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COMPARISON OF FAT MASS PERCENTAGE MEASUREMENTS OBTAINED USING VARIOUS EQUATIONS AND BIOELECTRICAL IMPEDANCE ANALYSIS (BIA) DEVICES ON CADET-STUDENTS AT A MILITARY ACADEMY

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ABSTRACT

Bioimpedance is a well-established technique for the indirect estimation of body composition. However, despite its benefits, bioimpedance is not considered the reference technique for assessing fat mass (FM), and there are many different devices that don't always give the same values. Therefore, the main aim of this study was to assess and compare the FM% of Cadet-students at the Military Academy obtained with different equations and bioimpedance devices. This is a cross-sectional observational study with 25 healthy, non-athletic Caucasian male adults (mean age: 24.0 ± 2.1 years). Although the three devices used to assess body composition at the Military Academy differed significantly (One-way repeated measures ANOVA), they showed moderate to good relative reliability. Of all the devices analyzed, the Tanita BF-562 device obtained the best absolute agreement (ICC = 0.68) with the established benchmark. In conclusion, it is recommended that whatever BIA device is used in the future to assess the FM% of Cadets, it is essential to always use it over time to detect any changes or adjust the values through regression.

Keywords: bioimpedance devices; fat mass; assessments; cadet-students; agreement.

RESUMO

A bioimpedância constitui uma técnica amplamente estabelecida para a estimativa indireta da composição corporal. Contudo, apesar das suas vantagens, não é considerada a técnica de referência para a avaliação da massa gorda (MG), existindo ainda diversos dispositivos que não produzem valores consistentes entre si. Assim, o principal objetivo deste estudo consistiu em avaliar e comparar a percentagem de massa gorda (MG%) de alunos-cadetes da Academia Militar, obtida através de diferentes equações e dispositivos de bioimpedância. Trata-se de um estudo observacional transversal, com uma amostra de 25 adultos do sexo masculino, caucasianos, saudáveis e não atletas (idade média: 24,0 ± 2,1 anos). Embora os três dispositivos utilizados para avaliar a composição corporal na Academia Militar tenham apresentado diferenças estatisticamente significativas (ANOVA de medidas repetidas a um fator), evidenciaram uma fiabilidade relativa moderada a boa. Entre os dispositivos analisados, o Tanita BF-562 apresentou a melhor concordância absoluta (ICC = 0,68) com o referencial estabelecido. Em conclusão, recomenda-se que, independentemente do dispositivo de bioimpedância utilizado futuramente para avaliar a MG% dos cadetes, este seja aplicado de forma consistente ao longo do tempo, de modo a detetar alterações ou a ajustar os valores através de modelos de regressão.

Palavras-chave: dispositivos de bioimpedância; massa gorda; avaliação; cadetes-alunos; concordância.

1. INTRODUCTION

Assessing body composition throughout life is essential, both for health reasons and for functional or physical performance (Ackland et al., 2012; ACSM's, 2022; Boileau & Lohman, 1977; Coutinho et al., 2013; Slaughter & Lohman, 1980). In the clinical field, not only sarcopenia and dehydration in the elderly are problems, overweight and obesity (Janssen et al., 2005; Rodriguez-Martine et al., 2020) at a young age are also a frightening scourge in terms of the diseases they can trigger (Yusuf, et al., 2004; Sharma & Chetty, 2005). Similar to athletes in competitive sports (Bongiovanni, et al., 2021), certain professional groups or specific populations, such as military personnel or individuals in physically demanding occupations (Friedl 2012), require regular and precise monitoring of body composition to optimize performance and health outcomes. In these contexts, the distribution and proportion of body mass components are particularly critical (Silva, 2018). The human body's complex morphological structure (Saltzman & Mogensen, 2012) allows for multiple approaches to body composition assessment (Lukaski, 1987), depending on the level of analysis desired, ranging from the atomic and molecular levels to cellular, tissue, and whole-body assessments (Wang et al., 1992). Although air-displacement plethysmography and hydrostatic weighing are classified as indirect methods (Wells & Fewtrell 2006), they are widely regarded as reference standards for assessing fat mass (FM) (Campa et al., 2021; Heymsfield et al., 2005). Within the framework of the two-component model (2CM) at the molecular level (Level II), as proposed by Wang et al. in 1992, these techniques also allow for the estimation of fat-free mass (FFM) (Brozek et al., 1963; Siri, 1961).

