.935; $p < 0.001$), across the overall sample and both sexes. Similarly, BIA systematically overestimated FFM and LSM in kilograms in all body segments limbs (r = 0.788-r = 0.962; $p < 0.001$), with the exception of FFM (kg) in the left lower limb of males, where it was underestimated (r = 0.878, $p < 0.001$). Regarding the anthropometric

Table 4. Segmental weight, fat-free mass, and lean soft mass (in kilograms and percentages) estimated by DXA, BIA, and ANT in the general sample: descriptive statistics, intra-subject differences and sex interaction effects.

		Assessment method (mean ± SD)				Differences between methods/formulas			Differences between methods/formulas *Sex		
		DXA	BIA	ANT Ritchie et al	ANT Scafoglieri et al.	p	ηp2	OP	p	ηp2	OP
Segmental weight (kg)	Trunk	31.73±7.40	39.07±6.92	–	–	<0.001	0.860	1.000	<0.001	0.054	0.967
	Right upper limb	3.88±1.14	4.06±1.02	–	–	0.328	0.004	1.000	<0.001	0.144	1.000
	Left upper limb	3.74±1.12	4.01±1.00	–	–	<0.001	0.068	1.000	<0.001	0.132	1.000
	Right lower limb	13.21±2.11	12.04±2.33	–	–	<0.001	0.406	1.000	0.200	0.006	0.249
	Left lower limb	12.92±2.11	12.02±2.29	–	–	<0.001	0.289	1.000	0.740	0.000	0.063
Fat free mass (kg)	Trunk	24.00±5.30	31.17±5.01	8.30±4.37	–	<0.001	0.925	1.000	<0.001	0.665	1.000
	Right upper limb	2.96±1.02	3.26±1.09	1.10±0.45	5.68±1.96	<0.001	0.685	1.000	<0.001	0.314	1.000
	Left upper limb	2.81±1.02	3.18±1.06	1.09±0.44	5.60±1.94	<0.002	0.038	1.000	<0.001	0.690	1.000
	Right lower limb	9.27±2.37	9.50±2.27	4.03±1.57	17.20±3.90	0.049	0.015	1.000	<0.001	0.721	1.000
	Left lower limb	9.08±2.31	9.45±2.25	3.91±1.56	17.19±3.73	<0.001	0.012	1.000	<0.001	0.726	1.000
Fat free mass (%)	Trunk	75.98±7.94	80.42±6.74	–	–	<0.001	0.626	1.000	<0.001	0.362	1.000
	Right upper limb	75.18±10.85	79.39±8.52	–	–	<0.001	0.378	1.000	<0.001	0.085	0.998
	Left upper limb	73.52±11.71	78.31±8.61	–	–	<0.001	0.468	1.000	<0.001	0.159	1.000
	Right lower limb	69.72±10.36	78.46±9.90	–	–	<0.001	0.473	1.000	0.016	0.023	0.679
	Left lower limb	69.85±10.31	78.18±9.79	–	–	<0.001	0.233	1.000	0.425	0.002	0.533
Lean Soft Mass (kg)	Trunk	23.31±5.16	29.73±4.82	–	–	<0.001	0.892	1.000	<0.001	0.069	0.991
	Right upper limb	2.79±0.98	3.08±1.02	–	–	<0.001	0.217	1.000	0.003	0.033	0.840
	Left upper limb	2.65±0.98	3.00±0.99	–	–	<0.001	0.344	1.000	0.076	0.012	0.427
	Right lower limb	8.78±2.25	8.98±2.16	–	–	0.082	0.012	0.994	0.171	0.007	0.278
	Left lower limb	8.61±2.20	8.94±2.14	–	–	0.002	0.037	1.000	0.032	0.018	0.577
Lean Soft Mass (%)	Trunk	73.78±7.73	76.60±6.49	–	–	<0.001	0.496	1.000	<0.001	0.343	1.000
	Right upper limb	70.57±10.71	75.09±7.93	–	–	<0.001	0.495	1.000	<0.001	0.191	1.000
	Left upper limb	69.21±11.63	74.02±8.04	–	–	<0.001	0.529	1.000	<0.001	0.255	1.000
	Right lower limb	66.03±9.91	74.19±9.49	–	–	<0.001	0.450	1.000	0.008	0.027	0.756
	Left lower limb	66.20±9.86	73.91±9.37	–	–	<0.001	0.436	1.000	0.028	0.019	0.594

* DXA: Dual X-ray absorptiometry; BIA: bioelectrical impedance analysis; ANT: anthropometry; kg: kilograms; %: percentages; OP: Observed power.

equations, Ritchie et al. consistently underestimated all measurements (r = –0.024-r = 0.809; p < 0.001), while Scafoglieri et al. overestimated them (r = 0.824-r = 0.972; p < 0.001), a trend that was consistent in the general sample and when divided by sex. These findings are presented in Table 7.

3.5. Estimation models using anthropometric variables

Correlations between all anthropometric variables and DXA segmental estimates were performed. The corresponding tables are provided as supplementary documents (Tables S1 to S6). Subsequently, a regression analysis was performed to generate models for estimating SW, FFM, and LSM according to different segments in kg, using anthropometric variables, based on the results obtained through the use of DXA.

Tables 8 and 9 show the linear regression models to predict the SW for the male and female sample, respectively. Each segmental variable presents three prediction models, which explained between 85.2% and 95.1% of the cases analyzed in males, and between 87% and 96.1% of the cases analyzed in females ($p < 0.001$). When analyzing trunk SW, the body mass variable was found to be the main predictor ($R^2 = 0.915$–0.961). In the analysis of total upper limb SW, the variable body mass and arm span were found to be the main predictors in males ($R^2 = 0.852$–0.893), while body mass and arm flexed and tensed girth were found to be the main predictors in females ($R^2 = 0.877$–0.943). In the analysis of total weight of the lower limbs, the variable body mass was found to be the main predictor ($R^2 = 0.870$–0.907).

Tables 10 and 11 show the linear regression models using anthropometric variables to predict FFM for the male and female samples, respectively. Each segmental variable presents between 1 and 6 prediction models, which explained between 78.3% and 88.6% of the cases in males, and between 70.9% and 86.4% of the cases in females ($p < 0.001$). In males, body mass was the most consistent predictor for trunk FFM ($R^2 = 0.854$–0.872). For the upper limbs, arm corrected girth and arm span were key variables ($R^2 = 0.856$–0.886). In the lower limbs, the thigh corrected girth and calf corrected girth were the strongest predictors for both sides ($R^2 = 0.801$–0.828). In females, body mass and subscapular skinfold was the most consistent predictor for trunk FFM ($R^2 = 0.853$–0.864). In the upper limbs, arm corrected girth and bi-styloid breadth were the dominant predictors ($R^2 = 0.709$–0.723), while in the lower limbs, thigh corrected girth, calf corrected girth and foot length emerged as the most important variables ($R^2 = 0.756$–0.811).

Tables 12 and 13 present linear regression models utilizing anthropometric variables to estimate LSM for the male and female samples, respectively. Each segmental variable includes between 1 and 5 prediction models, which explained 78% to 88.5% of the male cases, and 68.8% to 86.1% of the female cases ($p < 0.001$). Body mass was the main predictor in both groups for FFM trunk ($R^2 = 0.853$–0.872) and LSM trunk ($R^2 = 0.850$–0.868). For males, the variables arm corrected girth and arm span were found to be the main predictors for FFM in both upper limbs ($R^2 = 0.856$–0.886), and LSM in both upper limbs ($R^2 = 0.855$–0.885). For females, arm corrected girth and bi-styloid breadth were found to be the main predictors FFM in both upper limbs ($R^2 = 0.709$–0.723) and LSM in both upper limbs ($R^2 = 0.688$–0.690). For lower limbs FFM, the variables thigh corrected girth and stretch stature were found to be the main predictors of FFM of both lower limbs in males ($R^2 = 0.783$–0.828), while thigh corrected girth and calf corrected girth were identified as the main predictors of LSM in both lower limbs ($R^2 = 0.780$–0.820). On the other hand, thigh corrected girth and foot were the main predictors of FFM in both lower limbs for females ($R^2 = 0.756$–0.811), while calf corrected girth and foot were the main predictors of LSM in both lower limbs for females ($R^2 = 0.751$–0.802).

4. Discussion

The first objective of the present investigation was to analyze the intra-subject differences between DXA, BIA, and ANT, in the estimation of SW, FFM, and LSM. In this regard, significant differences were found in most cases between the methods used, with a few exceptions, such as SW in the left upper limb and LSM in kg in the right lower limb, where no significant differences were observed. However, these variables, with non-significant results, had a low observed power, indicating that the likelihood of detecting a true effect, if present, was limited [77]. Therefore, the absence of significance may be due to insufficient statistical power rather than the absence of true differences, and these results should be interpreted with caution [77]. In contrast, most variables for which significant differences were observed had a moderate to high power, indicating that the chances of identifying a true effect were substantial [77].

In this context, we adopted a within-subject comparison design to explore the behavior of each method under identical individual conditions. This approach allows the influence of inter-subject variability to be minimized, offering greater sensitivity to detect method-specific differences. Similar strategies have been successfully implemented in recent studies comparing DXA, BIA, and ANT [33,35,49,50].

To ensure the accuracy of the comparison between DXA and BIA, all participants were required to be well-hydrated before the assessments [37,38]. Hydration status was controlled and evaluated through USG, and only individuals classified as well-hydrated (USG ≤1.020) were included in the final analysis [57]. This controlled hydration ensured that the differences observed between the methods were not influenced by hydration variability, reinforcing the robustness of the findings. Despite this control, the significant differences between methods persisted.

Table 5. Differences between DXA and BIA for segmental weight, fat-free mass, and lean soft mass (kg and %) in total sample and divided by sex.

