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Assessing Body Composition With DXA and Bioimpedance: Effects of Obesity, Physical Activity, and Age

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Objective: This study evaluated to what extent dual-energy X-ray absorptiometry (DXA) and two types of bioimpedance analysis (BIA) yield similar results for body fat mass (FM) in men and women with different levels of obesity and physical activity (PA).

Methods and Procedures: The study population consisted of 37–81-year-old Finnish people (82 men and 86 women). FM% was estimated using DXA (GE Lunar Prodigy) and two BIA devices (InBody (720) and Tanita BC 418 MA). Subjects were divided into normal, overweight, and obese groups on the basis of clinical cutoff points of BMI, and into low PA (LPA) and high PA (HPA) groups. Agreement between the devices was calculated by using the Bland–Altman analysis.

Results: Compared to DXA, both BIA devices provided on average 2–6% lower values for FM% in normal BMI men, in women in all BMI categories, and in both genders in both HPA and LPA groups. In obese men, the differences were smaller. The two BIA devices provided similar means for groups. Differences between the two BIA devices with increasing FM% were a result of the InBody (720) not including age in their algorithm for estimating body composition.

Discussion: BIA methods provided systematically lower values for FM than DXA. However, the differences depend on gender and body weight status pointing out the importance of considering these when identifying people with excess FM.

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INTRODUCTION

Given existing trends toward an aging population and the growing adoption of unhealthy and sedentary lifestyles, obesity and associated negative health impacts will truly become a global problem in years to come. It is notable that in Finland, waist-to-hip ratio increased from 0.919 to 0.957 in men and from 0.785 to 0.817 in women between 1987 and 1997 (ref. 1). While obesity has been associated with a large number of diseases (2,3), it is the excess fat mass (FM) that is considered to be a modulating factor. One key to effective prevention strategies is to accurately identify people with excess FM who would benefit from targeted interventions.

BMI (weight/height^2) has been used to classify individuals as either underweight (<18.5), normal (18.5–24.9), overweight (≥25), or obese (≥30) (ref. 4). The popularity of this approach is due to its simplicity and the relatively good correlations with fatness (5). However, BMI cannot provide information regarding the FM, and it may misclassify those with high muscle mass into overweight or obese.

Bioelectric impedance assessments (6) have become increasingly popular for estimating body composition, because it is easy to use, non-invasive, relatively inexpensive, and can be performed across a wide range of subjects with regard to age, and body shape (7). Technological advances over the past decade include an increasing number of the contact electrodes from four to eight (8,9), use of multifrequency electrical levels to estimate both extracellular and intracellular fluids, and incorporating a digital scale for measuring body mass. These advances have prompted software development to provide detailed information not only on FM but also on estimates of lean mass, total body water (TBW), and fat distribution within the whole body and segmental lengths (10).

When compared to dual-energy X-ray absorptiometry (DXA) method, single or multifrequency bioimpedance analysis (BIA) units have provided good assessment of FM in healthy subjects and in patients with stable water levels using the four-electrode system (11–14), and eight-electrode system (6,10,15). However, the reference populations and the factors

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incorporated into the algorithms to estimate body composition are not always readily available with regard to age, physical activity (PA), or the level of obesity.

The Tanita BC 418 MA (single frequency) (15) and the InBody (720, multifrequency) are two recent devices that incorporate eight electrodes and have shown great promise for assessing FM in healthy individuals for clinical settings or fitness centers. The purpose of this study was to verify to what extent the DXA, InBody (720), and Tanita BC 418 MA yield similar results for FM and fat free mass (FFM) in men and women with different levels of BMI and PA.

METHODS AND PROCEDURES

Subjects

The study population consisted of 37–81-year-old male (n = 82) and female (n = 86) volunteers who resided in Central Finland and participated in a family study. Background information, including the health status, was collected via a self-administrated questionnaire. Persons with serious metabolic, cardiovascular, or endocrine diseases were excluded from the study. Written informed consent was obtained before the laboratory examinations. The Ethical Committee of the Central Hospital of Central Finland approved the study. All data were handled confidentially.

