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Body fat assessment in youth with overweight or obesity by an automated bioelectrical impedance analysis device, in comparison with the dual-energy x-ray absorptiometry: a cross sectional study

Hanen Samouda^{1*}  and Jérémie Langlet²

Abstract

Background: Bioelectrical impedance analysis (BIA) is a widely used method to assess total body fat (TBF) depots characterising obesity. Automated BIA devices provide an inexpensive and easy assessment of TBF, making them widely available to the general public and healthcare providers without specific qualification to assess body composition. The equations included in the automated BIA devices have been developed in very few specific populations, which means that they are not suitable to assess TBF for everyone and need to be validated before use in other populations. **The aim** of the present work is to evaluate the accuracy of the automated BIA device Tanita[®] BC-532 in youth of White European ethnicity, compared with the dual-energy x-ray absorptiometry (DEXA), gold standard measurement of TBF.

Methods: Total body fat percentage (TBF%) was measured with the BIA device Tanita[®] BC-532 and DEXA (Hologic[®] QDR4500W) in 197 youth of White European ethnicity ($N = 104$ girls), 7-17 years old, and visiting the *Diabetes & Endocrinology Care Paediatrics Clinic, Centre Hospitalier de Luxembourg*, for overweight or obesity management.

Results: TBF% evaluated with BIA was significantly correlated with TBF% measured with DEXA in both boys ($r_{\text{Pearson}} = 0.617$) and girls ($r_{\text{Pearson}} = 0.648$) ($p < 10^{-4}$). However, the residual mean between the assessment of TBF% by BIA and by DEXA [$\text{TBF}_{\text{BIA}} (\%) - \text{TBF}_{\text{DEXA}} (\%)$] is extremely high (mean \pm standard deviation = $10.52\% \pm 5.22\%$ in boys, respectively $9.96\% \pm 4.40\%$ in girls). The maximal absolute residual value is also very high, about 24% in both genders.

Conclusions: The automated BIA device Tanita[®] BC-532 appears to be not accurate to assess total body fat in youth with overweight or obesity. There is a need to calibrate the BIA device before its use in the populations where it was not previously validated.

Keywords: Adiposity, Body mass index, Overweight, Obesity, Fat mass, Dual-energy x-ray absorptiometry, Bioimpedance

Background

Body mass index (BMI) assessment has been widely used to define or diagnose obesity [1].

BMI values of more than 30 kg/m^2 have been recommended by the World Health Organisation (WHO)

*Correspondence: hanene.samouda@lih.lu

¹ Precision Health Department, Luxembourg Institute of Health, Strassen, Luxembourg

Full list of author information is available at the end of the article



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in order to diagnose obesity [1]. This cut-off has been commonly used worldwide, yet widely criticised for its poor sensitivity or ability to identify people having high total body fat (TBF), which in fine, defines obesity [1, 2]. A systematic review and meta-analysis showed that a BMI threshold $\geq 30 \text{ kg/m}^2$ fails to detect more than half of individuals with a high total fat mass due to a sensitivity value of the BMI not higher than 0.42, in comparison with the reference measurement of body fat by Dual-Energy-X-ray-Absorptiometry [3]. Actually, BMI does not distinguish between fat mass and fat free mass at the individual level. For a same high value of BMI, body composition might considerably vary between individuals. People having a high muscle mass or bone mass might be wrongly considered as having overweight or obesity [4–8].

Dual-Energy-X-ray-Absorptiometry (DEXA) is currently considered as the reference method for body composition assessment, providing a gold standard measurement of the body fat mass, muscle mass and bone mass at both total and regional levels (trunk, arms and legs) [9–13]. With around 3% margin of error, DEXA provides a highly accurate measurement of the different body compartments [9–13]. Body composition measurement by DEXA is easy to perform, rapid, with very low radiation exposure and very little inconvenience for the patient. These characteristics promoted DEXA use in clinical practice and research in order to accurately assess body fat [9–13]. Nevertheless, despite its multiple advantages, the major disadvantage of DEXA resides in the fact that the analysis requires an expensive equipment that few clinicians have at their disposal for a daily basis usage. DEXA equipment is also almost never available for a regular usage by researchers. Moreover, DEXA measurements of body composition cannot be performed in population based studies [9–13].

Bioelectrical impedance analysis (BIA) is an indirect assessment method of TBF, widely used in research and clinics. The method is based on the capacity of the hydrated tissues in the body to conduct electric current. The BIA devices include predictive equations of body fat developed in specific populations. These BIA devices measure the electric bioimpedance through Ohm's law, when a sinusoidal electric current of low intensity ($\pm 1 \text{ mA}$, mA) and at high frequency (more than 50 kHz, kHz) is transferred between several predefined points on the body through voltage [14]. The bioimpedance measures the resistance of the biological tissues to the electric current conduction. The equations included in the devices provide a calculation of the intra-cellular and extra-cellular fluids, and the total body water using the measured electric impedance and resistance for each

segment of the body, and predict total fat mass and fat free mass (FFM) [15–17].