		General sample (n=258)			Male sample (n=157)			Female sample (n=101)		
Methods	Segment	Mean diff ±SD	p value	Effect size (Cohen's d)	Mean diff ±SD	p value	Effect size (Cohen's d)	Mean diff ±SD	p value	Effect size (Cohen's d)
SW (kg)	Trunk	−7.33±1.78	<0.001	−1.025	−7.66±1.66	<0.001	−1.311	−6.82±1.84	<0.001	−1.143
	Right upper limb	−0.18±0.32	<0.001	−0.166	−0.28±0.34	<0.001	−0.368	−0.03±0.21	0.167	−0.049
	Left upper limb	−0.27±0.31	<0.001	−0.254	−0.36±0.34	<0.001	−0.481	−0.13±0.19	<0.001	−0.215
	Right lower limb	1.18±.83	<0.001	0.526	1.23±0.82	<0.001	0.627	1.09±0.85	<0.001	0.621
	Left lower limb	0.90±0.87	<0.001	0.409	0.92±0.86	<0.001	0.466	0.88±0.88	<0.001	0.509
FFM (%)	Trunk	−4.45±4.95	<0.001	9.402	−2.07±3.69	<0.001	−0.321	−8.15±4.35	<0.001	−1.090
	Right upper limb	−4.21±5.10	<0.001	−0.432	−3.02±4.15	<0.001	−0.544	−6.07±5.86	<0.001	−0.738
	Left upper limb	−4.79±5.62	<0.001	−0.466	−2.94±4.64	<0.001	−0.501	−7.67±5.82	<0.001	−0.942
	Right lower limb	−8.74±5.20	<0.001	−0.863	−9.37±5.21	<0.001	−1.512	−7.77±5.06	<0.001	−1.440
	Left lower limb	−8.34±5.16	<0.001	−0.829	−8.86±5.14	<0.001	−1.432	−7.52±5.10	<0.001	−1.385
LSM (kg)	Trunk	−6.41±1.56	<0.001	−0.018	−6.08±1.41	<0.001	−1.793	−6.92±1.66	<0.001	−2.356
	Right upper limb	−0.29±0.28	<0.001	−0.290	−0.33±0.32	<0.001	−0.562	−0.23±0.20	<0.001	−0.766
	Left upper limb	−0.36±0.28	<0.001	−0.355	−0.38±0.32	<0.001	−0.628	−0.32±0.18	<0.001	−1.085
	Right lower limb	−0.20±0.71	<0.001	−0.091	−0.25±0.80	<0.001	−0.165	−0.12±0.55	0.026	−0.140
	Left lower limb	−0.33±0.68	<0.001	−0.152	−0.40±0.77	<0.001	−0.266	−0.21±0.51	<0.001	−0.246
LSM (%)	Trunk	−2.81±5.08	<0.001	−0.395	−0.43±4.05	0.186	−0.068	−6.51±4.26	<0.001	−0.906
	Right upper limb	−4.52±5.16	<0.001	−0.480	−2.71±4.04	<0.001	−0.503	−7.32±5.46	<0.001	−0.959
	Left upper limb	−4.81±5.80	<0.001	−0.481	−2.47±4.48	<0.001	−0.433	−8.46±5.75	<0.001	−1.077
	Right lower limb	−8.16±5.02	<0.001	−0.841	−8.82±5.02	<0.001	−1.486	−7.14±4.86	<0.001	−1.371
	Left lower limb	−7.71±4.95	<0.001	−0.802	−8.26±4.92	<0.001	−1.397	−6.87±4.90	<0.001	−1.317

*SW: Segmental weight; FFM: Fat free Mass; LSM: Lean Soft Mass; kg: kilograms %: percentages.

The differences found can be attributed to the different terminologies and principles on which these different methods are based. More specifically, DXA, considered by the scientific community as the gold standard technique due to its high accuracy and replicability [22,79–81], works by differential X-ray absorption directly at the molecular level, to provide estimates of SW, FFM, and LSM [17,22,40]. In contrast, BIA can be operated using either single or multiple frequencies to assess the bioelectrical properties of the body, differentiating between the different molecules according to their ability to conduct electrical current [18,27,28]. Multi-frequency BIA presents distinct advantages, as it improves the accuracy of body composition assessments, particularly in evaluating appendicular skeletal muscle [28]. This capability may potentially allow for a more nuanced estimation of SW, FFM, and LSM as compared to single-frequency methods, which might not differentiate as effectively between various tissues in the body [18,27–29]. In addition, the results from single or multiple frequency BIA are not interchangeable [28,29]. ANT, based on body measurements, uses regression equations to provide molecular estimates [17,32,33,76]. Other studies have found similar intra-subject differences among the results reported by these methods for body composition, when assessing a body as a whole, highlighting the need for clear and standardized terminology in the scientific literature, as it can influence the interpretation and comparison of results between studies [33,35,82,83]. In fact, the present study clearly shows differences between FFM and LSM, which in previous research were used as equivalents [17,19–21]. This reinforces the analysis proposed by Wang et al. [17], in which the FFM presented the BMC within its quantification, which does not occur in the LSM [17].

In addition, an influence of sex was found on the intra-subject differences between variables and methods, indicating that sex had a significant effect on the comparability of most of the variables analyzed. This suggests that an individual's sex should be considered when comparing methods of estimating body

Table 6. Differences between DXA, BIA and ANT of estimating fat free mass by body segments (kg) for the total sample and divided by sex.

		General sample (n=258)			Male sample (n=157)			Female sample (n=101)		
Methods	Segment	Mean diff ±SD	p value	95%CI (min;max)	Mean diff ±SD	p value	95%CI (min;max)	Mean diff ±SD	p value	95%CI (min;max)
DXA vs BIA	Trunk	−6.41±0.10	<0.001	−6.65;-6.18	−6.08±0.11	<0.001	−6.36;-5.81	−6.92±0.17	<0.001	−7.33;-6.52
	Right upper limb	−0.29±0.02	<0.001	−0.34;-0.25	−0.33±0.03	<0.001	−0.40;-0.27	−0.23±0.02	<0.001	−0.28;-0.18
	Left upper limb	−0.36±0.02	<0.001	−0.40;-0.31	−0.38±0.03	<0.001	−0.45;-0.31	−0.32±0.02	<0.001	−0.37;-0.27
	Right lower limb	−0.20±0.04	<0.001	−0.32;-0.08	−0.25±0.06	0.001	−0.42;-0.08	−0.12±0.06	0.154	−0.27;0.02
	Left lower limb	−0.33±0.04	<0.001	−0.44;-0.21	−0.40±0.06	<0.001	−0.56;-0.24	−0.21±0.05	<0.001	−0.35;-0.08
DXA vs ANT Ritchie et al.	Trunk	15.70±0.35	<0.001	14.85;16.55	19.49±0.27	<0.001	18.85;20.13	9.80±0.26	<0.001	9.17;10.44
	Right upper limb	1.86±0.07	<0.001	1.68;2.04	2.69±0.04	<0.001	2.60;2.78	0.58±0.04	<0.001	0.48;0.67
	Left upper limb	1.72±0.07	<0.001	1.53;1.90	2.55±0.04	<0.001	2.45;2.64	0.42±0.04	<0.001	0.33;0.52
	Right lower limb	5.24±0.08	<0.001	5.02;5.46	7.13±0.11	<0.001	6.84;7.43	2.30±0.12	<0.001	1.98;2.63
	Left lower limb	5.17±0.16	<0.001	4.74;5.61	7.02±0.11	<0.001	6.74;7.30	2.30±0.12	<0.001	1.98;2.63
DXA vs ANT Scafoglieri et al.	Right upper limb	−2.72±0.06	<0.001	−2.88;-2.55	−3.36±0.05	<0.001	−3.49;-3.23	−1.72±0.06	<0.001	−1.87;-1.56
	Left upper limb	−2.80±0.06	<0.001	−2.96;-2.64	−3.42±0.05	<0.001	−3.55;3.29	−1.83±0.06	<0.001	−2.00;-1.66
	Right lower limb	−7.93±0.10	<0.001	−8.21;-7.66	−8.78±0.13	<0.001	−9.11;-8.45	−6.61±0.18	<0.001	−7.09;-6.14
	Left lower limb	−8.11±0.12	<0.001	−8.42;-7.80	−8.83±0.12	<0.001	−9.15;-8.51	−6.86±0.18	<0.001	−7.48;-6.49
BIA vs ANT Ritchie et al	Trunk	22.86±0.33	<0.001	22.06;23.67	26.37±0.25	<0.001	25.76;26.97	17.42±0.31	<0.001	16.68;18.17
	Right upper limb	2.16±0.07	<0.001	1.97;2.35	3.05±0.03	<0.001	2.97;3.13	0.78±0.03	<0.001	0.70;0.85
	Left upper limb	2.09±0.07	<0.001	1.90;2.28	2.97±0.03	<0.001	2.89;3.05	0.72±0.03	<0.001	0.65;0.79
	Right lower limb	5.47±0.06	<0.001	5.32;5.62	7.40±0.07	<0.001	7.23;7.58	2.46±0.10	<0.001	2.19;2.73
	Left lower limb	5.54±0.16	<0.001	5.12;5.96	7.46±0.07	<0.001	7.29;7.64	2.55±0.10	<0.001	2.28;2.82
BIA vs ANT Scafoglieri et al.	Right upper limb	−2.42±0.06	<0.001	−2.57;-2.26	−3.00±0.05	<0.001	−3.13;-2.86	−1.52±0.06	<0.001	−1.67;-1.36
	Left upper limb	−2.43±0.06	<0.001	−2.59;-2.27	−3.00±0.05	<0.001	−3.13;-2.87	−1.53±0.06	<0.001	−1.69;-1.36
	Right lower limb	−7.71±0.10	<0.001	−7.97;-7.44	−8.51±0.11	<0.001	−8.80;-8.21	−6.46±0.18	<0.001	−6.95;-5.97
	Left lower limb	−7.74±0.11	<0.001	−8.03;-7.45	−8.39±0.11	<0.001	−8.67;-8.10	−6.73±0.18	<0.001	−7.23;-6.24
ANT Ritchie et al. vs ANT Scafoglieri et al.	Right upper limb	4.58±0.12	<0.001	4.25;4.90	6.06±0.07	<0.001	5.86;6.23	2.29±0.06	<0.001	2.13;2.45
	Left upper limb	4.51±0.12	<0.001	4.19;4.84	5.97±0.07	<0.001	5.79;6.15	2.25±0.06	<0.001	2.10;2.40
	Right lower limb	13.17±0.09	<0.001	12.94;13.41	15.91±0.12	<0.001	15.59;16.23	8.91±0.13	<0.001	8.57;9.27
	Left lower limb	13.28±0.22	<0.001	12.70;13.86	−15.85±0.12	<0.001	−16.15;-15.54	9.28±0.12	<0.001	8.96;9.62

* DXA: Dual X-ray absorptiometry; BIA: bioelectrical impedance analysis; ANT: anthropometry.

composition, as it may affect the accuracy and interpretation of the results. These findings are along the same lines of previous studies, where a significant influence of sex was observed in body composition evaluation with different methods [33,35,36,52]. This could be due to physiological and anatomical differences between males and females, which affect the distribution and composition of body tissues [84–86]. These differences are influenced by sex hormones [87]. In females, estrogen tends to promote the accumulation of subcutaneous fat, whereas in males, testosterone promotes a greater development of FFM [88,89].

Table 7. Bland-Altman analysis for the agreement between methods of estimating segmental weight (kg), fat free mass (kg) and lean soft mass by body segments (kg) for the overall sample and divided by sex.