For a more precise and comprehensive assessment of fat mass, the four-component model (4CM) has been considered in the literature, the gold standard, as it overcomes some of the limitations of earlier models, such as variations in body water and density across age, sex, and ethnicity (Heyward & Stolarczyk, 1996; Wells et al., 2010). This method, however, requires the use of multiple indirect techniques and specialized equipment, including air-displacement plethysmography, deuterium dilution, and Dual Energy X-ray Absorptiometry (DEXA) (Wang et al., 1992). The high costs of traditional equipment, some of which is technically demanding and even invasive (e.g., involving isotopes or radiation), make these methods neither portable nor practical, with preparation procedures that are often time-consuming (Heymsfield et al., 2005). In contrast, doubly indirect methods such as anthropometry and bioimpedance have emerged as credible and efficient alternatives (Campa et al., 2024; Carrion et al., 2019; Heymsfield et al., 2015; Hillier et al., 2014; Jackson et al., 2009; Kasper et al., 2021; Kerr et al., 2017). These approaches are quicker and easier to administer, cost-effective, involve portable equipment, and are suitable for a wide range of environments, especially when assessing large groups, such as military personnel. Bioimpedance requires minimal training and demonstrates low intra- and inter-assessor variability (Kotler et al., 1996).

The technological evolution of bioimpedance devices in recent years has led to the development of equipment incorporating algorithms based on predictive regression equations derived from population-specific data — taking into account variables such as sex, age, weight, height, ethnicity, and physical activity level (Campa et al., 2024). As a result, a wide range of bioimpedance devices from various manufacturers (e.g., Tanita, Omron, Akern, InBody, Seca, ImpediMed, Xitron, RJL, Bodystat, among others) are now available on the market for estimating body composition. These devices operate on the principles of Ohm's law and utilize the distinct conductive properties of body tissues, such as water, muscle, and adipose tissue which offer varying levels of resistance to the painless and harmless passage of an electrical current (Buchholz et al., 2004; Ellis, 2000; Kyle et al., 2004; Lukaski, 1996; Lukaski & Piccoli, 2012). However, a major limitation lies in the lack of transparency regarding the algorithms embedded within each manufacturer's equipment and model, which can lead to discrepancies in body composition assessments. This issue is further complicated when different technological approaches, such as type (Bioelectrical Impedance Spectroscopy [BIS]; Bioelectrical Impedance Analysis [BIA]), configuration (e.g., leg-leg, hand-hand, foot-hand, or segmental), sampling frequency (Single Frequency [SF]; Multifrequency [MF]) or procedural differences (e.g., number and type of electrodes or sensors) are used (Campa et al., 2024; Dellinger et al., 2021; Siedler et al., 2023; Tinsley et al., 2020). Consequently, using equipment that provides raw measurements, such as resistance (R), reactance (Xc), and phase angle (PA), offers a significant advantage. These raw values allow for both quantitative analyses, through the application of predictive equations validated for specific populations, and qualitative assessments, including phase angle interpretation and bioelectrical impedance vector analysis (BIVA)

(Campa et al., 2021; Campa et al., 2019; Lukaski & Piccoli, 2012; Piccoli et al., 1994).

Over the past 50 years, the body composition of cadet students at the Military Academy has been assessed with some frequency, taking advantage of the procedural advantages of bioimpedance (Campa et al., 2021; Campa et al., 2024; Carrion, et al. 2019). However, these last decades have been rich in the development of new and technologically more accurate devices. Currently, the Military Academy gathers a huge amount of body composition data, obtained over the last decades although the devices used over the years have presented different technological approaches. The main aim of this study was therefore to assess and compare the FM percentage (FM%) of Cadet-students at the Military Academy obtained with different equations and bioimpedance devices.

2. MATERIALS AND METHODS

2.1. PARTICIPANTS

The study design was a cross-sectional observational study, carried out in April and May 2025, with a non-probabilistic and intentional sampling strategy, involving all Cadet-students who volunteered at the Military Academy in Amadora. G*Power software (version 3.1.9.7, Germany) was used to perform an a priori power analysis to calculate the required sample size for a repeated-measures ANOVA (within-subjects) design, based on the following parameters: four repeated measures within a single group, α = 0.05, power = 0.80, a medium effect size f = 0.25 (Cohen, 1988), correlation among repeated measures = 0.5 and a nonsphericity correction ε = 1. The required sample size recommendation was n = 24 (participants) in the assessment of FM%.

The inclusion criteria were Cadet-students from the Military Academy, with no illness, injury or medication. Consequently, the exclusion criteria were any injury or illness that could interfere with data collection and evaluation, the existence of a medical implant, have not complied with the prior indications, or not having signed the Informed, Free and Clarified Consent (IFCC) form. All participants were previously informed about the aim and protocol of the study, having voluntarily agreed to take part signing the IFCC form. The sample consisted of 25 healthy, non-athletic Caucasian male adults with a mean age of 24.0 ± 2.1, ranging from 21 to 29 years.