Automated BIA devices: More recently, less expensive and highly simplified BIA devices for TBF assessment have been developed. These BIA consist in bipedal, bimanual, or a combination of both devices [18–22]. These devices contain integrated electrodes inside, sending small electric current through the total body water. Electrodes positioning is therefore made easier and the body fat measurement faster. Bipedal BIA channel the electric current from foot to foot. In bimanual devices, electric current circulates from hand to hand. TBF is calculated based on the measured impedance [18–22]. These BIA analysers are portable, automated and easy to use, provide a direct reading of TBF and are widely available in the marketplace at affordable prices. This therefore highly increased their usage in non-specialising clinical setting and amongst the general public. However, automated TFM calculation provided by these BIA devices is based on nonspecific predictive equations, pre-established by the manufacturer and different according to the device, which raises the question of its accuracy [23]. In addition, body composition varies according to the ethnicity and environmental exposure [24–26]. Furthermore, the equations included in the automated BIA devices have been developed in very few specific populations, which means that they are not suitable to assess TBF for everyone and need to be validated before use in other populations [27–30].

The study aims to evaluate the accuracy of the automated BIA device Tanita® BC-532 in youth of White European ethnicity, in comparison with the DEXA.

Methods

Study participants

$N=197$ youth of White European ethnicity (93 boys, 104 girls) were invited to participate in the study as previously described [31–34]. They were aged between 7 and 17 years old, with overweight or obesity according to the IOTF definition [35], and visiting the *Diabetes & Endocrinology Care Paediatrics Clinic, Centre Hospitalier de Luxembourg* between September 2006 and June 2008 for overweight or obesity management [31–34]. The sample was compiled by inviting all the 7 to 17 years old children and adolescents, frequenting the Paediatrics Clinic and seeking for obesity treatment between September 2006 and June 2008, to participate in the study. Only the youth who had conditions in relation with body composition alterations, including the hypoparathyroidism, a leptin deficiency, the Laurence Moon Biedl syndrome and the Prader Willi syndrome were excluded from the study. The girls took part to the study outside their menstrual

period. The data of the present work were collected as part of a study on the impact of a multidisciplinary obesity management group program on health outcomes in children and adolescents with overweight and obesity. The participants were randomly assigned to either the multidisciplinary group program ($n = 92$) or the individual therapy ($n = 99$), according to the gender, age and overweight or obesity status as described in the Fig. 1 (CONSORT flow diagram). Five participants left the study after their allocation into the therapeutic program.

Anthropometry and physical examination

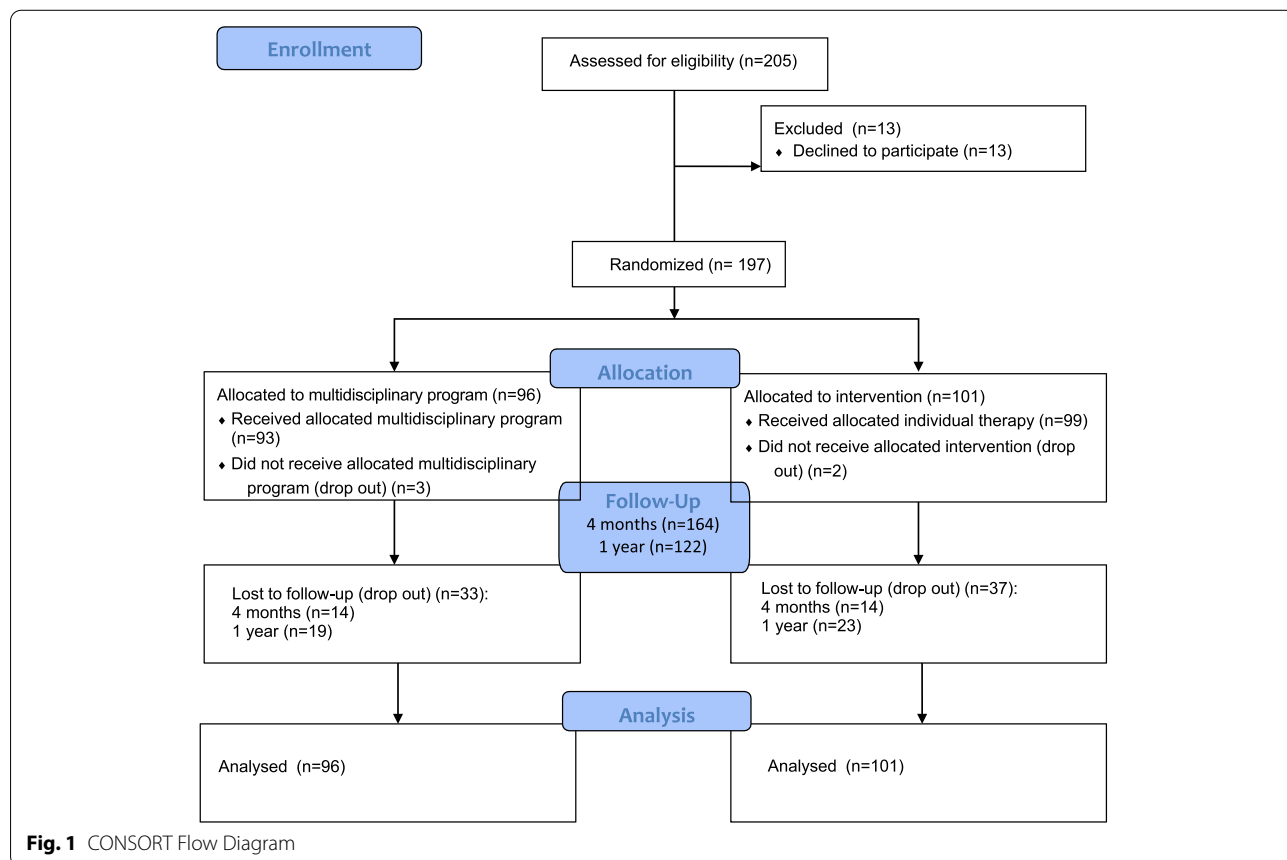
Height and weight were assessed according with the Lohman’s anthropometric reference manual [36]. The body mass index (BMI) was calculated. The Dutch L, M, and S values were used to define the BMI Z Scores [37]. The free LMS Growth software was used to establish the overweight and obesity cutoffs [38]: the 91th (boys) and 89th (girls) percentiles for overweight, respectively the 99th (boys) and 98th (girls) percentiles for obesity [37, 38]. The pubertal or Tanner stages were defined by physical examination [39, 40].