						95% Limits of agreement				
Variable	Body segment	Method	Pearson´s r (p)	Mean diff	95% CI	Lower limit	Upper limit	p	Regression equation	p
SW (kg)	**GENERAL SAMPLE (*n*=258)**									
	Trunk	DXA vs BIA	0.971 (p<0.001)	−7.334	−7.552 to −7.116	−10.816	−3.851	<.001	y = −4.929 + −0.068 x	<.001
	Right upper limb	DXA vs BIA	0.963 (p<0.001)	−.179	−0.218 to −0.140	−0.8041	0.446	<.001	y = 0.289 + −0.118 x	<.001
	Left upper limb	DXA vs BIA	0.962 (p<0.001)	−.267	−0.306 to −0.229	−0.881	0.347	<.001	y = 0.159 + −0.110 x	<.001
	Right lower limb	DXA vs BIA	0.935 (p<0.001)	1.177	1.075 to 1.279	−0.453	2.806	<.001	y = −0.156 + 0.106 x	<.001
	Left lower limb	DXA vs BIA	0.926 (p<0.001)	.904	0.797 to 1.010	−0.797	2.604	<.001	y = −0.188 + 0.088 x	<.001
	MALES (*n*=157)									
	Trunk	DXA vs BIA	0.961 (p<0.001)	−7.664	−7.926 to −7.402	−10.922	−4.407	<.001	y = −5.770 + −0.049 x	.033
	Right upper limb	DXA vs BIA	0.900 (p<0.001)	−.276	−0.330 to −0.222	−0.942	0.391	<.001	y = 0.079 + −0.077 x	.040
	Left upper limb	DXA vs BIA	0.897 (p<0.001)	−.358	−0.412 to −0.305	−1.027	0.310	<.001	y = −0.076 + −0.062 x	.299
	Right lower limb	DXA vs BIA	0.919 (p<0.001)	9.410	9.182 to 9.638	6.575	12.246	<.001	y = 0.324 + 0.959 x	<.001
	Left lower limb	DXA vs BIA	0.910 (p<0.001)	.918	0.782 to 1.054	−0.773	2.609	<.001	y = −0.617 + 0.115 x	.001
	FEMALES (*n*=101)									
	Trunk	DXA vs BIA	0.954 (p<0.001)	−6.821	−7.183 to −6.458	−10.417	−3.224	<.001	y = −5.133 + −0.056 x	.074
	Right upper limb	DXA vs BIA	0.941 (p<0.001)	−.029	−0.070 to 0.012	−0.437	0.379	.167	y = 0.196 + −0.07654 x	.032
	Left upper limb	DXA vs BIA	0.948 (p<0.001)	−.300	−0.337 to −0.264	−0.665	0.064	<.001	y = −0.271 + −0.016 x	.811
	Right lower limb	DXA vs BIA	0.891 (p<0.001)	1.094	0.926 to 1.261	−0.569	2.756	<.001	y = −0.527 + 0.145 x	.003
	Left lower limb	DXA vs BIA	0.876 (p<0.001)	.881	0.708 to 1.055	−0.841	2.604	<.001	y = −0.4330 + 0.119 x	.023

(*Continued*)

Table 7. (Continued).

Variable	Body segment	Method	Pearson´s r (p)	Mean diff	95% CI	95% Limits of agreement		p	Regression equation	p
						Lower limit	Upper limit			
FFM (kg)	**GENERAL SAMPLE (*n*=258)**									
	Trunk	DXA vs BIA	0.954 (p<0.001)	−7.165	−7.360 to −6.969	−10.288	−4.042	<.001	y = −8.723 + 0.057 x	.004
		DXA vs ANT Ritchie et al.	0.332 (p<0.001)	15.699	15.008 to 16.391	4.644	26.755	<0.001	y = 11.067 + .287 x	0.001
	Right upper limb	DXA vs BIA	0.962 (p<0.001)	−.298	−0.334 to −0.262	−0.878	0.282	<.001	y = −0.108 + −0.061 x	<.001
		DXA vs ANT Ritchie et al.	0.020 (p=0.751)	1.860	1.724 to 1.996	−0.315	4.035	<0.001	y = −.836 + 1.326 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.972 (p<0.001)	−2.715	−2.837 to −2.593	−4.667	−0.763	<0.001	y = .039 + −.637 x	<0.001
	Left upper limb	DXA vs BIA	0.961 (p<0.001)	−.373	−0.409 to −0.337	−0.946	0.200	<.001	y = −0.253 + −0.040 x	.025
		DXA vs ANT Ritchie et al.	−0.024 (p=0.705)	1.715	1.578 to 1.852	−0.474	3.904	<0.001	y = −.987 + 1.387 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.966 (p<0.001)	−2.799	−2.921 to −2.678	−4.742	−0.857	<0.001	y = −.132 + −.634 x	<0.001
	Right lower limb	DXA vs BIA	0.949 (p<0.001)	−.227	−0.318 to −0.135	−1.689	1.236	<.001	y = −0.638 + 0.044 x	.031
		DXA vs ANT Ritchie et al.	0.104 (p=0.096)	5.2411	4.910 to 5.572	−0.057	10.539	<0.001	y = .478 + .716 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.919 (p<0.001)	−7.931	−8.172 to −7.691	−11.771	−4.092	<0.001	y = −1.213 + −.508 x	<0.001
	Left lower limb	DXA vs BIA	0.950 (p<0.001)	−.368	−0.456 to −0.279	−1.780	1.044	<.001	y = −0.595 + 0.025 x	.221
		DXA vs ANT Ritchie et al.	0.111 (p=0.075)	5.172	4.849 to 5.496	−0.001	10.346	<0.001	y = .783 + .676 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.913 (p<0.001)	−8.106	−8.336 to −7.877	−11.774	−4.438	<0.001	y = −1.675 + −.4896 x	<0.001
	MALES (*n*=157)									
	Trunk	DXA vs BIA	0.922 (p<0.001)	−6.874	−7.101 to −6.647	−9.699	−4.049	<.001	y = −10.800 + 0.128 x	<.001
		DXA vs ANT Ritchie et al.	0.674 (p<0.001)	19.492	18.968 to 2.016	12.978	26.006	<0.001	y = 23.041 + −.202 x	0.005
	Right upper limb	DXA vs BIA	0.866 (p<0.001)	−.361	−0.413 to −0.309	−1.007	0.285	<.001	y = −0.459 + 0.026 x	.553
		DXA vs ANT Ritchie et al.	0.745 (p<0.001)	2.687	2.619 to 2.756	1.835	3.540	<0.001	y = 1.500 + .512 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.920 (p<0.001)	−3.358	−3.453 to −3.263	−4.542	−2.174	<0.001	y = −.262 + −.580 x	<0.001
	Left upper limb	DXA vs BIA	0.859 (p<0.001)	−.419	−0.472 to −0.366	−1.079	0.240	<.001	y = −0.590 + 0.046 x	.299
		DXA vs ANT Ritchie et al.	0.739 (p<0.001)	2.547	2.477 to 2.617	1.678	3.416	<0.001	y = 1.303 + .560 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.909 (p<0.001)	−3.423	−3.519 to −3.327	−4.615	−2.231	<0.001	y = −.446 + −.572 x	<0.001
	Right lower limb	DXA vs BIA	0.874 (p<0.001)	6.733	6.526 to 6.939	4.167	9.299	<.001	y = −0.859 + 1.028 x	<.001
		DXA vs ANT Ritchie et al.	0.620 (p<0.001)	7.131	6.913 to 7.350	4.414	9.849	<0.001	y = 5.128 + .279 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.824 (p<0.001)	−8.779	−9.026 to −8.532	−11.852	−5.706	<0.001	y = −1.789 + −.462 x	<0.001
	Left lower limb	DXA vs BIA	0.878 (p<0.001)	−.443	−0.572 to −0.314	−2.043	1.157	<.001	y = −2.187 + 0.163 x	<.001
		DXA vs ANT Ritchie et al.	0.644 (p<0.001)	7.018	6.808 to 7.227	4.411	9.624	<0.001	y = 5.050 + .281 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.835 (p<0.001)	−8.828	−9.063 to −8.592	−11.761	−5.894	<0.001	y = −2.160 + −.447 x	<0.001
	FEMALES (*n*=101)									
	Trunk	DXA vs BIA	0.868 (p<0.001)	−7.617	−7.956 to −7.278	−10.981	−4.253	<.001	y = −1.776 + −0.258 x	<.001
		DXA vs ANT Ritchie et al.	0.809 (p<0.001)	9.804	9.287 to 1.321	4.672	14.936	<0.001	y = 16.802 + −.501 x	<0.001
	Right upper limb	DXA vs BIA	0.795 (p<0.001)	−.200	−0.240 to −0.16	−0.591	0.191	<.001	y = −0.152 + −0.025 x	.719
		DXA vs ANT Ritchie et al.	0.609 (p<0.001)	0.575	.505 to .645	−0.124	1.274	<0.001	y = 1.298 + −.454 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.855 (p<0.001)	−1.715	−1.827 to −1.603	−2.825	−0.604	<0.001	y = .887 + −.9501 x	<0.001
	Left upper limb	DXA vs BIA	0.811 (p<0.001)	−.300	−0.337 to −0.264	−0.665	0.064	<.001	y = −0.271 + −0.016 x	.811
		DXA vs ANT Ritchie et al.	0.581 (p<0.001)	0.422	.352 to .491	−0.268	1.111	<0.001	y = 1.089 + −.438 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.838 (p<0.001)	−1.829	−1.952 to −1.707	−3.047	−0.611	<0.001	y = .872 + −1.020 x	<0.001
	Right lower limb	DXA vs BIA	0.830 (p<0.001)	−.155	−0.266 to −0.043	−1.261	0.952	.007	y = −2.064 + 0.271 x	<.001
		DXA vs ANT Ritchie et al.	0.684 (p<0.001)	2.303	2.065 to 2.540	−0.056	4.661	<0.001	y = 5.579 + −.563 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.844 (p<0.001)	−6.614	−6.964 to −6.263	−10.090	−3.137	<0.001	y = 2.870 + −.923 x	<0.001
	Left lower limb	DXA vs BIA	0.849 (p<0.001)	−.251	−0.354 to −0.148	−1.272	0.770	<.001	y = −1.794 + 0.221 x	<.001
		DXA vs ANT Ritchie et al.	0.678 (p<0.001)	2.303	2.063 to 2.543	−0.086	4.693	<0.001	y = 5.695 + −.594 x	<0.001
		DXA vs ANT Scafoglieri et al.	0.828 (p<0.001)	−6.985	−7.350 to −6.620	−10.610	−3.360	<0.001	y = 2.973 + −.962 x	<0.001

(*Continued*)

Table 7. (Continued).