Methods

PA assessment. Leisure time PA level was evaluated using a self-administrated PA questionnaire. Subjects were divided into two groups on the basis of their PA: low (LPA = less than four times and/or 4 h/week) and high (HPA = at least four times and 4 h/week).

Anthropometric measurements. All measurements were performed after an overnight fasting (12 h). Participants were weighed with light clothes and without shoes. Height was determined using a fixed wall-scale measuring device to the nearest 0.1 cm. Weight was determined within 0.1 kg for each subject using an electronic scale, calibrated before each measurement session. BMI was calculated as weight (kg) per height $(m)^2$.

For the purpose of this study, we classified the subjects into three groups on the basis of clinical cutoff points of BMI for overweight and obese that are used by the general community. Normal group was defined as BMI < 25 kg/m^2 (31 men, 44 women), overweight as BMI = 25–30 kg/m^2 (40 men, 27 women), and obese as BMI > 30 kg/m^2 (11 men, 15 women).

DXA assessment. DXA (Prodigy with software version 9.3; GE Lunar, Madison, WI) was used to measure whole FM, percentage of FM (FM%), and FFM. All metal items were removed from the participants to ensure the accuracy of the measurement. The subjects were positioned in the center of the table for each scan. They were scanned using the default scan mode automatically selected by the Prodigy software. Precision of the repeated measurements expressed as the percent coefficient of variation was 2.2% for FM%.

Bioimpendence assessments

InBody body composition analyzer. InBody (720) (Biospace, Korea) is a multifrequency impedance plethysmograph body composition analyzer, which takes readings from the body using an eight-point tactile electrode method, measuring resistance at five specific frequencies (1 kHz, 50 kHz, 250 kHz, 500 kHz, and 1 MHz) and reactance at three specific frequencies (5 kHz, 50 kHz, and 250 kHz). TBW was estimated from area, volume, length, impedance, and a constant proportion (specific resistivity). FFM was estimated by dividing TBW by 0.73. Readings of FFM and FM% are reported in this paper.

Data were electronically imported to Excel using Lookin'Body 3.0 software. Precision of the repeated measurements expressed as coefficient of variation was, on average, 0.6% for FM%.

Tanita segmental body composition analyzer. The Tanita BC 418 MA Segmental Body Composition Analyzer (Tanita, Japan) is a single-frequency BIA device that uses eight polar electrodes. This device uses single-point load cell weighing system in the scale platform, and it can provide separate body mass readings for different segments of the body such as right arm, left arm, trunk, right leg, and left leg. An algorithm incorporating impedance, age, and height is used to estimate FM%. In this paper, we report the whole body FFM and FM%. The guidelines for this device suggest categorizing individuals into two activity levels: standard and athlete. The Tanita BC 418 MA manual categorizes the athletic mode as follows: the person must be at least 17 years old, should be involved in intense aerobic exercises for at least 10 h a week, and the person's heart pulse rate at rest should be <60 (16). Precision (coefficient of variation) of repeated measurements was on average 0.3% for FM%.

Statistical analysis

Data were checked for normality by Shapiro–Wilk's W test before each analysis. Descriptive results are reported as means ± s.d. and ranges. A P value of <0.05 was considered statistically significant. The correlation among FM% values measured by the different devices was estimated using Kendall τ correlation. The two BIA devices were compared to each other and to DXA in FM% as the mean of the difference ± 1.96 s.d. across the range of BMIs by using the Bland–Altman analysis (17). Using regression analyses we compared the difference between the three devices with regard to age and the influence of age in differences obtained between Tanita BC 418 MA and InBody (720) with BMI and PA levels. Kruskal–Wallis ANOVA (when data were not normally distributed) and one-way ANOVA with Tukey test were used to test the differences between three groups by BMI. Mann–Whitney U test (when data were not normally distributed) and t-test independent were used to compare gender differences and two groups by PA. Statistica for Windows 7.1 software was used to perform the statistical analyses.