Body fat measurement by dual-energy x-ray absorptiometry

The gold standard measurement of total body fat percentage (TBF_{DEXA}%) was measured with the dual-energy X-ray absorptiometry using the Hologic® QDR4500W densitometer (Hologic Inc., Waltham, MA, USA). The TBF% was assessed at five conventional predefined areas: trunk, left and right arms, and left and right legs [32, 41].

Body fat evaluation by bioelectrical impedance analysis

Total body fat percentage was measured with the automated BIA device Tanita® BC-532 (Tanita Corp., Tokyo, Japan) (TBF%_{BIA Tanita® BC-532}) according to the recommendations of the manufacturer. The evaluation of the TBF% with the BIA Tanita® BC-532 was performed immediately prior to the DEXA examination. The Tanita® BC-532 is a foot-to-foot bioelectrical impedance device. In order to control the hydration status, the study participants were asked to not eat or drink liquids, including coffee and alcohol for the adolescents, and to not practice vigorous physical activity 8 hours before the measurement. The study participants were standing on a platform scale including electrodes, enabling the electric current to pass from one foot to another. Before



the measurement, the study participants provided information on their physical activity level (inactive, active or athlete). This information was entered into the BIA device, in addition to the age and sex information. The impedance is measured via this process and the body fat percentage is calculated through pre-established body fat predictive algorithms included in the device, and taking into consideration the age, gender, weight, height and level of physical activity.

Statistics

The Kolmogorov–Smirnov test and Q–Q plots were performed in order to evaluate the normal distribution of the data. The accuracy of the Tanita® BC-532 to predict the TBF% was assessed by means of several statistical analyses:

- Student’s t-tests for paired samples to compare the average percentage of total body fat assessed with the Tanita® BC-532 [TBF_{BIA} (%)] and its reference measurement with the DEXA [TBF_{DEXA} (%)],
- Analysis of variance (ANOVA) to assess the differences among the means of the total body fat percentage observed with the BIA Tanita® BC-532% in the 5 Tanner stages,
- Bivariate regression analyses to analyse the associations between the percentage of total body fat assessed by the automated bioelectrical impedance meter [TBF_{BIA Tanita® BC-532} (%)] and measured by the dual-energy x-ray absorptiometry [TBF_{DEXA} (%)],
- Analysis of the residual values, or differences between the prediction of the TBF% with the BIA Tanita® BC-532 and measurement by DEXA [TBF_{BIA Tanita® BC-532} (%) - TBF_{DEXA} (%)].
- Assessment of the accuracy of TBF% predicted by the Tanita® BC-532 by means of the Bland and Altman [42] adapted representations of the differences between TBF_{BIA Tanita® BC-532} (%) values and the gold standard measurement of total body fat by DEXA [TBF_{DEXA} (%)] in function of the average of the two methods.

The results were displayed as mean ± standard deviation, minimal and maximal values. The *p*-values < 0.05 were considered as significant. We used the SPSS for Windows, Version 25.0 in order to perform the statistical analyses.