The study was conducted in accordance with national and international guidelines for scientific research with human beings, including the Declaration of Helsinki (2013) and the Oviedo Convention (1997). This trial is part of a larger ongoing longitudinal prospective research study called AFUNPRO-MAC (Anthropometric and Functional Profile of Military Academy Cadets). The AFUNPRO-MAC intends to assess the morphology, body composition and functional performance of Cadet-students at the Military Academy, and was previously approved by the Commandant of the Military Academy, by the Research, Development and Innovation of the Military Academy (CINAMIL), by the Research Ethics Council of the Faculty of Human Motricity (CEIFMH) (Approval Nº 1 of 12 January 2024), and conformed to all ethical standards for human research as set out in declaration of Helsinki (WMA, 2013).

2.2. PROCEDURES

The body composition measurements were conducted in the morning (8:00 a.m.), after a 10-minute rest and required that participants were at least on an 8-hour fast, have refrained from exercise during the 12 hours before evaluation, and presenting a hydrated state. The room was suitable and comfortable, with a temperature between 21.8 and 22.7ºC and humidity ranging from 54% to 57%. Except for the bioimpedance devices, all electronic equipment (mobile phones, smartwatches, computers, ...) was left outside the room. The anthropometric and bioimpedance parameters were assessed by an anthropometric technician accredited with level I by the International Society for the Advancement of Kinanthropometry (ISAK), with a maximum Technical Measurement Error (TME) of 7.5% for fat folds and 1.5% for other measurements and with extensive experience in the use, according to the general recommendations of each manufacturer, of different bioimpedance devices.

Participants were instructed not to perform moderate or vigorous physical exercise during the previous 24 hours, nor to consume alcohol or stimulant beverages containing caffeine or theine during the 48 hours before the assessments. To ensure greater control of conditions, assessments were always conducted on Thursdays, guaranteeing identical daily routines and meals at the Military Academy. Approximately 30 minutes before the assessments, participants were asked to empty their bladders and bowels and to present themselves barefoot, wearing shorts, a light T-shirt, and without any metal objects.

2.3. ANTHROPOMETRIC MEASURES

The variables stature and weight were assessed according to the ISAK recommendations. Stature was measured with the participants in a bipedal position, to the nearest of 0.1 cm, with an anthropometer (GPM, Swiss Made). Weight was measured using a SECA scale (Germany Made) on a flat, firm surface, with an accuracy of up to 0.5 kg. Skinfold and girth measurements were taken according to standard procedures used by the ISAK (Esparza-Ros, Vaquero-Crisóbal e Marfell-Jones 2019). The five skinfold thicknesses (triceps, subscapular, biceps, iliac crest and front thigh) and five girths (arm relaxed, waist, thigh, gluteal and calf) were measured with an accuracy of 0.5 mm and 0.1 cm, respectively, using a Slimguide® skinfold calliper (Creative Heath Products, Plymouth Mitch, Patent Pend., 1 mm precision) and an anthropometric measuring tape (CESCORF, Porto Alegre, Brazil), by a level-I ISAK Accredited Anthropometrist. The intra-observer technical error of measurement (TEM) was 1.1% (with a coefficient of reliability (R = 0.99), well below the accepted value for skinfolds (Esparza-Ros, Vaquero-Crisóbal e Marfell-Jones 2019).

2.4. BIOELECTRIC IMPEDANCE ANALYSIS (BIA) DEVICES

Three BIA devices (OMRON BF300, TANITA BF-562 and TANITA BC-601) were used to directly assess FM%. The OMRON BF300 Body Fat Monitor (Model HBF-300-E, Matsusaka Co, Ltd, Japan) is a hand-hand type, with a single frequency (SF) of 50 kHz, four metal sensors (two in each hand) and evaluates FM% automatically. Before each assessment, the participant's height (cm), weight (kg), age (years) and sex (M/F) were entered into the device. The assessments were carried out in a bipedal position with the legs about 35º to 45º apart, arms fully extended forwards (holding the equipment), parallel to the ground.

The Body Fat Monitor/Scale TANITA BF-562 (Tanita Corporation, Japan) is a leg-leg type, single frequency (SF) of 50 kHz, has four metal sensors (two in each foot) and also evaluates FM% automatically. Before starting the measurements, the assessment date was updated, and only each participant's dates of birth, height (cm) and sex (M/F) were entered into the device. Age and weight were not entered, as the scale automatically weighs and calculates age. The assessments were carried out in the bipedal position, with the arms hanging close to the body.

The TANITA BC-601 Segmental Body Composition Monitor (Tanita Corporation, Japan) is of the segmental type, uses an alternating current of 100 µA, a single frequency (SF) of 50 kHz and eight metal sensors (two in each hand/foot). The data entry procedures are the same as those for the TANITA BF-562, with the only addition being the entry of each participant's physical activity level (1, 2 or 3). Assessments of FM% and other body composition components were obtained automatically. Participants were in a bipedal position, but with their arms stretched forwards, holding the equipment's monitor.