RESULTS

Physical characteristics and body composition

The characteristics of the study population are presented in **Table 1**. As expected, men weighed more, were taller, had higher BMI and FFM but lower levels of FM and FM% than women (P < 0.05–0.001, for all measured variables). The participants represented a large range in FM% from 6 to 44% for males and 13 to 49% for females. DXA provided higher estimates of FM (P < 0.05) and FM% (2–5%, P < 0.001) than both BIA devices in men and higher FM than InBody (720) (P < 0.05) and higher FM% than both BIA devices (P < 0.001 for both) in women. Both BIA devices provided similar estimates of FM, FM%, and FFM in both men and women.

Table 1 Physical characteristics of the subjects

	Men (n = 82)		Women (n = 86)	
Variables	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max
Age (years)	54.2 (11.0)	37–79	56.1 (11.7)	38–81
Height (cm)	176.2 (6.5)*	153–193	163.4 (6.1)	147–177
BMI (kg/m^2)	26.5 (3.2)**	21–35	25.5 (4.6)	18–39
Scale weight (kg)	82.3 (11.0)*	60–105	68.2 (12.5)	49–117

Values are means and s.d. in parentheses. Significantly different from women *P < 0.001, **P < 0.05.

There were moderate-to-high correlations between FM% among the BIA devices and DXA for men ($r = 0.54–0.78$, $P < 0.05–0.001$) and women ($r = 0.37–0.91$, $P < 0.05–0.001$). The correlation coefficients were of similar magnitude (0.55–0.78) within each of the BMI or PA groups regardless of gender.

Body composition estimation based on BMI categories

Body composition measured using three methods according to the BMI categories is presented in Tables 2 and 3.

In men, all three devices provided higher estimates of FM and FM% as BMI increased from normal to obese (Table 2). Only DXA and Tanita BC 418 MA provided higher quantities of FFM between the normal vs. obese men ($P < 0.05$). When examining the differences in assessment of body composition between Tanita BC 418 MA, InBody (720), and DXA, we found that DXA provided higher estimates of FM and FM% within the normal and overweight groups ($P < 0.05$) compared to InBody (720) and Tanita BC 418 MA. In obese men, all three instruments provided a similar estimate of FM%. Results of FFM among techniques varied according to BMI groups with InBody (720) providing higher estimates than DXA for those in the normal weight group ($P < 0.05$). There were no differences in age among the BMI groups.

In women, all devices provided higher estimates of FM and FM%, as BMI increased from normal to obese (Table 3). Compared to the normal group, the obese group had higher quantities of FFM in all devices ($P < 0.01$) and had older participants. When examining the differences between Tanita BC 418 MA, InBody (720), and DXA, within all BMI groups DXA provided higher estimates of FM% than the BIA devices ($P < 0.05$ for both). No differences were found in FM% between the overweight and obese women in all three instruments. DXA provided higher estimates of FM and lower of FFM in normal group compared to InBody (720) ($P < 0.01$). In obese women, all three instruments provided similar estimates of FM and FFM.

When the subjects were stratified according to their BMI (normal, overweight, obese), significant differences in BIAs and DXA were apparent in the Bland–Altman results as shown

Table 2 Comparison of three methods in estimating of body composition within and between groups according to BMI in men, average values, and s.d. in parentheses

	Men								
	Normal (n = 31)		Overweight (n = 40)		Obese (n = 11)		P		
Variables	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	No-Ow	No-Ob	Ow-Ob
Fat free mass (kg)									
DXA	58.5 (4.9)	49–70	61.9 (8.3)	46–88	63.5 (3.6)	59–73	NS	0.01	NS
InBody	61.7 (5.6)*	47–75	64.8 (8.7)	47–91	65.0 (4.5)	58–72	NS		
Tanita	60.5 (5.0)	48–71	64.5 (7.2)	47–87	65.4 (3.8)	58–71	0.05	0.05	NS
Percentage of fat mass									
DXA	22.2 (4.8)	10–31	27.4 (4.9)	17–38	33.3 (5.3)	22–41	0.01	0.001	0.05
InBody	16.4 (5.1)**	6–27	23.1 (5.2)**	10–34	31.7 (6.1)	21–44	0.001	0.001	0.05
Tanita	18.0 (4.5)***	9–27	23.3 (4.2)**	14–31	31.2 (5.1)	24–41	0.001	0.001	0.01