Variable	Body segment	Method	Pearson´s r (p)	Mean diff	95% CI	95% Limits of agreement		p	Regression equation	p
						Lower limit	Upper limit			
LSM (kg)	**GENERAL SAMPLE (*n*=258)**									
	Trunk	DXA vs BIA	0.953 (p<0.001)	−6.413	−6.604 to −6.221	−9.474	−3.351	<.001	y = −8.295 + 0.071 x	<.001
	Right upper limb	DXA vs BIA	0.962 (p<0.001)	−.294	−0.328 to −0.259	−0.841	0.253	<.001	y = −0.182 + −0.038 x	.030
	Left upper limb	DXA vs BIA	0.960 (p<0.001)	−.358	−0.392 to −0.324	−0.903	0.187	<.001	y = −0.312 + −0.016 x	.358
	Right lower limb	DXA vs BIA	0.949 (p<0.001)	−.199	−0.287 to −0.112	−1.596	1.197	<.001	y = −0.591 + 0.044 x	.031
	Left lower limb	DXA vs BIA	0.950 (p<0.001)	−.326	−0.410 to −0.242	−1.669	1.016	<.001	y = −0.560 + 0.027 x	.183
	MALES (*n*=157)									
	Trunk	DXA vs BIA	0.921 (p<0.001)	−6.084	−6.306 to −5.862	−8.843	−3.325	<.001	y = −9.981 + 0.132 x	<.001
	Right upper limb	DXA vs BIA	0.865 (p<0.001)	−.334	−0.384 to −0.285	−0.953	0.284	<.001	y = −0.474 + 0.039 x	.375
	Left upper limb	DXA vs BIA	0.859 (p<0.001)	−.382	−0.433 to −0.332	−1.014	0.250	<.001	y = −0.581 + 0.057 x	.202
	Right lower limb	DXA vs BIA	0.874 (p<0.001)	−.248	−0.374 to −0.122	−1.813	1.316	<.001	y = −2.215 + 0.191 x	<.001
	Left lower limb	DXA vs BIA	0.880 (p<0.001)	−.400	−0.521 to −0.278	−1.911	1.111	<.001	y = −2.159 + 0.173 x	<.001
	FEMALES (*n*=101)									
	Trunk	DXA vs BIA	0.861 (p<0.001)	−6.924	−7.251 to −6.597	−10.171	−3.677	<.001	y = −1.854 + −0.233 x	<.001
	Right upper limb	DXA vs BIA	0.788 (p<0.001)	−.230	−0.269 to −0.192	−0.613	0.152	<.001	y = −0.138 + −0.049 x	.477
	Left upper limb	DXA vs BIA	0.802 (p<0.001)	−.319	−0.356 to −0.283	−0.680	0.0414	<.001	y = −0.249 + −0.040 x	.554
	Right lower limb	DXA vs BIA	0.823 (p<0.001)	−.124	−0.232 to −0.015	−1.199	0.952	.026	y = −2.025 + 0.286 x	<.001
	Left lower limb	DXA vs BIA	0.843 (p<0.001)	−.212	−0.312 to −0.112	−1.206	0.782	<.001	y = −1.739 + 0.231 x	<.001

*SW: Segmental weight; FFM: Fat free Mass; LSM: Lean Soft Mass; kg: kilograms; DXA: Dual X-ray; BIA: bioelectrical impedance analysis; ANT: anthropometry.

Table 8. Regression models of segmental total body weight estimated by DXA using anthropometric variables in the male group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
Trunk SW	Model 1	0.915	<0.001	Body Mass	1668.229	0.957	<0.001	TTSW= −3.909+0.498*Body Mass
	Model 2	0.944	<0.001	Body Mass	1295.349	0.853	<0.001	TTSW= −2.561+0.444*Body Mass 0.250*Left Subscapular Skinfold
				Left Subscapular Skinfold		0.199	<0.001	
	Model 3	0.951	<0.001	Body Mass	986.003	0.716	<0.001	TTSW= −11.811+0.373*Body mass+0.275*Left subscapular sf+0.156*Right Chest Corrected Girth
				Left Subscapular Skinfold		0.219	<0.001	
				Right Chest Corrected Girth		0.153	<0.001	
Right upper limb SW	Model 1	0.872	<0.001	Right Arm Flexed and Tensed Girth	346.517	0.583	<0.001	TRULSW= −5.128+0.133*Right Arm Flexed and Tensed Girth+0.021*Body Mass+0.019*Arm Span
				Body Mass		0.318	<0.001	
				Arm Span		0.204	<0.001	
	Model 2	0.882	<0.001	Right Arm Flexed and Tensed Girth	283.770	0.554	<0.001	TRULSW= −6.024+0.126*Right Arm Flexed and Tensed Girth+0.018*Body Mass+0.015*Arm Span +0.278*Right Humerus Breadth(cm)
				Body Mass		0.278	<0.001	
				Arm Span		0.164	<0.001	
				Right Humerus Breadth		0.134	<0.001	
	Model 3	0.890	<0.001	Right Arm Flexed and Tensed Girth	245.092	0.308	<0.001	TRULSW= −5.285+0.070*Right Arm Flexed and Tensed Girth+0.022*Body Mass+0.012*Arm Span +0.258*Right Humerus Breadth+0.055*Right Arm Corrected Girth
				Body Mass		0.337	<0.001	
				Arm Span		0.133	<0.001	
				Right Humerus Breadth		0.125	0.001	
				Right Arm Corrected Girth		0.235	0.001	
Left arm SW	Model 1	0.852	<0.001	Left Forearm Girth	443.135	0.611	<0.001	TLULSW= −4.098+0.244*Left Forearm Girth+0.024*Body Mass
				Body Mass		0.358	<0.001	
	Model 2	0.877	<0.001	Left Forearm Girth	363.783	0.342	<0.001	TLULSW= −3.350+0.137*Left Forearm Girth+0.026*Body Mass+0.068*Left Arm Corrected Girth
				Body Mass		0.402	<0.001	
				Left Arm Corrected Girth		0.283	<0.001	
	Model 3	0.893	<0.001	Left Forearm Girth	318.707	0.376	<0.001	TLULSW= −5.71+0.151*Left Forearm Girth+0.020*Body Mass+0.067* Left Arm Corrected Girth+0.014*Arm Span
				Body Mass		0.299	<0.001	
				Left Arm Corrected Girth		0.277	<0.001	
				Arm Span		0.151	<0.001	
Right lower limb SW	Model 1	0.886	<0.001	Body Mass	600.719	0.857	<0.001	TRLLSW= −6.986+0.162*Body Mass+0.086*Right Trochanterion Height
				Right Trochanterion Height		0.211	<0.001	
	Model 2	0.910	<0.001	Body Mass	518.272	0.638	<0.001	TRLLSW= −13.203+0.121*Body Mass+0.099*Right Trochanterion Height+0.218*Right Calf Girth
				Right Trochanterion Height		0.243	<0.001	
				Right Calf Girth		0.262	<0.001	
	Model 3	0.920	<0.001	Body Mass	435.267	0.471	<0.001	TRLLSW= −16.642+0.089*Body Mass+0.120*Right Trochanterion Height+0.173*Right Calf Girth +0.100*Right Thigh Middle Girth
				Right Trochanterion Height		0.294	<0.001	
				Right Calf Girth		0.209	<0.001	
				Right Thigh Middle Girth		0.226	<0.001	

(*Continued*)

Table 8. (Continued).

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
Left lower limb SW	Model 1	0.870	<0.001	Body Mass	516.785	0.843	<0.001	TLLLSW = −7.305+0.159*Body Mass+0.088*Left Iliospinale Height
				Left Iliospinale Height		0.206	<0.001	
	Model 2	0.893	<0.001	Body Mass	426.031	0.599	<0.001	TLLLSW= −14.231+0.113*Body Mass+0.103*Left Iliospinale Height+0.240*Left Calf Girth
				Left Iliospinale Height		0.242	<0.001	
				Left Calf Girth		0.278	<0.001	
	Model 3	0.903	<0.001	Body Mass	355.701	0.368	<0.001	TLLLSW= −19.133+0.070*Body Mass+0.128*Left Iliospinale Height+0.236*Left Calf Girth+0.100*Left 1cm Gluteal Thigh Girth
				Left Iliospinale Height		0.301	<0.001	
				Left Calf Girth		0.273	<0.001	
				Left 1cm Gluteal Thigh Girth		0.245	<0.001	

*SW: Segmental weight; TTSW: Total trunk segmental weight; TRULSW: Total right upper limb segmental weight; TLULSW: Total left upper limb segmental weight; TRLLSW: Total Right lower limb segmental weight; TLLLSW: Total Left lower limb segmental weight.

These hormonal differences result in different patterns of body composition and mass distribution between the sexes that may affect comparability between methods [88,89].

The second objective of this study was to assess the agreement of BIA and two anthropometric equations in comparison with DXA, which was chosen as the reference method due to its high accuracy and low measurement variability, as supported by previous studies [22,79–81]. Additionally, the hydration status of all participants was controlled, ensuring they were well-hydrated before measurements, minimizing its potential impact on the comparison between BIA and DXA [37,38,57]. The Bland-Altman analysis indicated that most methods did not demonstrate agreement in estimating SW, FFM, and LSM as compared to DXA, with the only exception being BIA, which showed agreement when estimating SW in the right upper limb in females. The lack of agreement between DXA and BIA may be partially explained by the differences in the operating principles of the devices, as previously mentioned [17,22,40,66]. Furthermore, differences in the software used to process the data between both methods could also have influenced the results [18,90]. Future studies should examine how the application of various BIA formulas might improve the agreement with DXA in the body segments analyzed.

Regarding the anthropometric equations, several factors could explain the lack of agreement with the DXA values. The equation of Ritchie et al. [45] utilized a different DXA instrument model, specifically the LUNAR DXA (GE Medical Systems), which differs from the Hologic Horizon used in the present study [45]. Previous research has demonstrated that different DXA instrument models can produce significantly different estimates [90,91]. Moreover, Ritchie et al. [45] did not specify the anthropometric protocol used, which may have led to measurements being taken at different sites as compared to the ISAK protocol followed in this study [45,76]. Additionally, their division of body segments was different from the present study, as the authors subdivided the trunk into chest, waist, and hips, and the lower limbs into upper leg and calf [45]. This variation in body segmentation could have contributed to the lack of agreement, since it was necessary to integrate their segments into the groups we used in order to make comparisons in this study. In the case of Scafoglieri et al. [44] both the DXA instrument models and the software used were different. That study employed the Hologic QDR model with software for Windows XP (version 12.4.3) [44], whereas this study used the Hologic Horizon and APEX 13.6.0.5 software. Previous studies have shown that different DXA instrument models and software versions can yield divergent results [90]. Additionally, Scafoglieri's equation estimated both arms and legs simultaneously, which may have limited its precision when applied to individual segments, as was done in this study [44].