The AKERN BIA101 BIVA PRO device (Akern, Florence, Italy), widely used and validated in the literature, is a foot-hand type device that uses an alternating current of 250 µA and a single simple frequency (SF) of 50 kHz to measure the raw values of Resistance (R), Reactance (Xc) and Phase Angle (PA), enabling that the most appropriate equations from the M3C body composition model (Wang, Pierson e Heymsfield 1992) to be chosen, according to the specific characteristics of a given sample, to assess the components of body composition. Before each assessment, the battery was charged (above 80%), the quality of the cables was checked and the device was calibrated. Normal values were recognized when R was 383 ± 10 Ω and Xc was 45 ± 5 Ω, as indicated by AKERN. For each participant, after the skin areas had been properly cleaned with alcohol (70%) and dried, two pairs (emitter/sensor) of new BIATRODES electrodes (Akern, Florence, Italy) were placed at specific locations (on the back of the right hand and right foot), with a minimum distance of 5 cm between each pair, in accordance with the manufacturer's recommendations. The assessments were carried out in the supine position, with the legs stretched out and separated from each other 45º, the arms stretched out and separated from the torso about 30º, and the palms of the hands facing downwards.

The raw values obtained (R, Xc or Z) were then entered into prediction equations validated in the literature and carefully selected based on the specific characteristics of the sample (sex, ethnicity, age, level of physical activity, ...) to indirectly estimated FM%.

To create a reference for comparing OMRON BF300, TANITA BF-562 and TANITA BC-601 devices, we initially use 29 equations developed based on different body composition models — M2C and M3C (Wang, Pierson e Heymsfield 1992) — that met the general requirements (Fragoso e Bonito 2024). From these, we retained three equations (3, 6 and 20) that yielded the strongest associations with participants' sum of skinfold measurements, as indicated by the highest coefficients of determination (R^2). Each participant's FM% was estimated using the three selected equations and the average of these values served as their individual benchmark. The mean of the individual values from the three equations achieved a better R^2 than any of the equations individually and was therefore used as the benchmark. We used

Excel 2024 MSO software (version 2408, Microsoft) to process the data, particularly for the various calculations required by the different FM% prediction equations.

2.5. STATISTICAL ANALYSIS

The descriptive analysis allowed the sample's characterization and consisted of the mean (M) and standard deviation (SD) for the following variables: age (years), height (cm), weight (kg), resistance (R), reactance (Xc), impedance (Z), five skinfold thicknesses (triceps, subscapular, biceps, iliac crest and front thigh) (mm), five girths (arm relaxed, waist, thigh, gluteal and calf) (cm), and the FM% obtained directly by each device, or indirectly by averaging the results of the three carefully selected predictive equations.

One-way repeated measures ANOVA was used to evaluate the differences in FM% mean values among the methods (different devices/equations). Normality and sphericity assumptions were verified using Shapiro-Wilk test and Mauchly's test, respectively. When statistically significant differences were identified, Bonferroni-corrected post hoc pairwise comparisons were conducted to determine which devices/equations differed. The effect size for the repeated measures ANOVA was assessed using partial eta-squared (η^2p). According to (Cohen 1992), η^2p values was considered as small ($\eta^2p < 0.06$), medium ($0.06 \leq \eta^2p < 0.14$), or large ($\eta^2p \geq 0.14$).

The Intraclass Correlation Coefficient (ICC) was calculated to find out the degree of reproducibility of the results, namely the relative consistency and absolute agreement of the measurements. According to Koo e Li (2016), reliability was classified as poor (ICC < 0.50), moderate (0.50 ≤ ICC < 0.75), good (0.75 ≤ ICC < 0.90) or excellent (ICC ≥ 0.90). In addition, the agreement between the FM% obtained by the different devices/equations was examined using Bland-Altman plots, which involved analyzing the mean difference (bias) and estimating the limits of agreement and their 95% confidence intervals. Simple linear regression of differences versus means was used to test for proportional bias, and a significant regression line indicated that the bias varied with the magnitude of the measurements. The significance level (α) established was 0.05 and statistical significance was considered if $p < 0.05$. All statistical analyses were performed using SPSS Statistics software (version 30, IBM).

3. RESULTS

Table 1 shows the anthropometric and body composition characteristics of the participants. The cadets have a mean height of 175.7 + 6.4 cm and a mean weight of 74.8 + 9.5 kg. The mean sum of the five skinfolds is 54.0 + 14.1 mm. The FM% assess with the Omron BF300 with 13.0 + 4.6% has the lowest mean value, while the Tanita BF-562 with 18.0 + 3.9% has the highest mean result.