InBody was the InBody (720) (Biospace, Korea), Tanita was the Tanita BC 418 MA (Tanita, Japan) device, and dual-energy X-ray absorptiometry (DXA) was the Prodigy, GE Lunar, Madison, WI (with software version 9.3). Significantly different from DXA *$P < 0.05$, **$P < 0.001$, ***$P < 0.01$.
NS, not significant.

Table 3 Comparison of three methods in estimating of body composition within and between groups according to BMI in women, average values, and s.d. in parentheses

	Women								
	Normal (n = 44)		Overweight (n = 27)		Obese (n = 15)		P		
Variables	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	No-Ow	No-Ob	Ow-Ob
Fat free mass (kg)									
DXA	41.1 (4.5)	35–52	41.9 (3.5)	36–49	46.5 (5.1)	38–58	NS	0.001	0.05
InBody	44.5 (5.0)*	37–56	45.2 (4.2)*	36–53	50.0 (7.0)	37–65	NS	0.01	NS
Tanita	42.8 (3.8)	35–51	44.8 (3.2)**	39–51	49.9 (6.0)	38–61	NS	0.01	0.05
Percentage of fat mass									
DXA	32.0 (6.1)	17–43	40.3 (3.0)	35–49	44.9 (5.8)	26–49	0.001	0.001	NS
InBody	26.1 (5.6)***	13–38	35.3 (3.5)***	29–43	41.8 (5.0)**	31–49	0.001	0.001	NS
Tanita	28.3 (5.1)**	16–37	35.7 (2.8)***	29–40	41.6 (3.9)**	32–47	0.001	0.001	NS

InBody was the InBody (720) (Biospace, Korea), Tanita was the Tanita BC 418 MA (Tanita, Japan) device, and dual-energy X-ray absorptiometry (DXA) was the Prodigy, GE Lunar, Madison, WI (with software version 9.3). Significantly different from DXA *$P < 0.01$, **$P < 0.05$, ***$P < 0.001$.
NS, not significant.

in Tables 2 and 3 and Figure 1. InBody (720) had lower FM% values by almost 6% than DXA in the normal group in men and women. Obese men showed significantly smaller differences compared to the normal and overweight groups ($P < 0.001$ and $P < 0.05$). In women, only obese group differed significantly from the normal group ($P < 0.01$). Tanita BC 418 MA had also lower values than DXA in all groups, but the differences among the BMI groups were not significant between