The third objective of the present study was to develop prediction equations using ANT to estimate SW, FFM, and LSM in kg and percentages, based on the results obtained by DXA as a gold standard. In the SW analysis of both males and females, body mass was present in all the prediction equations in the different segments. This could be because body mass reflects the sum of fat, muscle, bone, and residual mass, which explains why it is the variable that most predicts SW for all segments [17]. However, for the upper limbs in the male group, the body mass variable alone did not achieve a sufficient level of prediction. Thus, the right

Table 9. Regression models of segmental total body weight estimated by DXA using anthropometric variables in the female group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
Trunk SW	Model 1	0.936	<0.001	Body Mass	1444.372	0.967	<0.001	TTSW=−5.790+0.537*Body Mass
	Model 2	0.954	<0.001	Body Mass	1011.709	0.827	<0.001	TTSW=−3.234+0.459*Body mass+0.144*Right subscapular skinfold
				Right Subscapular Skinfold		0.194	<0.001	
	Model 3	0.961	<0.001	Body Mass	797.221	0.725	<0.001	TTSW=−6.949+0.403*Body Mass+0.104*Right Subscapular Skinfold+0.440*Antero-posterior Chest Depth
				Right Subscapular Skinfold		0.140	<0.001	
				Antero-posterior Chest Depth		0.169	<0.001	
Right upper limb SW	Model 1	0.879	<0.001	Body Mass	716.683	0.937	<0.001	TRULSW=−0.191+0.051*Body Mass
	Model 2	0.927	<0.001	Body Mass	626.034	0.584	<0.001	TRULSW=−1.321+0.032*Body Mass+0.083*Right Arm Flexed and Tensed Girth
				Right Arm Flexed and Tensed Girth		0.416	<0.001	
	Model 3	0.942	<0.001	Body Mass	525.716	0.430	<0.001	TRULSW=−2.708+0.023*Body Mass+0.086*Right Arm Flexed and Tensed Girth+0.125*Right Wrist Girth
				Right Arm Flexed and Tensed Girth		0.433	<0.001	
				Right Wrist Girth		0.186	<0.001	
Left upper limb SW	Model 1	0.877	<0.001	Body Mass	708.609	0.937	<0.001	TLULSW=−0.264+0.050*Body Mass
	Model 2	0.932	<0.001	Body Mass	673.433	0.516	<0.001	TLULSW=−2.612+0.028*Body Mass+0.163*Left Forearm Girth
				Left Forearm Girth		0.481	<0.001	
	Model 3	0.943	<0.001	Body Mass	531.563	0.479	<0.001	TLULSW=−2.407+0.026*Body Mass+0.104*Left Forearm Girth+0.047*Left Arm Flexed and Tensed Girth
				Left Forearm Girth		0.306	<0.001	
				Left Arm Flexed and Tensed Girth		0.232	<0.001	
Right lower limb SW	Model 1	0.873	<0.001	Body Mass	335.649	0.857	<0.001	TRLLSW=−4.917+0.148*Body Mass+0.083*Right Iliospinale Height
				Right Iliospinale Height		0.211	<0.001	
	Model 2	0.890	<0.001	Body Mass	261.356	0.638	<0.001	TRLLSW=−9.797+0.085*Body Mass+0.098*Right Iliospinale Height+0.125*Right 1cm Gluteal Thigh Girth
				Right Iliospinale Height		0.243	<0.001	
				Right 1cm Gluteal Thigh Girth		0.262	<0.001	
	Model 3	0.904	<0.001	Body Mass	226.888	0.471	<0.001	TRLLSW=−11.499+0.080*Body Mass+0.089*Right Iliospinale Height+0.116*Right 1cm Gluteal Thigh Girth +0.113*Right Calf Corrected Girth
				Right Iliospinale Height		0.294	<0.001	
				Right 1cm Gluteal Thigh Girth		0.209	<0.001	
				Right Calf Corrected Girth		0.226	<0.001	
Left lower limb SW	Model 1	0.870	<0.001	Body Mass	328.527	0.821	<0.001	TLLLSW=−5.937+0.143*Body Mass+0.095*Left Iliospinale Height
				Left Iliospinale Height		0.230	<0.001	
	Model 2	0.888	<0.001	Body Mass	257.438	0.562	<0.001	TLLLSW=−10.303+0.098*Body Mass+0.101*Left Iliospinale Height+0.186*Left Calf Girth
				Left Iliospinale Height		0.246	<0.001	
				Left Calf Girth		0.287	<0.001	
	Model 3	0.907	<0.001	Body Mass	233.240	0.208	<0.001	TLLLSW=−17.449+0.036*Body Mass+0.117*Left Iliospinale Height+0.193*Left Calf Girth+0.094*Hips Girth
				Left Iliospinale Height		0.284	<0.001	
				Left Calf Girth		0.300	<0.001	
				Hips Girth		0.357	<0.001	

*SW: Segmental weight; TTSW: Total trunk segmental weight; TRULSW: Total tight upper limb segmental weight; TLULSW: Total left upper limb segmental weight; TRLLSW: Total Right lower limb segmental weight; TLLLSW: Total Left lower limb segmental weight.

Table 10. Regression models of segmental fat free mass estimated by DXA using anthropometric variables in the male group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
FFM trunk	Model 1	0.854	<0.001	Body Mass	222.172	1.241	<0.001	FFMT=15.335+0.419*Body Mass-0.150*Hips Girth-0.556*Waist Girth+0.516*Left Waist Corrected Girth
				Hips Girth		−0.252	0.004	
				Waist Girth		−1.050	<0.001	
				Left Waist Corrected Girth		0.850	<0.001	
	Model 2	0.860	<0.001	Body Mass	185.677	1.092	<0.001	FFMT=8.026+0.368*Body Mass-0.116*Hips Girth-0.535*Waist Girth+0.469*Left Waist Corrected Girth+0.105*Right Chest Corrected Girth
				Hips Girth		−0.194	0.028	
				Waist Girth		−1.011	<0.001	
				Left Waist Corrected Girth		0.773	<0.001	
				Right Chest Corrected Girth		0.157	0.011	
	Model 3	0.872	<0.001	Body Mass	169.961	1.097	*p*<0.001	FFMT=5.903+0.307*Body Mass-0.115*Hips Girth-0.289*Waist Girth+0.293*Left Waist Corrected Girth+0.548*Right Chest Corrected Girth-0.437*Chest Girth
				Hips Girth		−0.193	0.023	
				Waist Girth		−0.546	0.003	
				Left Waist Corrected Girt		0.482	0.003	
				Right Chest Corrected Girth		0.824	<0.001	
				Chest Girth		−0.807	<0.001	
FFM right upper limb	Model 1	0.856	<0.001	Right Arm Corrected Girth	456.163	0.753	<0.001	FFMRUL=−6.572+0.155*Right Arm Corrected Girth+0.032*Arm Span
				Arm Span		0.388	<0.001	
	Model 2	0.879	<0.001	Right Arm Corrected Girth	372.185	0.715	<0.001	FFMRUL=−6.930+0.147*Right Arm Corrected Girth+0.024*Arm Span+0.379*Right Bi-Styloid Breadth
				Arm Span		0.285	<0.001	
				Right Bi-Styloid Breadth		0.195	<0.001	
	Model 3	0.886	<0.001	Right Arm Corrected Girth	294.853	0.715	<0.001	FFMRUL=−7.084+0.147*Right Arm Corrected Girth+0.017*Arm Span+0.316*Right Bi-Styloid Breadth+0.086*Right Midstylion-dactylion Length
				Arm Span		0.202	<0.001	
				Right Bi-Styloid Breadth		0.162	<0.001	
				Right Midstylion-dactylion Length		0.132	0.004	
FFM left upper limb	Model 1	0.869	<0.001	Left Arm Corrected Girth	337.435	0.703	<0.001	FFMLUL=−7.227+0.152*Left Arm Corrected Girth +0.026*Arm Span+0.324*Left Bi-Styloid Breadth
				Arm Span		0.309	<0.001	
				Left Bi-Styloid Breadth		0.172	<0.001	
	Model 2	0.874	<0.001	Left Arm Corrected Girth	262.432	0.554	<0.001	FFMLUL=−7.501+0.120*Left Arm Corrected Girth +0.026*Arm Span+0.325*Left Bi-Styloid Breadth+0.034*Left Arm Flexed and Tensed Girth
				Arm Span		0.312	<0.001	
				Left Bi-Styloid Breadth		0.173	<0.001	
				Left Arm Flexed and Tensed Girth		0.163	0.017	
	Model 3	0.884	<0.001	Left Arm Corrected Girth	231.229	0.542	<0.001	FFMLUL=−7.198+0.117*Left Arm Corrected Girth +0.026*Arm Span+0.271*Left Bi-Styloid Breadth+0.108*Left Arm Flexed and Tensed Girth-0.075*Left Arm Relaxed Girth
				Arm Span		0.309	<0.001	
				Left Bi-Styloid Breadth		0.144	<0.001	
				Left Arm Flexed and Tensed Girth		0.524	<0.001	
				Left Arm Relaxed Girth		−0.358	<0.001	

(*Continued*)

Table 10. (Continued).

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
FFM right lower limb	Model 1	0.801	<0.001	Right Calf Corrected Girth	205.149	0.313	<0.001	FFMRLL=−21.228+0.224*Right Calf Corrected Girth+0.163*Right Trochanterion Height +0.161*Right Thigh Corrected Girth
				Right Trochanterion Height		0.483	<0.001	
				Right Thigh Corrected Girth		0.396	<0.001	
	Model 2	0.810	<0.001	Right Calf Corrected Girth	162.334	0.281	<0.001	FFMRLL=−22.161+0.201*Right Calf Corrected Girth+0.137*Right Trochanterion Height +0.158*Right Thigh Corrected Girth +0.174*Right Foot(cm)
				Right Trochanterion Height		0.404	<0.001	
				Right Thigh Corrected Girth		0.388	<0.001	
				Right Foot		0.137	0.007	
	Model 3	0.816	<0.001	Right Calf Corrected Girth	133.572	0.263	<0.001	FFMRLL=−21.224+0.189*Right Calf Corrected Girth+0.129*Right Trochanterion Height +0.215*Right Thigh Corrected Girth +0.190*Right Foot-0.055 Right Thigh Middle Girth
				Right Trochanterion Height		0.382	<0.001	
				Right Thigh Corrected Girth		0.528	<0.001	
				Right Foot		0.149	0.003	
				Right Thigh Middle Girth		−0.149	0.039	
	Model 4	0.822	<0.001	Right Calf Corrected Girth	115.666	0.208	<0.001	FFMRLL=−21.588+0.149*Right Calf Corrected Girth+0.127*Right Trochanterion Height +0.234*Right Thigh Corrected Girth +0.151*Right Foot-0.088*Right Thigh Middle Girth+0.170*Right Ankle Girth
				Right Trochanterion Height		0.375	<0.001	
				Right Thigh Corrected Girth		0.575	<0.001	
				Right Foot		0.118	0.020	
				Right Thigh Middle Girth		−0.240	0.003	
				Right Ankle Girth		0.133	0.019	
	Model 5	0.828	<0.001	Right Calf Corrected Girth	102.415	0.187	0.001	FFMRLL=−18.260+0.134*Right Calf Corrected Girth+0.117*Right Trochanterion Height +0.253*Right Thigh Corrected Girth +0.103*Right Foot-0.156*Right Thigh Middle Girth+0.162*Right Ankle Girth+0.031*Body Mass
				Right Trochanterion Height		0.346	<0.001	
				Right Thigh Corrected Girth		0.621	<0.001	
				Right Foot		0.081	0.127	
				Right Thigh Middle Girth		−0.426	<0.001	
				Right Ankle Girth		0.127	0.023	
				Body Mass		0.197	0.028	
	Model 6	0.825	<0.001	Right Calf Corrected Girth	118.024	0.190	0.001	FFMRLL=−17.188+0.136*Right Calf Corrected Girth+0.128*Right Trochanterion Height +0.257*Right Thigh Corrected Girth-0.173*Right Thigh Middle Girth+0.187*Right Ankle Girth+0.038*Body Mass
				Right Trochanterion Height		0.378	<0.001	
				Right Thigh Corrected Girth		0.632	<0.001	
				Right Thigh Middle Girth		−0.470	<0.001	
				Right Ankle Girth		0.146	0.008	
				Body Mass		0.241	0.005	

(*Continued*)

Table 10. (Continued).