Male (*n* = 25)	*M*	*SD*
Age (years)	24.0	2.1
Height (cm)	175.7	6.4
Weight (kg)	74.8	9.5
Skinfolds		
Triceps (TRI, mm)	10.6	3.3
Biceps (BIC, mm)	4.4	2.2
Subscapular (SBS, mm)	10.9	2.9
Iliac crest (SIL, mm)	15.3	5.9
Front thigh (CRL, mm)	12.8	3.9
∑5SKF (mm)	54.0	14.1
Girths		
Arm relaxed (cm)	31.9	2.5
Waist (cm)	81.9	5.7
Gluteal (cm)	95.2	5.4
Thigh (cm)	57.0	3.1
Calf (cm)	37.5	2.4
Bioimpedance (*Akern BIA101 BIVA PRO*)		
Resistance (R, Ω)	502.3	49.2
Reactance (Xc, Ω)	66.4	9.1
Impedance (Z, Ω)	506.7	49.1
FM (%) by *Omron BF300*	13.0	4.6
FM (%) by *Tanita BF-562*	18.0	3.9
FM (%) by *Tanita BC-601*	14.8	4.3

Table 1. Descriptive Characteristics of Participants.
Note. FM – Fat Mass; ∑5SKF – Sum of five Skinfolds (TRI, BICSBS, SIL, CRL).

The benchmark FM% was calculated by averaging the values of the three equations with the highest R^2. The selected equations have a correlation (R) with the ∑5SKF between .90 and .97, and a respective coefficient of determination (R^2) between .81 and .94. We would like to highlight that the FM% obtained from the average of the three previous equations has higher R and R^2 values, .97 and .95 respectively, with a confidence interval of between .94 and .99, as shown in table 2.

Devices	Reference Method	Descriptive			Corr. with ∑5SKF		R^2
		n	*M*	*SD*	*R*	95% CI	
Omron BF300	BIA	25	13.0	4.6	.71**	[.45., .87]	.51
Tanita BF-562	BIA	25	18.0	3.9	.63**	[.31., .82]	.39
Tanita BC-601	BIA	25	14.8	4.3	.65**	[.35., .83]	.43
Equations							
(3) Lean, Han & Deurenberg (1996)	UW	25	15.9	4.0	.96**	[.92., .98]	.93
(6) Durnin & Womersley (1974)	UW	25	18.1	3.3	.97**	[.93., .99]	.94
(20) Van Loan & Mayclin (1987)	ID	25	19.0	3.1	.90**	[.79., .96]	.81
Mean of three Equations (Mean Eq)		**25**	**17.7**	**3.6**	.97**	[.94., .99]	**.95**

Table 2. Descriptive Statistics of FM% obtained using BIA devices, Selected Equations and Correlations with ∑5SKF.

Note. BIA - Bioelectric Impedance Analysis; UW – underwater; ID – isotope dilution; ∑5SKF – Sum of five skinfolds (TRI, BIC, SBS, SIL, CRL); Pearson Coefficient (*R*); Coefficient of Determination (R^2); CI – Confidence Interval; $^{**}p$ <.001 (2-tailed). BD – body density; FM – fat mass; TBW – total body water; R – resistance, H – height; W – weight. (3) Lean, Han & Deurenberg_1 (1996): BD = 1.1862 − 0.0684 log (BIC+TRI+SBS+SIL) – 0.000601 (Age); FM% = [(4.96/BD) − 4.51] * 100 (Siri adapted). (6) Durnin & Womersley_1 (1974): BD = 1.1765 – 0.0744 log (TRI+BIC+SBS+SIL); FM% = [(4.96/BD) − 4.51] * 100 (Siri adapted). (20) Van Loan & Mayclin (1987): TBW = 9.9868 + 0.000724 (H^2) + 0.2822 (W) − 0.0153 (R) − 2.3313 (Sex) −0.1319 (Age); FM% = [(2.122/BD) + (0.779 * TBW) – 1.356] * 100 (Silva et al. 2004).

The comparison of FM% values obtained from the different devices/equations, conducted using the repeated measures ANOVA, followed by the Bonferroni multiple comparisons test, showed that there were statistically significant differences (F(3,72) = 37.50, $p < 0.001$, $\eta^2 p = 0.61$) between all the devices/equations, except between the Tanita BF-562 and Mean Eq (benchmark) pair, with a mean difference of 0.30 (p = 1.000) and a 95% confidence interval between −1.454 and 2.054.

Figure 1 shows an integrated view of the FM% obtained by each device plotted against the mean fat mass of the selected equations (Mean Eq), that was used as a benchmark. The concordance line was also added to facilitate the visual assessment of consistency and agreement. All devices showed considerable consistency with the reference (lines closely parallel to the concordance line), with systematic underestimation by the *Omron BF300* and *Tanita BC-601*, and slight overestimation by the *Tanita BF-562* up to ≈18 of FM% and slight underestimation thereafter.