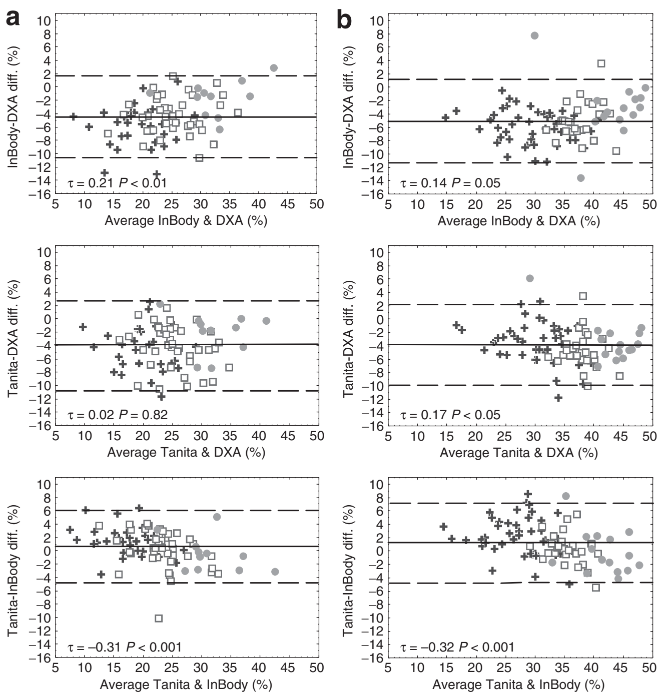

Figure 1 Kendall's τ and Bland–Altman analysis plotted from percentage of fat mass among all methods divided by BMI of (**a**) men and (**b**) women. The solid line represents the mean and the broken line the ±2 s.d. for the whole sample, and each dot represents an individual. Plus signs represent the normal group, open squares the overweight group, and filled circles the obese group. DXA, dual-energy X-ray absorptiometry.

Tanita BC 418 MA and DXA. The agreement between Tanita BC 418 MA and InBody (720) was almost perfect, when the subject's BMI was >25 kg/m^2. In the Tanita BC 418 MA–InBody (720) comparison, normal group was significantly different from the overweight and obese group ($P < 0.05$ and $P < 0.01$, respectively) in women.

Body composition estimation based on PA

Body composition measured using three methods according to the PA categories are presented in Table 4. In men, the HPA group had lower FM% than the LPA group estimated by DXA ($P < 0.01$) and InBody (720) ($P < 0.05$) but not by Tanita BC 418 MA. In the LPA group, FM% values measured by DXA were higher compared to the estimates from Tanita BC 418 MA ($P < 0.001$ for men and $P < 0.001$ for women) and InBody (720) ($P < 0.001$, respectively). FM measured by DXA provided higher values than both BIA devices in men ($P < 0.05$) and higher than InBody (720) in women ($P < 0.05$). DXA provided lower values for FFM than the BIA devices in both genders ($P < 0.05$). There were no differences in age between the PA groups.

The results of Bland–Altman analysis with respect to the PA groups are presented in Table 4 and Figure 2. We found that the absolute difference in FM% between Tanita BC 418 MA and DXA was smaller within the HPA group than within LPA group in men, but between InBody (720) and DXA it was not significant. The opposite phenomenon was found between Tanita BC 418 MA and InBody (720), namely the LPA groups were closer to zero than the HPA groups.

Differences in body composition estimation between BIA devices due to age

Since Tanita BC 418 MA incorporates age into their estimation of body composition and InBody (720) does not, we evaluated whether the difference in FM% between the two devices was due to age. We performed a correlation with the difference between the devices across the age range. When we compared

Table 4 Comparison of three methods in estimating of body composition within and between groups according to physical activity, average values, and 2 s.d. in parentheses

	Men				Women				Men
	LPA (n = 62)		HPA (n = 20)		LPA (n = 67)		HPA (n = 19)		
Variables	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	Mean (s.d.)	Min–Max	P
Fat free mass (kg)									
DXA	59.7 (5.8)	46–76	64.2 (8.8)	51–88	42.4 (5.0)	35–58	42.1 (3.3)	37–47	0.05
InBody	62.7 (6.4)*	47–79	66.6 (9.0)	50–91	45.8 (5.8)*	36–65	45.4 (4.5)	37–56	0.05
Tanita	62.5 (5.7)**	47–76	65.0 (8.1)	53–87	44.9 (5.1)**	35–61	44.0 (3.4)	37–49	NS
Percentage of fat mass									
DXA	27.4 (5.9)	14–41	22.7 (5.4)	10–33	37.8 (7.0)	24–49	33.6 (8.1)	17–47	0.01
InBody	22.8 (7.1)***	7–44	18.4 (6.7)	6–29	32.7 (7.6)***	17–49	28.4 (8.1)	13–43	0.05
Tanita	23.1 (6.2)***	9–41	20.1 (5.6)	9–29	33.7 (6.4)*	19–47	30.2 (7.2)	16–42	NS

InBody was the InBody (720) (Biospace, Korea), Tanita was the Tanita BC 418 MA (Tanita, Japan) device, and dual-energy X-ray absorptiometry (DXA) was the Prodigy, GE Lunar, Madison, WI (with software version 9.3). Significantly different from DXA *$P < 0.01$, **$P < 0.05$, ***$P < 0.001$. In women, differences between low physical activity (LPA) and high physical activity (HPA) are not significant (NS).