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
FFM left lower limb	Model 1	0.783	<0.001	Left Thigh Corrected Girth	184.173	0.369	<0.001	FFMLLL=−25.114+0.156*Left Thigh Corrected Girth+0.117*Stretch Stature+0.207*Left Calf Corrected Girth
				Stretch Stature		0.463	<0.001	
				Left Calf Corrected Girth		0.279	<0.001	
	Model 2	0.803	<0.001	Left Thigh Corrected Girth	154.451	0.377	<0.001	FFMLLL=−24.213+0.159*Left Thigh Corrected Girth+0.079*Stretch Stature+0.181*Left Calf Corrected Girth+0.262*Left Foot
				Stretch Stature		0.311	<0.001	
				Left Calf Corrected Girth		0.243	<0.001	
				Left Foot		0.216	<0.001	
	Model 3	0.815	<0.001	Left Thigh Corrected Girth	133.034	0.589	<0.001	FFMLLL=−22.985+0.249*Left Thigh Corrected Girth+0.076*Stretch Stature+0.174*Left Calf Corrected Girth+0.254*Left Foot-0.087*Left Thigh Middle Girth
				Stretch Stature		0.300	<0.001	
				Left Calf Corrected Girth		0.234	<0.001	
				Left Foot		0.210	<0.001	
				Left Thigh Middle Girth		−0.230	0.002	
	Model 4	0.824	<0.001	Left Thigh Corrected Girth	116.760	0.558	<0.001	FFMLLL=−22.505+0.236*Left Thigh Corrected Girth+0.032*Stretch Stature+0.198*Left Calf Corrected Girth+0.230*Left Foot±0.075*Left Thigh Middle Girth+0.071*Left Iliospinale Height
				Stretch Stature		0.126	0.131	
				Left Calf Corrected Girth		0.267	<0.001	
				Left Foot		0.190	0.001	
				Left Thigh Middle Girth		−0.198	0.006	
				Left Iliospinale Height		0.204	0.007	
	Model 5	0.821	<0.001	Left Thigh Corrected Girth	138.453	0.554	<0.001	FFMLLL=−21.238+0.234*Left Thigh Corrected Girth+0.210*Left Calf Corrected Girth +0.263*Left Foot-0.072*Left Thigh Middle Girth +0.102*Left Iliospinale Height
				Left Calf Corrected Girth		0.283	<0.001	
				Left Foot		0.218	<0.001	
				Left Thigh Middle Girth		−0.189	0.009	
				Left Iliospinale Height		0.292	<0.001	

*FFM: Fat free mass; FFMT: Fat free mass trunk; FFMRUL: Fat free mass light upper limb; FFMLUL: Fat free mass left upper limb; FFMRLL: Fat free mass right lower limb; FFMLLL: Fat free mass left lower limb.

upper limb SW equation included right arm flexed and tensed girth and arm span, while the left upper limb SW equation included left forearm girth. The inclusion of the girths could be because these variables in limbs are an indicator of FFM [24,32]. The presence of arm span suggests that the length of the upper limbs significantly contributes to the overall weight of the upper limbs. This is likely because longer limbs have more bone and muscle mass, which increases their overall weight, making arm span a relevant predictor of upper limb SW [92].

Body mass also did not have a sufficient level of prediction along for the prediction of lower limb SW in either sex. Thus, trochanterion height was included in the right lower limb SW equation in males, while iliospinale height was included in the left lower limb SW equation for males, and both right and left lower limb SW for females. The inclusion of both heights highlights the importance of limb length in estimating SW. Longer limbs have greater muscle and bone mass, which increases their total weight [92]. Therefore, these height measurements are critical for accurately predicting lower limb SW, as they take into account the distribution of muscle and bone mass throughout the limbs [92].

Body mass also played an important role to consider in trunk FFM and LSM for both males and females. However, in both cases, other variables had to be included to obtain a meaningful model. In this sense, hip girth and waist girth were inversely related to trunk FFM and LSM in both males and females. Hip and waist girth are related with abdominal fat mass in this area [93,94], which could justify its opposite influence on FFM and LSM. Furthermore, left waist corrected girth was directly related with trunk FFM and LSM in males. Corrected girths are indicators of musculoskeletal development [24,32,43], which together with the fact that males have a greater tendency to hypertrophy than females [24,32,92,95,96], explains why it predicts FFM and LSM for the trunk in males. In the case of females, the right abdominal skinfold, left subscapular skinfold, and stretch stature, were inversely related to trunk FFM and LSM. This inverse relationship can be explained by the fact that higher trunk skinfold measurements indicate higher fat mass, which reduces the proportion of lean mass in the trunk [32,52,97]. Additionally, stretch stature, being inversely related, suggests that taller

Table 11. Regression models of segmental fat free mass estimated by DXA using anthropometric variables in the female group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
FFM trunk	Model 1	0.853	<0.001	Body Mass	138.959	1.229	<0.001	FFMT=11.135+0.315*Body Mass-0.082*Right Abdominal Skinfold-0.107*Left Subscapular Skinfold-0.053*Stretch Stature
				Right Abdominal Skinfold		−0.214	0.001	
				Left Subscapular Skinfold		−0.237	0.002	
				Stretch Stature		−0.123	0.016	
	Model 2	0.864	<0.001	Body Mass	120.755	1.509	<0.001	FFMT=19.771+0.387* Body Mass-0.067*Right Abdominal Skinfold-0.120*Left Subscapular Skinfold-0.066*Stretch Stature-0.111*Hips Girth
				Right Abdominal Skinfold		−0.176	0.004	
				Left Subscapular Skinfold		−0.265	0.001	
				Stretch Stature		−0.154	0.002	
				Hips Girth		−0.288	0.006	
FFM right upper limb	Model 1	0.709	<0.001	Right Arm Corrected Girth	78.654	0.655	<0.001	FFMRUL=−3.005+0.091* Right Arm Corrected Girth+0.011* Arm Span+0.241*Right Bi-Styloid Breadth
				Arm Span		0.257	<0.001	
				Right Bi-Styloid Breadth		0.234	<0.001	
FFM left upper limb	Model 1	0.723	<0.001	Left Arm Corrected Girth	62.717	0.669	<0.001	FFMLUL=−3.107+0.093*Left Arm Corrected Girth+0.069*Left Midstylion-dactylion Lenghth+0.0162* Left Bi-Styloid Breadth+0.036*Left Radiale Stylion Length
				Left Midstylion-dactylion Length		0.216	0.005	
				Left Bi-Styloid Breadth		0.170	0.016	
				Left Radiale Stylion Length		0.141	0.034	
FFM right lower limb	Model 1	0.756	<0.001	Right Thigh Corrected Girth	99.961	0.433	<0.001	FFMRLL=−8.952+0.113*Right Thigh Corrected Girth+0.317*Left Foot+0.129*Right Calf Corrected Girth
				Left Foot		0.352	<0.001	
				Right Calf Corrected Girth		0.288	<0.001	
	Model 2	0.774	<0.001	Right Thigh Corrected Girth	82.308	0.443	<0.001	FFMRLL=−11.180+0.115*Right Thigh Corrected Girth+0.194*Left Foot+0.126*Right Calf Corrected Girth+0.031*Stretch Stature
				Left Foot		0.216	0.004	
				Right Calf Corrected Girth		0.281	<0.001	
				Stretch Stature		0.193	0.006	
FFM left lower limb	Model 1	0.790	<0.001	Left Calf Corrected Girth	90.424	0.356	<0.001	FFMLLL=−9.792+0.157* Left Calf Corrected Girth+0.146*Left Foot+0.092*Left Thigh Corrected Girth+0.052*Left Iliospinale Height
				Left Foot		0.208	0.002	
				Left Thigh Corrected Girth		0.362	<0.001	
				Left Iliospinale Height		0.231	<0.001	
	Model 2	0.799	<0.001	Left Calf Corrected Girth	75.634	0.421	<0.001	FFMLLL=−9.810+0.186*Left Calf Corrected Girth+0.160*Left Foot+0.113*Left Thigh Corrected Girth+0.053*Left Iliospinale Height-0.060*Left Calf Girth
				Left Foot		0.229	0.001	
				Left Thigh Corrected Girth		0.442	<0.001	
				Left Iliospinale Height		0.237	<0.001	
				Left Calf Girth		−0.172	0.042	
	Model 3	0.811	<0.001	Left Calf Corrected Girth	67.135	0.526	<0.001	FFMLLL=−7.442+0.232*Left Calf Corrected Girth+0.140*Left Foot+0.086*Left Thigh Corrected Girth+0.042*Left Iliospinale Height-0.144*Left Calf Girth+0.029*Body Mass
				Left Foot		0.200	0.003	
				Left Thigh Corrected Girth		0.336	<0.001	
				Left Iliospinale Height		0.190	0.003	
				Left Calf Girth		−0.412	0.002	
				Body Mass		0.306	0.019	

*FFM: Fat free mass; FFMT: Fat free mass trunk; FFMRUL: Fat free mass right upper limb; FFMLUL: Fat free mass left upper limb; FFMRLL: Fat free mass right lower limb; FFMLLL: Fat free mass Left lower limb.