Results

The Table 1 shows the characteristics of the study participants. The reference values of TBF_{DEXA}% are about 44.4% ± 6.5% (min: 28.4%; max: 59.7%) in boys,

Table 1 Study participant’s characteristics

	Boys (N = 93)		Girls (N = 104)	
	Mean ± SD	Min - Max	Mean ± SD	Min - Max
Age (years)	11.8 ± 2.3	7.3 - 16.7	12.1 ± 2.4	7.4 - 17.3
Height (m)	1.54 ± 0.13	1.27 - 1.81	1.54 ± 0.12	1.27 - 1.82
Weight (kg)	68.3 ± 19.9	35.1 - 137.0	68.5 ± 22.0	33.9 - 151.0
BMI (kg/m²)	28.2 ± 4.9	19.1 - 42.8	28.3 ± 5.6	19.6 - 47.4
BMI Z Score	1.8 ± 0.5	0.7 - 3.0	1.8 ± 0.6	0.5 - 3.2
TBF_{DEXA} (%)	44.4 ± 6.5*	28.4 - 59.7*	47.5 ± 6.7	29.6 - 63.1
TBF_{BIA Tanita® BC-532} (%)	34.5 ± 7.7*	23.4 - 58*	38.1 ± 6.6	26 - 59.2
	N	Percentage	N	Percentage
Overweight (N, %)	28	30.1	39	37.5
Obesity (N, %)	65	69.9	65	62.5

TBF_{DEXA} (%): total body fat percentage assessed with dual-energy x-ray absorptiometry

TBF_{BIA Tanita® BC-532} (%): total body fat percentage assessed with the bioelectrical impedance analyser

Min: minimal value. Max: maximal value. SD: standard deviation

**p* < 10⁻⁴ (Student’s t-tests for paired samples)

respectively 47.5% ± 6.7% (min: 29.6%; max: 63.1%) in girls. The values of TBF_{DEXA}% were significantly different than the values of TBF_{BIA Tanita® BC-532}% in both boys [34.5% ± 7.7% (min: 23.4%; max: 58%)] and girls [38.1% ± 6.6% (min: 26%; max: 59.2%)] (*p* < 10⁻⁴).

One girl had a maximal value of 59.2% of TBF (%) by the BIA Tanita® BC-532. She was 14 years old, had a height of 1.72 m, a weight of 140.3 kg and a TBF_{DEXA} (%) of 63.1%.

Two boys had a maximal value of 58% of TBF (%) by the BIA Tanita® BC-532. They were respectively 11 and 16 years old, had a height of 1.56 m and 1.79 m, a weight of 101 kg and 137 kg and a TBF_{DEXA} (%) of 57.1 and 49.2%. The means of TBF (%) by the BIA Tanita® BC-532 were significantly different according to the Tanner stage only in girls (Table 2).

The bivariate regression analyses showed that the TBF%_{BIA Tanita® BC-532} evaluated with the automated bioimpedance analyser was significantly correlated with the total body fat percentage measured with the DEXA (TBF%_{DEXA}) in boys (*r*_{Pearson} = 0.617) and girls (*r*_{Pearson} = 0.648) (*p* < 10⁻⁴) (Table 3). Tanner stage was included in the bivariate regression in girls because of the significant differences observed in the means of TBF (%) by the BIA Tanita® BC-532, according to the Tanner stage in girls (Table 3). However, Tanner stage did not significantly contributed to improve the prediction of TBF%_{DEXA} by TBF%_{BIA Tanita® BC-532} in girls as shown in Table 3. Indeed, in the model adjusted on Tanner stage in girls, the variance explained was the

Table 2 Body fat percentage by the Tanita® BC-532, according to the Tanner stage

Tanner stage	I N (%)	IIN (%)	III N (%)	IVN (%)	VN (%)	P-Value
Boys (N = 93)	42 (45.2%)	28 (30.1%)	7 (7.5%)	10 (10.8%)	6 (6.5%)	0.607
TBF_{BIA Tanita® BC-532} (%)	24.9 ± 7.1	23.4 ± 8.2	27.1 ± 4.6	26.9 ± 7.2	24.2 ± 12.1	
Girls (N = 104)	23 (22.1%)	28 (26.9%)	15 (14.4%)	9 (8.7%)	29 (27.9%)	< 10 ⁻⁴
TBF_{BIA Tanita® BC-532} (%)	26.8 ± 4.0	29.5 ± 5.8	26.0 ± 7.4	33.2 ± 7.3	31.5 ± 6.2	

TBF BIA Tanita® BC-532 (%): total body fat percentage assessed with the bioelectrical impedance analyser, expressed as mean ± standard deviation (SD)

*p < 10⁻⁴ (ANOVA)

Table 3 Univariate regression analysis between the percentage of total body fat assessed by the automated bioelectrical impedancemeter Tanita® BC-532 and measured by the dual-energy x-ray absorptiometry