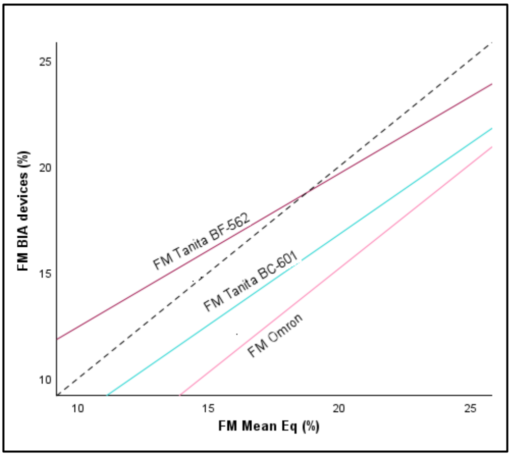

Figure 1. Integrated graph with the fat mass obtained by each device, with the FM Mean Eq (%) as a benchmark

Note. FM BIA devices (%): Omron BF300; Tanita BF-562; Tanita BC-601. FM Mean Eq (%): Lean, Han & Deurenberg (1996); Durnin & Womersley (1974); Van Loan & Mayclin (1987).

Table 3 presents the results of Intraclass Correlation Coefficient (ICC) which makes possible the quantitative assessment of both consistency (relative reliability) and absolute agreement. In terms of relative reliability, the results indicate moderate to good values, whereas absolute agreement ranges from poor to moderate.

Devices or equations	Consistency		Absolute Agreement	
	ICC	95% CI	ICC	95% CI
All	.78	[.64; .88]	.58	[.24; .80]
Omron BF300 vs Mean Eq	.74	[.50; .88]	.45	[-.10; .79]
Tanita BF-562 vs Mean Eq	.67	[.38; .84]	.68	[.39; .84]
Tanita BC-601 vs Mean Eq	.70	[.42; .85]	.56	[.03; .81]

Table 3. Relative Reliability (consistency) and Absolute Agreement of FM% values obtained with different devices/equations.
Note. ICC – Intraclass Correlation Coefficient; CI – Confidence Interval.
FM Mean Eq (%): Lean, Han & Deurenberg (1996); Durnin & Womersley (1974); Van Loan & Mayclin (1987).

Figure 2 shows the respective Bland-Altman plots for each pair of FM% devices/equation. A systematic bias is observed in the *Omron BF300* and *Tanita BC-601,* both reporting consistently lower values, but with most values within the limits of agreement. The graphs also reveal wide limits of agreement in all the devices, which does not represent an excellent absolute agreement. Nevertheless, the *Tanita BF-562* presents the best absolute agreement.

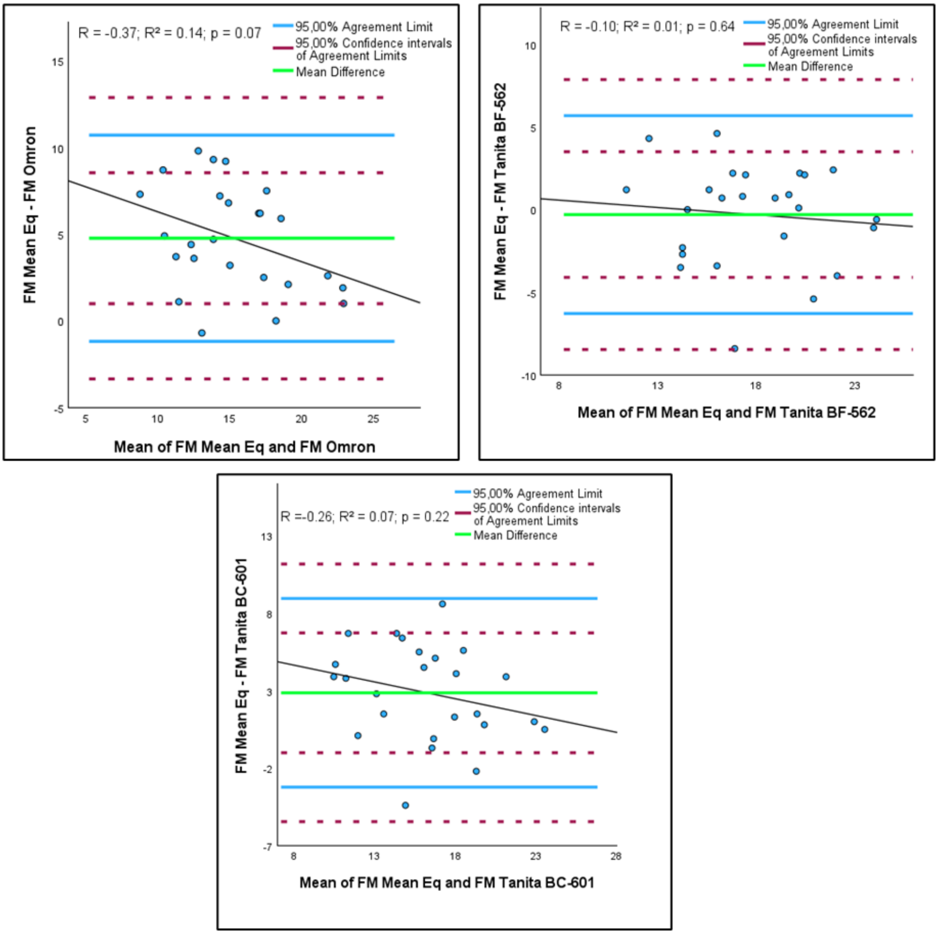

Figure 2. Bland-Altman Plots for Agreement between each FM% device with FM% Mean Eq