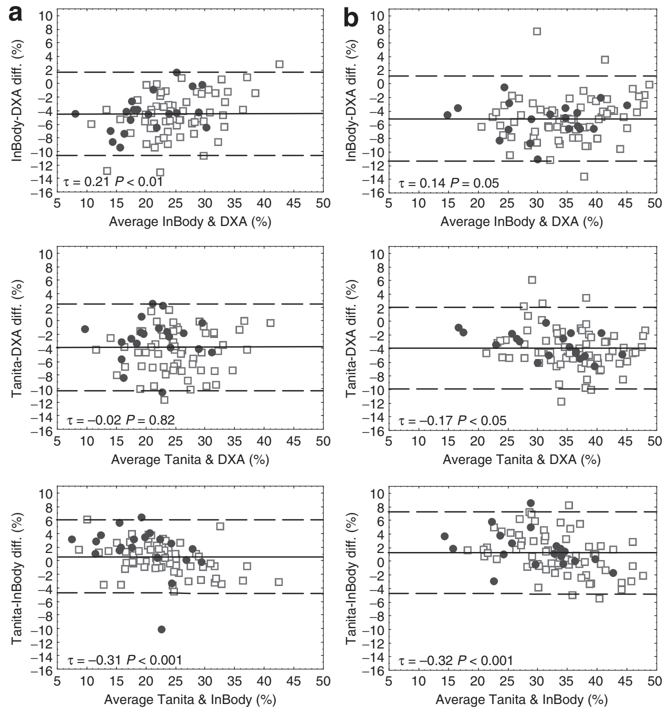

Figure 2 Kendall's τ and Bland–Altman analysis plotted from percentage of fat mass among all methods divided by PA (**a**) men and (**b**) women. The solid line represents the mean and the broken line represents the ±2 s.d., and each dot represents an individual. Filled circles represent the high physical activity group, while open squares represent the low physical activity group. DXA, dual-energy X-ray absorptiometry.

the results between InBody (720) and Tanita BC 418 MA, we found an increasing disparity between FM% as age increased for both men ($r = -0.26$, $P = 0.02$) and women ($r = -0.43$, $P < 0.001$). After adjusting for age, there was no difference in FM%, as assessed by the two devices across the range of BMI or PA for men or women ($P > 0.05$). However, the significant relationships between InBody (720) or Tanita BC 418 MA with BMI levels or PA remained when adjusting for age.

DISCUSSION

In this study, we compared DXA and two types of bioimpedance devices to assess FM% in men and women with different levels of BMI and PA. We found that DXA provided higher estimation of FM% compared to the two BIA devices in all comparisons, whereas the two BIA provided in similar group means. However, we found a non-systematic bias between Tanita BC 418 MA and InBody (720) estimates for FM% due to age in levels of BMI and PA, and these were gender specific. While our correlations between the eight-electrode BIA devices and DXA for FM% were moderate, they were smaller than those in other reports (6,10,15). To interpret our results, we need to examine the limitations of DXA as a reference, the underlying assumptions of the BIA technology and equations used to assess individuals by both BIA devices.

A limitation of our study was the use of DXA as the reference standard for both BIA devices. Due to different manufacturers and beam configuration, the relative validity of DXA compared to a four-component model has to be examined for each DXA. Recently a validation study using the GE Lunar Prodigy DXA (the same device as we have used) (18) reported a non-differential overestimate of FM% compared to the 4C model for non-obese men (1.7%, $P < 0.001$) and women (2.0%, $P < 0.001$) and for obese women (2.3%, $P < 0.05$). Our results showed that the Prodigy provided a higher estimate of FM% than BIA devices. This implies that the BIA devices used in this study may provide a true underestimate of FM%.