	Model	Model				TBF _{BIA Tanita®}		Tanner stage	
		r _{Pearson}	R ²	SEE (%)	P-Value	r _{Pearson} partial	P-Valuepartial	r _{Pearson} partial	P-Valuepartial
Boys (N = 93)	TBF _{DEXA} (%) = [0.617 × TBF _{BIA Tanita® BC-532} (%) + 26.24]	0.617	0.381	5.18	< 10 ⁻⁴	0.617	< 10 ⁻⁴	–	–
Girls (N = 104)	TBF _{DEXA} (%) = [0.648 × TBF _{BIA Tanita® BC-532} (%) + 22.17]	0.648	0.420	5.16	< 10 ⁻⁴	0.648	< 10 ⁻⁴	–	–
Girls (N = 104)	Model adjusted on Tanner stage in Girls	0.648	0.420	5.18	< 10 ⁻⁴	0.618	< 10 ⁻⁴	–0.019	0.848

TBF DEXA (%): total body fat percentage assessed with dual-energy x-ray absorptiometry

TBF BIA Tanita® BC-532 (%): total body fat percentage assessed with the bioelectrical impedance analyser

same as in the model without adjustment (r_{Pearson}: 0.648; R² = 0.420; SEE = 5.18%; p < 10⁻⁴). Tanner stage did not significantly contributed to the variance explanation in the model (r_{Pearson} partial: – 0.019; P-Value partial: 0.848) (Table 3).

The standard error of estimation (SEE) of the TBF% by the BIA Tanita® BC-532 was about 5.18% in boys and 5.16% in girls (Table 3). In addition, the residual mean (absolute value) between the assessment of TBF% by the BIA Tanita® BC-532 and its measurement by DEXA [TBF_{BIA Tanita® BC-532} (%) - TBF_{DEXA} (%)] was extremely high (mean ± standard deviation = 10.52% ± 5.22% in boys, respectively 9.96% ± 4.40% in girls). The maximal absolute residual value was also very high, about 24% in both genders (Table 4). The adapted Bland and Altman representations show the differences between the total body fat percentage as evaluated by bioimpedance (TBF_{BIA Tanita® BC-532}%) and measured by dual-energy x-ray absorptiometry (TBF_{DEXA} %) regressed across the average of TBF % as assessed by the 2 methods (1/2 TBF_{BIA Tanita® BC-532}% + TBF_{DEXA} %) (Figs. 2 and 3). For both genders, the mean values of the (TBF_{BIA Tanita® BC-532}% - TBF_{DEXA} %) residuals were different from zero, possibly implying the existence of a systematic error of the total body fat prediction with the Tanita® BC-532 (Residual mean: – 9.92% in boys; – 9.36% in

Table 4 Evaluation of the precision of the automated bioelectrical impedancemeter Tanita® BC-532 to assess the total body fat, compared to the dual-energy x-ray absorptiometry: residual values