Note. FM Omron BF300 (%); FM Tanita BF-562 (%); FM Tanita BC-601 (%) and FM Mean Eq (%).

4. DISCUSSION

Based on the cellular properties of the tissues that make up the human body, bioelectrical impedance analysis (BIA) can be effectively used to quickly assess changes in body composition across different population including the general public, military personnel, and athletes. This technique can provide key information about Total Body Water (TBW), Fat-Free Mass (FFM) and Fat Mass (FM), enabling timely adjustments to training programs, hydration strategies, and dietary plans.

The main aim of this study was to assess and compare the FM% of male cadet-students at the Military Academy, obtained using different equations and bioimpedance devices. The results showed that the *Omron BF300* device reported the lowest average fat mass values (13.0 ± 4.6%), followed by *Tanita BC-601* device (14.8 ± 4.3%), and the FM Mean Eq (17.7 ± 3.6%), while the *Tanita BF-562* device presented the highest values (18.0 ± 3.9%).

Regarding the characteristics of the sample under study, they have average height and weight values that are relatively similar to those of cadets from similar Armed Forces Officer Schools (Agostinelli et al., 2024; Beutler et al., 2009; Botta et al., 2023; Oliveira et al., 2021; Newman et al., 2022; Roberts et al., 2023; Spartali et al., 2014). Specifically with regard to FM%, the average values obtained by the Military Academy cadets are within the range of 13.0% to 18.0% (depending on the device used), and do not differ from those presented by male cadets (with similar average ages) belonging to foreign military academies (Aandstad et al., 2020; Botta et al., 2023; Steed et al., 2016).

There are various ways of assessing body composition and we could of course, as usual, use the reference method (M4C) (Wang et al., 1992) with multiple indirect techniques and specialized equipment (including air-displacement plethysmography, deuterium dilution, and dual energy x-ray absorptiometry) to assess the FM% of student cadets. But we wanted to simplify things and try to create an alternative, quick, simple, cheap and practical way, without the problem of propagating of the measurement error associated to each equipment (necessary in the M4C model), which would also allow us to accurately assess subjects (so-called normal) with normal fat percentage values. Skinfolds are one of the most popular and widely used techniques, being a good way of assessing body fat distribution, being the technique least affected by daily activities (exercise, meals, hydration status, caffeine, menstrual cycle, ...) (Kasper et al., 2021) (Kerr et al., 2017). According to Doran et al. (2013), the sum of skinfolds in normal adults has a high degree of agreement with DEXA.

Initially, 29 equations were used, carefully selected according to the type of subjects (athletes or not), sex, ethnicity, age, amount of fat and the type of equations, following the methodology recommended by Fragoso e Bonito (2024) in order to reduce the errors associated with the population studied. The correlations of the equations and the three BIA devices with ∑5SKF were then analyzed.

Among all the measurement methods used, the average obtained from the three equations (FM Mean Eq) showed the best coefficient of determination (R = .95) with ∑5SKF, representing a best precision of real fat than only each equation.

After adopting the FM Mean (17.7% ± 3.6) as the reference, we compared the results with those obtained from the different devices. The ANOVA results showed statistically significant differences between the reference and the devices, except for the Tanita BF-562 device ($p = 1.000$).

All the devices showed moderate or good reliability (Koo e Li 2016) with relative reliability ($0.67 \leq \text{ICC} \leq 0.78$) and absolute agreement ($0.45 \leq \text{ICC} \leq 0.68$). *The Tanita BF-562* device distinguished itself with an ICC of 0.67 and 0.68, respectively.

Regarding the agreement between the different devices, none showed statistically significant differences (all $p \geq 0.07$), with the majority of values between limits of agreement. *Tanita BF-562* device proved to be the one with the best absolute agreement (ICC = 0.68), without significative proportional bias tendence ($p = 0.64$). However, for Cadet-students with less fat mass (≤ ≈18%), this device overestimates slight the values compared to the reference (FM Mean Eq), while for Cadet-students with more fat mass (> ≈18%), it begins to underestimate slight them. In slimmer adult men, fat is mainly localized in the limbs, varying little with age, while in less slender men fat also begins to accumulate in the trunk, unlike women who accumulate more in the gluteal-femoral region (Hermsdorff & Monteiro, 2004). As the *Tanita BF-562* is a leg-leg type device, i.e. it assesses the fat mass of the lower limbs while estimating the rest of the body, this could be the reason for underestimating the values of cadets with more than 18% fat mass.