Table 12. Regression models of segmental lean soft mass estimated by DXA using anthropometric variables in the male group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
LSM trunk	Model 1	0.851	$p<0.001$	Body Mass	217.742	1.232	<0.001	LSMT=14.678+0.404*Body Mass-0.145*Hips Girth-0.539*Waist Girth+0.505*Left Waist Corrected Girth
				Hips Girth		−0.250	0.005	
				Waist Girth		−1.048	<0.001	
				Left Waist Corrected Girth		0.856	<0.001	
	Model 2	0.858	$p<0.001$	Body Mass	181.732	1.083	<0.001	LSMT=7.619+0.355*Body Mass-0.112*Hips Girth-0.519*Waist Girth+0.460*Left Waist Corrected Girth +0.101*Right Chest Corrected Girth
				Hips Girth		−0.193	0.030	
				Waist Girth		−1.008	<0.001	
				Left Waist Corrected Girth		0.780	<0.001	
				Right Chest Corrected Girth		0.156	0.012	
	Model 3	0.868	$p<0.001$	Body Mass	164.765	1.088	<0.001	LSMT=5.637+0.357*Body Mass-0.111*Hips Girth-0.289*Waist Girth+0.295*Left Waist Corrected Girth +0.515*Right Chest Corrected Girth-0.442*Chest Girth
				Hips Girth		−0.192	0.025	
				Waist Girth		−0.562	0.003	
				Left Waist Corrected Girth		−0.501	0.002	
				Right Chest Corrected Girth		0.796	<0.001	
				Chest Girth		−0.775	0.001	
LSM right upper limb	Model 1	0.855	$p<0.001$	Right Arm Corrected Girth	452.652	0.760	<0.001	LSMRUL=−6.219+0.150*Right Arm Corrected Girth +0.030*Arm Span
				Arm Span		0.376	<0.001	
	Model 2	0.878	$p<0.001$	Right Arm Corrected Girth	368.248	0.722	<0.001	LSMRUL=−6.560+0.143*Right Arm Corrected Girth +0.022*Arm Span+0.362*Right Bi-Styloid Breadth
				Arm Span		0.273	<0.001	
				Right Bi-Styloid Breadth		0.194	<0.001	
	Model 3	0.885	$p<0.001$	Right Arm Corrected Girth	292.567	0.722	<0.001	LSMRUL=−6.712+0.143*Right Arm Corrected Girth +0.015*Arm Span+0.300*Right Bi-Styloid Breadth +0.085*Right Midstylion-dactylion Length
				Arm Span		0.188	<0.001	
				Right Bi-Styloid Breadth		0.161	<0.001	
				Right Midstylion-dactylion Length		0.135	0.003	
LSM left upper limb	Model 1	0.864	$p<0.001$	Left Arm Corrected Girth	324.557	0.710	<0.001	LSMLUL=−6.842+0.147*Left Arm Corrected Girth +0.024*Arm Span+0.303*Left Bi-Styloid Breadth
				Arm Span		0.300	<0.001	
				Left Bi-Styloid Breadth		0.168	<0.001	
	Model 2	0.869	$p<0.001$	Left Arm Corrected Girth	252.218	0.560	<0.001	LSMLUL=−7.107+0.116*Left Arm Corrected Girth +0.024*Arm Span+0.305*Left Bi-Styloid Breadth +0.032*Left Arm Flexed and Tensed Girth
				Arm Span		0.302	<0.001	
				Left Bi-Styloid Breadth		0.169	<0.001	
				Left Arm Flexed and Tensed Girth		0.164	0.019	
	Model 3	0.885	$p<0.001$	Left Arm Corrected Girth	233.244	0.217	0.030	LSMLUL=−6.779+0.045*Left Arm Corrected Girth +0.025*Arm Span+0.220*Left Bi-Styloid Breadth +0.100*Left Arm Flexed and Tensed Girth-0.029*Left Triceps Skinfold
				Arm Span		0.313	<0.001	
				Left Bi-Styloid Breadth		0.122	0.001	
				Left Arm Flexed and Tensed Girth		0.504	<0.001	
				Left Triceps Skinfold		−0.203	<0.001	

(*Continued*)

Table 12. (Continued).

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
LSM right lower limb	Model 1	0.795	$p<0.001$	Right Calf Corrected Girth	198.291	0.315	<0.001	LSMRLL=−19.988+0.214*Right Calf Corrected Girth +0.153*Right Trochanterion Height+0.152*Right Thigh Corrected Girth
				Right Trochanterion Height		0.476	<0.001	
				Right Thigh Corrected Girth		0.395	<0.001	
	Model 2	0.803	$p<0.001$	Right Calf Corrected Girth	155.293	0.285	<0.001	LSMRLL=−20.803+0.194*Right Calf Corrected Girth +0.130*Right Trochanterion Height+0.150*Right Thigh Corrected Girth+0.152*Right Foot
				Right Trochanterion Height		0.404	<0.001	
				Right Thigh Corrected Girth		0.388	<0.001	
				Right Foot		0.126	0.014	
	Model 3	0.809	$p<0.001$	Right Calf Corrected Girth	127.769	0.268	<0.001	LSMRLL=−19.903+0.182*Right Calf Corrected Girth +0.123*Right Trochanterion Height+0.204*Right Thigh Corrected Girth+0.167*Right Foot-0.052*Right Thigh Middle Girth
				Right Trochanterion Height		0.381	<0.001	
				Right Thigh Corrected Girth		0.529	<0.001	
				Right Foot		0.138	0.007	
				Right Thigh Middle Girth		−0.151	0.040	
	Model 4	0.815	$p<0.001$	Right Calf Corrected Girth	110.076	0.243	<0.001	LSMRL=−16.644+0.165*Right Calf Corrected Girth +0.113*Right Trochanterion Height+0.224*Right Thigh Corrected Girth+0.118*Right Foot-0.121*Right Thigh Middle Girth+0.030Body Mass
				Right Trochanterion Height		0.350	<0.001	
				Right Thigh Corrected Girth		0.579	<0.001	
				Right Foot		0.098	0.067	
				Right Thigh Middle Girth		−0.347	0.003	
				Body Mass		0.204	0.028	
	Model 5	0.820	$p<0.001$	Right Calf Corrected Girth	97.191	0.194	0.001	LSMRL=−17.104+0.132*Right Calf Corrected Girth +0.111*Right Trochanterion Height+0.239*Right Thigh Corrected Girth+0.087*Right Foot-0.147*Right Thigh Middle Girth+0.029*Body Mass +0.145*Right Ankle Girth
				Right Trochanterion Height		0.346	<0.001	
				Right Thigh Corrected Girth		0.620	<0.001	
				Right Foot		0.072	0.003	
				Right Thigh Middle Girth		−0.421	<0.001	
				Body Mass		0.195	0.034	
				Right Ankle Girth		0.120	0.036	

(*Continued*)

Table 12. (Continued).

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
LSM left lower limb	Model 1	0.780	$p<0.001$	Left Thigh Corrected Girth	181.012	0.373	<0.001	LSMLLL=−23.714+0.150*Left Thigh Corrected Girth +0.110*Stretch Stature+0.197*Left Calf Corrected Girth
				Stretch Stature		0.457	<0.001	
				Left Calf Corrected Girth		0.279	<0.001	
	Model 2	0.799	$p<0.001$	Left Thigh Corrected Girth	151.382	0.381	<0.001	LSMLLL=−22.863+0.153*Left Thigh Corrected Girth +0.074*Stretch Stature+0.172*Left Calf Corrected Girth+0.247*Left Foot
				Stretch Stature		0.307	<0.001	
				Left Calf Corrected Girth		0.244	<0.001	
				Left Foot		0.215	<0.001	
	Model 3	0.812	$p<0.001$	Left Thigh Corrected Girth	130.287	0.387	<0.001	LSMLLL=−21.694+0.155*Left Thigh Corrected Girth +0.071*Stretch Stature+0.166*Left Calf Corrected Girth+0.239*Left Foot-0.026*Left Thigh Skinfold
				Stretch Stature		0.296	<0.001	
				Left Calf Corrected Girth		0.234	<0.001	
				Left Foot		0.208	<0.001	
				Left Thigh Skinfold		−0.113	0.002	
	Model 4	0.820	$p<0.001$	Left Thigh Corrected Girth	113.860	0.384	<0.001	LSMLLL=−21.252+0.154*Left Thigh Corrected Girth +0.031*Stretch Stature+0.188*Left Calf Corrected Girth+0.218*Left Foot-0.023*Left Thigh Skinfold +0.066*Left Iliospinale Height
				Stretch Stature		0.127	0.133	
				Left Calf Corrected Girth		0.266	<0.001	
				Left Foot		0.189	0.001	
				Left Thigh Skinfold		−0.098	0.007	
				Left Iliospinale Height		0.198	0.010	
	Model 5	0.817	$p<0.001$	Left Thigh Corrected Girth	135.033	0.388	<0.001	LSMLLL=−20.043+0.156*Left Thigh Corrected Girth +0.199*Left Calf Corrected Girth+0.249*Left Foot-0.022*Left Thigh Skinfold+0.095*Left Iliospinale Height
				Left Calf Corrected Girth(cm)		0.282	<0.001	
				Left Foot		0.217	<0.001	
				Left Thigh Skinfold		−0.094	0.009	
				Left Iliospinale Height		0.286	<0.001	

*LSM: Lean soft mass; LSMT: Lean soft mass trunk; LSMRUL: Lean soft mass right upper limb; LSMLUL: Lean soft mass left upper limb; LSMRL: Lean soft mass right lower limb; LSMLLL: Lean soft mass left lower limb.

females may have a lower FFM and LSM. The inverse relationship may be due to taller females tending to greatly distribute lean mass across their limbs rather than concentrating it in the trunk, leading to a lower proportion of trunk FFM and LSM [98]. Additionally, females generally have a predisposition to accumulate fat in the central region, including the abdomen and hips, due to influences from hormones such as estrogen [98,99]. Taller females may particularly exhibit this tendency of fat accumulation in the trunk, which could further reduce the relative amount of lean mass in that region, reinforcing the observed inverse relationship [98,99]. Given these preliminary results, some questions still remain.

The prediction models for both right and left upper limb FFM and LSM included arm corrected girth, arm span, and bi-styloid breadth in males. The same variables were significant predictors, with the addition of the midstylion-dactylion length for the left upper limb in females. The positive relationship of arm corrected girth suggests that a larger corrected arm girth, reflecting greater muscle mass, directly contributes to higher FFM and LSM [32,100]. Additionally, the inclusion of arm span indicates that a longer upper limb length, associated with more bone and muscle mass, plays a significant role in predicting upper limb composition [92]. Similarly, bi-styloid breadth further reinforces the influence of skeletal size on FFM and LSM [101,102]. The inclusion of midstylion-dactylion length in females suggests that hand size plays a crucial role in the distribution and estimation of FFM and LSM in the arms. Since the hands contain minimal FM, larger hands could contribute to a greater amount of fat-free mass in the upper limbs [32,92,103,104]. However, despite these predictors, the models for females did not reach the expected levels of accuracy ($R^2 = 0.688–0.723$), indicating that the estimation of FFM and LSM in the upper limbs may be less reliable in females.