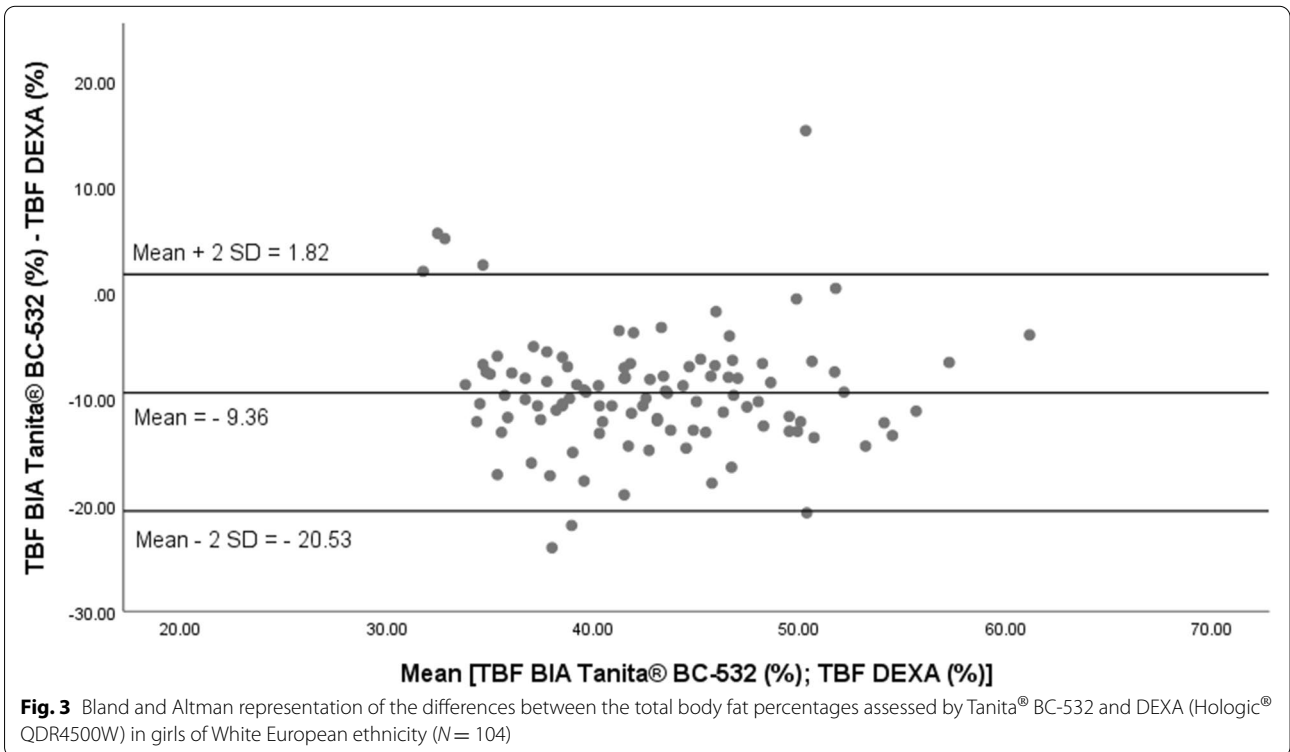
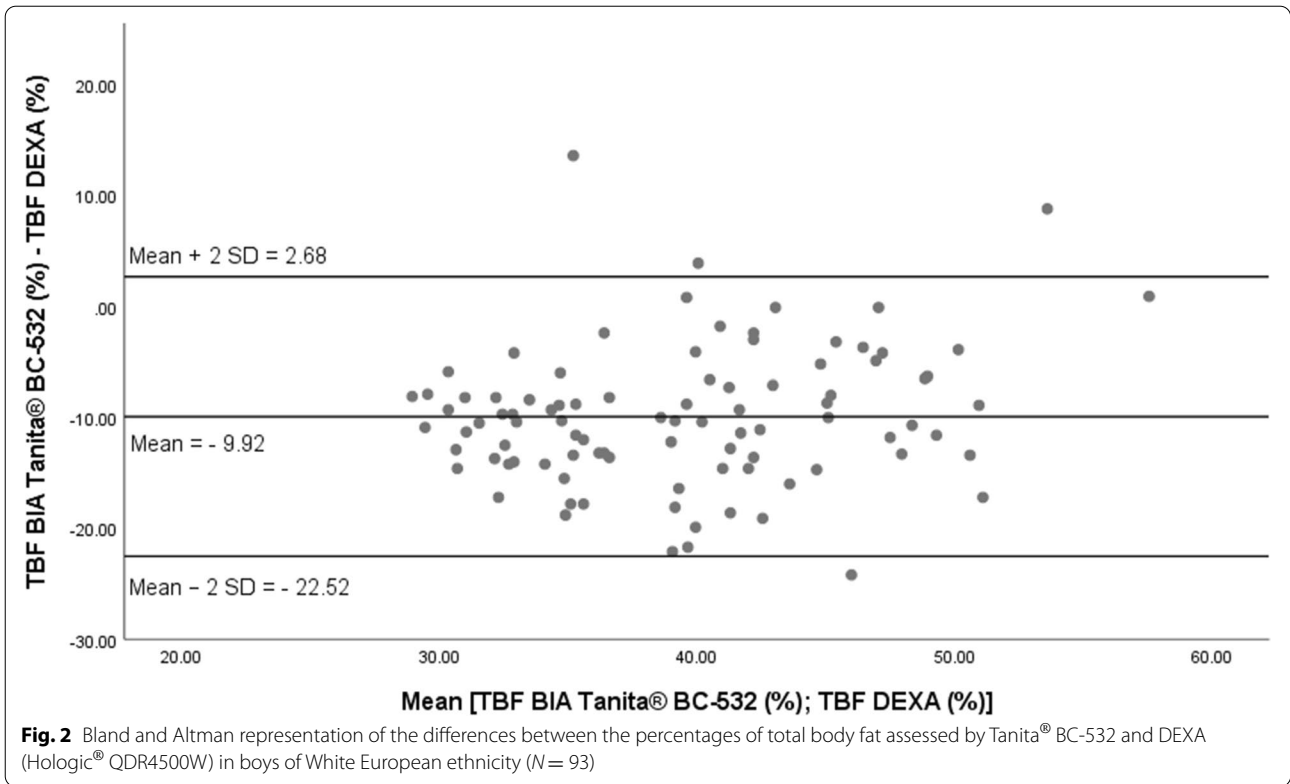
	Boys (N = 93) TBF _{DEXA} (%) = [0.617 × TBF _{BIA Tanita® BC-532} (%) + 26.24]	Girls (N = 104) TBF _{DEXA} (%) = [0.648 × TBF _{BIA Tanita® BC-532} (%) + 22.17]
Residuals (%)		
Mean ± SD	– 9.92 ± 6.30	– 9.36 ± 5.59
Min	– 24.20	– 24.00
Max	13.60	15.40
Residuals (absolute value)		
Mean ± SD	10.52 ± 5.22	9.96 ± 4.40
Max	24.20	24

TBF DEXA (%): total body fat percentage assessed with dual-energy x-ray absorptiometry

TBF BIA Tanita® BC-532 (%): total body fat percentage assessed with the bioelectrical impedance analyser Tanita® BC-532

Residuals (%) = [TBF_{BIA Tanita® BC-532} (%) - TBF_{DEXA} (%)]

girls). However, the differences between the TBF_{BIA Tanita® BC-532} (%) and the TBF_{DEXA} % values were not significantly correlated with the average of the two methods (Figs. 2 and 3).