The *Omron BF300* is an arm-arm device and works in the opposite way to the previous one, i.e. it assesses the fat mass of the upper limbs by estimating the rest of the body's fat. However, it shows a systematic bias (good consistency, poor absolute agreement), underestimating the cadets' fat mass values by an average of approximately 5% and not showing a significant proportional bias ($p = 0.07$). The reason for the good consistency may be that only one of the five skinfolds assessed was not located on the upper limbs or trunk.

The *Tanita BC-601* is a segmental type, i.e. it assesses the whole body. It doesn't have as good a consistency as the *Omron BF300*, which may be due to the issue of fat distribution and localization of skinfolds, underestimating FM values by an average of around 3%, with no significant proportional bias ($p = 0.22$). It has better absolute agreement than the *Omron BF300*, possibly due to being able to assess whole body fat mass. The graphs show that the difference between the three devices is mainly due to the respective differences in the mean values obtained, although there is relative reliability between them (Figure 1 and 2). This leads us to the possibility of neutralizing these differences by adjusting the respective lines obtained by regression.

A study by Moreno et al. (2001) showed that when compared with the fat mass values obtained using the Siri Equation (Siri, 1961), the *Omron BF300* device also underestimated the fat mass values (1.2%) but showed an ICC > 0.95 and good agreement.

Also, a study carried out by Minderico et al. (2008) to compare the FM% assessed with bioelectric impedance (BIA) devices with the four-component model (*gold standard*), showed that the *Omron BF300* device did not present equal values, but did not differ statistically significantly ($p > 0.05$) from the reference model in any body composition variable.

Other previous studies by Filho et al. (2011) and Silva et al. (2014) carried out with different bioimpedance devices, but from the same manufacturers (OMRON and TANITA), also reported no statistically significant differences. The study by Pateyjohns, et al. (2006) also showed that a TANITA model had good agreement and is recommended for assessing large groups, such as military personnel.

The study by Lintsi et al. (2004) had already reported that the *Omron BF300* device tended to underestimate FM%, as our study corroborates. This hand-hand type device only assesses the upper part of the human body, underestimating the rest, which concentrates most of the body mass. Perhaps this is one of the explanatory facts, because the same logic (but inversely) applies to the *Tanita BF-562*, which is of the leg-leg type and obtains the highest results.

The following strengths stand out in our study: (1) the sample is well representative (age, ethnicity, level of physical activity) of the population of male cadet-students at the Military Academy; (2) the prerequisites of the participants and the procedures before and during the assessments were scrupulously demanded or complied with; (3) the selection of three prediction equations among dozens existing was rigorous and judicious, based on the best coefficients of determination (R^2), resulting from the correlation with the sum of the participants' fat skinfolds; (4) the average of the three prediction equations (FM Mean Eq) used as a reference to compare each BIA device included anthropometric and bioimpedance equations validated in the literature; and, (5) the anthropometric measurements were assessed by an anthropometric technician accredited with level I by the International Society for the Advancement of Kinanthropometry (ISAK).

Although in our opinion the objective of this study has been fully achieved, we must list any limitations that need to be mitigated. Thus, after our reflection, although the G*Power software recommended a minimum sample of 24 participants for the statistical analysis carried out, it seems to us that in future studies on this specific population of Military Academy student cadets, it might be advantageous to use a sample with more participants, and preferably one that allows both sexes to be assessed. Another limitation was the use of only five skinfolds to assess fat, and of these, only one (front thigh) was located on the lower limbs, even though the sample did not include women. The results we obtained could be the consequence of either the number of skinfolds used or the skinfolds that were chosen, so there could be a possibility of bias.

In future studies, if necessary, it will be possible to use the mean of three equations (Mean Eq) to compare the FM% of cadets currently studying at the Military Academy, with the fat mass values of past student cadets, documented over the years. Furthermore, if assessments are carried out on this population using these devices, it may be pertinent to adjust the values using regression for each bioimpedance device.

5. CONCLUSIONS

Although the three devices used to assess body composition at the Military Academy differed significantly, they showed moderate to good relative reliability. The *Omron BF300* present the best consistency. Of all the devices analyzed, the *Tanita BF-562* device obtained the best absolute agreement with the established benchmark, very slightly overestimating the FM of the Cadets with values up to ≈18%, then underestimating it from this value onwards, but also very slightly. It is recommended that whatever BIA device is used in the future to assess the FM% of

Cadets, it is essential to always use the same one over time to detect any changes. Ideally, if possible, it would be desirable for the assessment to be conducted using a hand-foot device that provides us raw values, allowing us to input them into prediction equations validated in the literature.

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