In predicting both right and left lower limb FFM and LSM, both males and females had common predictors, such as calf corrected girth and thigh corrected girth, which are strong indicators of muscle

Table 13. Regression models of segmental lean soft mass estimated by DXA using anthropometric variables in the female group in kg.

Variable	Analysis	R^2	p value	Included independent variables	F	SC	p value	Equation
LSM trunk	Model 1	0.850	$p<0.001$	Body Mass	135.496	1.231	<0.001	LSMT=11.494+0.307*Body Mass-0.078*Right Abdominal Skinfold-0.104*Left Subscapular Skinfold-0.056*Stretch Stature
				Right Abdominal Skinfold		−0.209	0.001	
				Left Subscapular Skinfold		−0.237	0.003	
				Stretch Stature		−1.134	0.009	
	Model 2	0.861	$p<0.001$	Body Mass	117.738	1.513	<0.001	LSMT= 19.962+0.378*Body Mass-0.064*Right Abdominal Skinfold-0.116*Left Subscapular Skinfold-0.069*Stretch Stature-0.109*Hips Girth
				Right Abdominal Skinfold		−0.171	0.005	
				Left Subscapular Skinfold		−0.265	0.001	
				Stretch Stature		−0.166	0.001	
				Hips Girth		−0.291	0.006	
LSM right upper limb	Model 1	0.688	$p<0.001$	Right Arm Corrected Girth	71.334	0.659	<0.001	LSMLUL=−2.735+0.087*Right Arm Corrected Girth+0.010*Arm Span+0.217*Right Bi-Styloid Breadth
				Arm Span		0.241	<0.001	
				Right Bi-Styloid Breadth		0.221	0.001	
LSM left upper limb	Model 1	0.690	$p<0.001$	Left Arm Corrected Girth	72.040	0.679	<0.001	LSMLUL=−2.600+0.090*Left Arm Corrected Girth+0.085*Left Midstylion-dactylion Length+0.158Left Bi-Styloid Breadth
				Left Midstylion-dactylion Length		0.278	0.003	
				Left Bi-Styloid Breadth		0.173	0.003	
LSM right lower limb	Model 1	0.760	$p<0.001$	Right Thigh Corrected Girth	75.804	0.441	<0.001	LSMRLL=−10.229+0.109*Right Thigh Corrected Girth+0.177*Right Foot+0.126*Right Calf Corrected Girth +0.027*Stretch Stature
				Left Foot		0.206	0.007	
				Right Calf Corrected Girth		0.293	<0.001	
				Stretch Stature		0.175	0.015	
LSM left lower limb	Model 1	0.751	$p<0.001$	Left Calf Corrected Girth	97.634	0.390	<0.001	LSMLLL=−6.973+0.164*Left Calf Corrected Girth+0.228*Left Foot+0.078*Left Thigh Corrected Girth
				Left Foot		0.340	<0.001	
				Left Thigh Corrected Girth		0.322	<0.001	
	Model 2	0.778	$p<0.001$	Left Calf Corrected Girth	84.062	0.365	<0.001	LSMLLL=−9.095+0.154*Left Calf Corrected Girth+0.138*Left Foot+0.088*Left Thigh Corrected Girth+0.045*Left Iliospinale Height
				Left Foot		0.206	0.003	
				Left Thigh Corrected Girth		0.360	<0.001	
				Left Iliospinale Height		0.212	0.001	
	Model 3	0.789	$p<0.001$	Left Calf Corrected Girth	71.062	0.437	<0.001	LSMLLL=−9.114+0.184*Left Calf Corrected Girth+0.153*Left Foot+0.109*Left Thigh Corrected Girth+0.047*Left Iliospinale Height-0.064*Left Calf Girth
				Left Foot		0.229	0.001	
				Left Thigh Corrected Girth		0.449	<0.001	
				Left Iliospinale Height		0.218	0.001	
				Left Calf Girth		−0.192	0.028	
	Model 4	0.802	$p<0.001$	Left Calf Corrected Girth	63.377	0.547	<0.001	LSMLLL=−6.738+0.231*Left Calf Corrected Girth+0.133*Left Foot+0.082*Left Thigh Corrected Girth+0.036*Left Iliospinale Height-0.148*Left Calf Girth+0.029*Body Mass
				Left Foot		0.199	0.004	
				Left Thigh Corrected Girth		0.338	<0.001	
				Left Iliospinale Height		0.169	0.009	
				Left Calf Girth		−0.444	0.001	
				Body Mass		0.321	0.016	

*LSM: Lean soft mass; LSMT: Lean soft mass trunk; LSMRUL: Lean soft mass right upper limb; LSMLUL: Lean soft mass left upper limb; LSMRLL: Lean soft mass right lower limb; LSMLLL: Lean soft mass left lower limb.

mass in the lower extremities [32,100,101]. Additionally, measurements related to lower limb length, such as trochanterion height in males and iliospinale height in females, were included, highlighting the importance of skeletal structure in these estimates [92]. Furthermore, for males, the variable stretch stature was incorporated, emphasizing the relevance of total height in predicting FFM and LSM of the lower limbs [32,34,100]. Total height serves as an indicator of overall body size and significantly impacts the distribution of muscle and bone mass throughout the body. An increased height is typically associated with larger skeletal structures and a greater volume of muscle mass, thereby contributing to elevated levels of FFM and LSM in the lower limbs [34,105–107]. The prediction model for females also included foot length, suggesting that foot size plays a significant role in estimating FFM and LSM in the lower limbs. Given the minimal adipose tissue in the feet, a larger foot size likely contributes to an increased amount of fat-free mass in the lower limbs [32,92,108,109].

This study presents several innovative and relevant strengths for the assessment of body composition. Among them, we find that the current investigation offers an anthropometric strategy capable of estimating SW, FFM, and LSM, it analyses the influence of sex on this estimation, and validates the results with DXA. In addition, it introduces the first approach that takes into account the left and right side of the body for the generation of prediction equations for SW, FFM, and LSM in kg and percentages of each segment. This novel approach allows for the accurate estimation of FFM and LSM percentages in specific segments, offering a significant innovation and advance in ANT. Furthermore, this is the first study to analyze the differences obtained through the use of DXA, BIA, and ANT in the segmental masses. Another strength is that all the participants' hydration status was carefully controlled, ensuring accurate comparisons between methods such as DXA and BIA. The analysis of the differences between the regression models for SW, FFM, and LSM highlights the importance of considering sex and lateral differences in body composition. The dominance of the right side in most individuals may explain the variability in predictors between the right and left sides of the body, as the preferential use of one limb may influence the development of FFM and LSM [104]. This holistic approach allows for the identification of body asymmetries and personalized interventions based on the specific structure and composition of each body segment, marking an important advance in sports science and medicine.

The findings of this study carry significant practical implications for both sports and clinical settings. The comparison between DXA, BIA, and current anthropometric proposals demonstrates that these methods are not interchangeable for assessing SW, FFM, or LSM segmentally. This underscores the necessity for consistency in employing the same technique when evaluating an individual over time. The introduction of new anthropometric equations facilitates the segmental estimation of SW, FFM, and LSM, offering a viable alternative to DXA, which, while more precise, is also more costly [22,32]. This anthropometric approach presents practical advantages, as it is one of the most cost-effective and accessible methods for body composition assessment [22,24]. Segmental evaluations yield insights into the distribution of body composition across various regions, enabling tailored interventions in both athletic and clinical contexts [13,14]. In sports, the capacity to assess SW alongside segmental FFM and LSM allows for a comprehensive analysis of muscle and weight distribution [3,10]. This is vital for optimizing athletic performance, as SW reveals how different proportions of FFM and LSM contribute to each segment's ability to generate force and power [10,11]. Identifying imbalances enables coaches to target specific areas, enhancing symmetry, improving performance, and reducing injury risks [5,6]. In clinical environments, segmental assessments are crucial for monitoring changes in body composition, particularly during rehabilitation or body recomposition efforts [110,111]. Understanding the relative proportions of FFM and LSM within specific segments allows clinicians to track localized changes in response to treatment, exercise, or nutritional strategies [13,14,110]. This approach enhances the monitoring of muscle recovery, fat loss, and muscle gain across various body regions, facilitating personalized interventions to restore optimal health and functionality [13,14,111].

In terms of limitations, it is important to note that the anthropometric equations used were originally formulated for the right side of the body, and for the purposes of this research, were replicated on both sides [44,45]. As for BIA, the device used did not provide all electrical properties, which limited the analysis [18]. Furthermore, in the prediction of the left and right upper limb in the female group, for both FFM and LSM, the target level of prediction of $R^2 = 0.750$ was not reached, indicating that ANT may have limitations in estimating these masses in the segments. Additionally, it is possible that not all female participants had a standard 28-day menstrual cycle, as individual cycles can vary significantly in length and consistency.

Previous studies have demonstrated that menstrual cycle length can widely differ among women, as they are influenced by factors such as hormonal birth control and other physiological conditions [56,112]. This variability may have impacted the standardization of the timing of assessments in relation to their menstrual phases. Therefore, further in-depth studies on this issue are needed. Moreover, all participants in this study were Caucasian, which limits the generalizability of the findings to other ethnic groups. The predictive equations developed may not be applicable to individuals of different racial or ethnic backgrounds, as body composition can vary significantly across populations [23]. Future studies should aim to replicate this research with other racial and ethnic groups to expand the applicability of the findings.

Future lines of research should focus on applying this strategy at the tissue level for muscle mass estimation and in other masses and tissues, such as skeletal mineral mass and skeletal tissue, where there are currently no strategies available for segmental estimation by ANT.

In conclusion, the present study revealed that in general, there are intra-subject differences in the estimation of SW, FFM, and LSM between DXA, BIA, and ANT. In addition, the sex factor was found to significantly influence the differences found, indicating that it should be considered when comparing methods of estimating body composition. In general, BIA and the previous ANT equations did not show agreement with DXA for estimating SW, FFM, and segmental LSM. Therefore, new prediction equations were developed based on anthropometric measurements, using DXA as a reference. The equations showed significant differences between males and females, reflecting the different distribution of FFM and LSM between the sexes. Body mass stood out as the strongest predictor in both sexes for the trunk. In females, subcutaneous fat had a greater impact on the prediction of FFM, LSM, and SW in the limbs, while in males, the variables more strongly linked to muscle mass, such as girths, proved to be more pertinent for SW, FFM, and LSM. In both sexes, the variables related to bone structure, such as lengths and heights, also had an influence on these parameters. The equations developed demonstrate an acceptable accuracy, although they have limitations in the estimation of FFM and LSM in the upper limbs of females.

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