Discussion

The foot-to-foot automated bioimpedance analysis devices [18–22, 30, 43–47] enable an easy and quick assessment of the total body fat, compared to the multi-frequencies BIA devices [48, 49] that have been developed and validated in specific populations and used in specialised areas. The positioning of the electrodes is easiest. Their low cost and the automated calculation of the total body fat facilitated their use by non specialised healthcare providers and researchers in body composition, as well as by the general public, without selecting population-specific body fat equations [30, 43–47].

We assessed the accuracy of the automated BIA device Tanita® BC-532 in comparison with the DEXA, gold standard measurement of total body fat. Several authors used the DEXA technique in order to investigate the accuracy of the *bioelectrical impedance* in predicting total fat mass [18–20, 23, 43, 45–47].

Our results showed that the values of $TBF_{DEXA}\%$ were significantly different from the values of $TBF_{BIA\ Tanita\ BC-532}\%$ in both genders. This is in agreement with the findings of previously published studies showing significant differences in the TBF values evaluated by automated BIA devices and the DEXA [45–47]. In a study conducted in France by Lazzar et al. [45] in 53 adolescents with overweight or obesity, the two foot-to-foot BIA devices Tanita® BF-625 and Téfal BodymasterVision® showed low means differences between the TBF% assessed by BIA and DEXA. Similar results were observed in the study conducted by Kasvis et al. [47] using the automated BIA device Tanita® TBF-310 in 7–13 years old youth with overweight or obesity. In the study conducted by Barreira in 5–18 years old youth, the Tanita® SC-240 body composition analyser provided a different body fat estimation from the DEXA in boys and girls of White American ethnicity, unlike in boys and girls of Black American ethnicity [46].

The correlation coefficients and standard error of estimation between the $TBF\%_{DEXA}$ and the $TBF\%_{BIA\ Tanita\ BC-532}$ are relatively high in our study and comparable to the values published in the literature for other foot-to-foot automated bioimpedance analysis devices such as the Tanita® BF-625, the Téfal BodymasterVision®, the Tanita® TBF-310 [45, 47]. However, compared to the DEXA, the absolute value of the residual mean between the assessment of the TBF% by the BIA Tanita® BC-532 and its measurement by DEXA was extremely high in our study, about 10.52% in boys, and 9.96% in girls, with a maximal value about 24%, namely $\frac{1}{4}$ of the total body fat. Previously published studies observed similar errors and limitations of the automated BIA devices in predicting total fat mass in both adults [18–20, 23] and youth [43, 45–47]. In children and adolescents, the difference

between TBF assessed by BIA and measured by a gold standard fat mass method varied between –12.3 and 13.7% [43]. Lazzar et al. [45] showed that the two foot-to-foot BIA devices Tanita® BF-625 and Téfal BodymasterVision® provided significantly different values of TBF% from DEXA. The average differences between body fat assessed by BIA and DEXA were about –2.5% [$TBF_{DEXA}\% - TBF_{Tanita\ BF-625}\%$] ($p=0.001$), respectively –1.8% [$TBF_{DEXA}\% - TBF_{Téfal\ BodymasterVision}\%$] ($p=0.096$) [45]. In addition, the two foot-to-foot BIA devices underestimated the TBF%, compared to the DEXA [45]. In our study, residuals (absolute value, mean \pm SD) were about $10.52\% \pm 5.22\%$ in boys and $9.96\% \pm 4.40\%$ in girls. The Bland and Altman representations did not show any systematic under- or overestimation of the TBF% by the BIA Tanita® BC-532. In 7–13 years old youth from Montréal, Québec, Canada, the Bland and Altman representations showed a low level of agreement between the total body fat measured by DEXA and predicted by the BIA device Tanita® TBF-310 [47]. The average error between the measurement of body fat with DEXA and its estimation with the Tanita® SC-240 was about –1.0% in a group of 5–18 years old youth of Black and White American ethnicity, the average absolute error was about 3.9% [46], although the BIA underestimated the %TBF in the youth of White American ethnicity [46].

To the best of our knowledge, this is the first study evaluating the accuracy of the automated BIA device Tanita® BC-532 in youth. Previous validations of the Tanita® BC-532 by means of the DEXA were conducted in adults. Compared to the DEXA, the Tanita® BC-532 significantly underestimated the TBF% by 6.2 to 10.7% in 18–80 years old adults with a wide range of BMI from Shanghai [50].