BIA relies on the differing behavior of biological tissues in response to an applied electrical current. The total impedance incorporates both resistance and capacitance components. Some studies showed that single-frequency BIA is a valid estimator of body composition in healthy individuals (19,20), while others state that it tends to overestimate the FFM, thereby underestimating FM% of the obese, and overestimating FM% of the athletes (19,21,22). The multi-frequency BIA methods avoid the problems encountered in the single-frequency BIA devices by using low and high frequency electric currents. The different currents allow for estimates of extracellular water and intracellular water, as well as TBW (23). Bedogni *et al.* concluded (24) that the InBody (720) device provides precise and accurate estimates of TBW in healthy subjects.

InBody (720) and Tanita BC 418 MA provided similar estimates of FFM and FM% when comparing weight and PA groups. The Bland–Altman plots revealed a discrepancy between the BIA devices and DXA for FM% both in absolute amounts (2–5%) and with increasing FM%. Other researchers have reported the same phenomenon (13,15,25). Recent studies that compared InBody (720) to DXA's other than the Prodigy, Salmi (10) found 4.7% difference in overweight and obese subjects, while Demura *et al.* (25) found only 0.1% difference in a Japanese sample using a Lunar DP-X. When the Tanita BC 418 MA device was compared to the Prodigy, the Tanita BC 418 MA underestimated total fatness by 5.0% in overweight and obese subjects (15), and 1.5% in normal and obese subjects (6) using the Lunar DP-X as a comparator.

The Tanita BC 418 MA device uses different algorithms when determining FM% of athletic vs. non-athletic individuals. There are physiological differences between athletes and non-athletes. It is well established that hydration levels differ between very active and relatively inactive persons (26). Those under rigorous PA training may have a different distribution of FFM and FM in the trunk and appendages. The principle of BIA with regard to resistance and reactance should hold regardless of the FM/FFM ratio. However, the arms and legs provide 85% of the total body impedance but only 35% of total body volume (27). Thus, PA levels could conceivably affect estimation of FFM and, therefore, FM%, if distribution of muscle mass is disproportionate in different PA levels. Both the InBody (720) and DXA devices showed significant differences in FFM, and FM% between LPA and HPA group, while the Tanita BC 418 MA did not. The question remains whether the criterion for selecting the athletic mode in the Tanita BC

418 MA is accurate or might provide additional error by not capturing individuals who are more physically active than the mainstream population but does not meet the criterion as suggested by the manufacturer.

The algorithm to calculate FFM by Tanita BC 418 MA incorporates age, height, gender, and impedance. In contrast, the InBody (720) uses only the electrical properties obtained from the BIA device. We found that both age and gender contributed to the difference in FM% between InBody (720) and Tanita BC 418 MA. Age adjustment erased these differences.

Our results and others (13) suggest that there is a wide range of individual error when assessing FM%. Compared to DXA, BIA may underestimate the FM% as much as 12% in the population at the lower ranges of FM%, and it may overestimate FM% even with 8% in the upper range of FM%. Thus it is questionable whether either the Tanita BC 418 MA or InBody (720) is valid for assessing FM% of healthy individuals in a clinical setting.

In summary, the disagreement between the BIA and DXA in assessing FM in different categories of BMI and habitual recreational PA in men and women points out the importance of taking body mass and non-competitive PA also into account when estimating body composition in adult populations. However, the non-systematic bias between the assessment of FM% evidenced between Tanita BC 418 MA and InBody (720) appears to be due to the absence of age in the algorithm used by InBody (720) to estimate FFM. The inclusion of age is warranted in post-hoc analyses, when using FM% from InBody (720) compared to Tanita BC 418 MA. While BIA may be reasonable for characterizing groups, the application of FM% to an individual is cautioned, until more research on the applicability and refinement of the current algorithms are performed.

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DISCLOSURE

The authors declared no conflict of interest.

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