These errors might be explained by the fact that the equations predicting the TBF% included in the BIA were developed in a population different from the study population where the BIA is used [30]. The performance of a predictive equation might vary according to the population, as previously shown in a multicentric study conducted with the hand-to-hand automated BIA device, OMRON® BF 306, in different populations from Netherlands, Italy and Finland [51]. The BIA devices are dedicated to be used within the specific populations where the predictive models of TBF were developed, and are not useful for other individuals and groups [27–30]. This might be a limitation of our study.

An additional limitation of the study is the difficulty to assess the hydration status especially as the automated BIA devices do not enable this assessment, although the girls took part to the study outside their menstrual period, which might have controlled, at least for a part, the consistency of the hydration status of the study participants.

Due to the high estimation errors of the total body fat by the automated BIA, it is important to carefully interpret the values of TBF obtained from automated BIA devices in the clinical setting, in particular when the values are used in order to diagnose obesity [30, 52].

Furthermore, when taking body composition measurements in young people, the assessment of puberty is important, although the epidemiological studies previously published on the relationship between obesity and puberty are controverted, especially in boys [53–56]. From one side, the earlier onset of puberty seems to be associated with obesity in girls, but not in boys having obesity who seems to have a late onset of puberty, while boys with overweight display an earlier puberty onset [53–56]. This controversy might be explained by a possible important limitation of the epidemiological studies to accurately assess the pubertal stages, in particular regarding the difficulty to differentiate between adipose tissue and thelarche in girls having obesity; and the difficulty to perform a physical examination and orchidometry in boys, which limits the examination to a subjective visual process, as underlined by Reinehr and Roth (2019) [53]. In our study, the means of TBF (%) by the BIA Tanita® BC-532 were significantly different according to the Tanner stage in girls. However, Tanner stage did not significantly contribute to improve the prediction of TBF%_{DEXA} by TBF%_{BIA Tanita® BC-532} in girls.

In addition, usually the algorithms used to calculate TBF values, and included in the BIA devices available in the market, are non-public. Therefore, we do not know whether these body fat predictive algorithms were adjusted on the puberty's status. This in particular the case of the Tanita® BC-532 BIA device we used in the present work.

A limitation of the total body fat prediction by BIA lies in the fact that the method is based on a two exclusive body compartments model (fat mass and fat free mass) [15–17], which assimilate the water conducting the electric current to the whole fat free mass, without taking specifically in consideration the difference in the fat free mass component (bone, muscle and water compartments).

While affordable BIA technologies have improved over the years, they are not yet validated in all populations, including children, as our study highlights. There is a need for automated, validated, and affordable TBF measurement methods applicable to different populations. Such devices should safely and easily be used for clinical research and epidemiologic purposes but also in healthcare settings and to be used directly by individuals from home. Improving the equations/algorithms used to calculate TBF values in different populations is required. Such improvement could be done by combining for

instance BIA data and anthropometric measurements of the human body. To include populations ranging from children to the elderly, such body dimensions should also be precise, validated, automated as well as affordable. Fully validated and automated devices for TBF measurements would help better diagnose patients with obesity but would also be unique in the digital health devices market, especially for the smart scales segment which is expected to show an annual growth rate (CAGR 2022–2026) of 7.27% worldwide and a projected market volume of US\$4770.33 m by 2026 [57].

Conclusions

The automated BIA device Tanita® BC-532 appears to be not accurate to assess total body fat in youth of White European ethnicity with overweight or obesity. There is a need to calibrate the BIA device before its use in the populations where it was not previously validated.

Abbreviations

BMI: Body mass index; CAGR: Compound Annual Growth Rate; DEXA: Dual-energy x-ray absorptiometry; kHz: Kilohertz; mA: Milliampere; SEE: Standard error of estimation; SD: Standard deviation; TBF: Total body fat; TBF%: Total body fat percentage; WHO: World Health Organisation.

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Authors' contributions

HS conceived the study, collected and analysed the data, interpreted the statistical analyses and wrote the first draft of the manuscript. JL contributed to the manuscript writing. Both authors critically revised the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

The data that support the findings of this study are available from the Luxembourg Institute of Health but restrictions apply to the availability of these data, and so are not publicly available. Data are however available from the corresponding author upon reasonable request and with permission of the Luxembourg Institute of Health.

Declarations

Ethics approval and consent to participate

The National Ethics Committee (CNER N° 200505/04) and the National Commission for Data Protection in Luxembourg authorised the study. The study was conducted in accordance with the Declaration of Helsinki. All the participants and their parents gave a written informed consent before the start of the study.

Consent for publication

Not applicable.

Competing interests

The author declare no conflict of interest.

Author details

¹Precision Health Department, Luxembourg Institute of Health, Strassen, Luxembourg. ²Business Development Office, Luxembourg Institute of Health, Strassen, Luxembourg.

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