



Original article

Development and validation of impedance-based equations for the prediction of total body water and fat-free mass in children aged 8–11 years



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SUMMARY

Background/objectives: Accuracy of impedance analysis depends on population-specific prediction equations. The aim of this study was to propose new prediction equations to estimate body composition using impedance analysis for healthy Tunisian children and validate them using the deuterium oxide dilution (D₂O) technique.

Subjects/methods: Body composition was estimated by the Tanita impedance analyzer. The validity of this system was investigated in 134 school children aged between 8 and 11 years. The validity of other published equations was also tested in our sample. Total body water (TBW) and Fat-Free Mass (FFM) were determined using the D₂O technique. Participants were divided equally into development (n = 67) and validation groups (n = 67) to develop prediction equation using linear regression models.

Results: The comparison between body composition obtained by Tanita system and by D₂O technique illustrated a significant difference (p < 0.01). Compared to D₂O technique, Tanita impedance analysis underestimates fat mass and overestimates FFM and TBW. The prediction equations for TBW and FFM were developed with sex, age, weight and resistance index as possible predictor variables. The selected equations presented the highest adjusted coefficient of determination (R²), the lowest standard error of the estimate (SEE) value and the lowest p-values. The pure error was 1.263 for the TBW equation and 1.646 for the FFM. The Bland Altman plot illustrated the good level of concordance between the TBW and FFM predicted by the new equations and measured by isotope dilution.

Conclusions: Our study provides valid prediction equations for estimation of TBW, FFM from impedance analysis measures for Tunisian children. These equations are applicable to children aged between 8 and 11 years.

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1. Introduction

Body composition evaluation and control are relevant to monitor conditions and delay in development of obesity-related diseases, such as cardiovascular disease, metabolism and

endocrine disorders [1]. It's important to assess the body composition in childhood owing to the fact that nutrition throughout infancy is associated with the risk of disease and mortality in adulthood [2].

In fact, the measurement of body composition in terms of fat mass (FM), fat-free mass (FFM) and Total body water (TBW) has been considered as a superior approach to evaluate nutritional status which goes beyond the information given by weight and height [3,4].

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Body composition can be measured for individuals using accurate and precise techniques such as hydrodensitometry, deuterium oxide dilution (D₂O) technique, dual-energy X-ray absorptiometry (DXA), quantitative Magnetic Resonance Imaging and Ultrasound [1]. However these techniques are expensive and require specifically trained technicians. Moreover, these techniques are not adapted for large epidemiological studies [5].

Bioelectrical impedance analysis (BIA) is reliable, cheap and non-invasive body composition assessment techniques for both clinical and field settings [6]. BIA methods rely on the frequency-dependent response of different body tissues to the application of a weak alternating current and determines an estimate of TBW that is converted to an estimate of FFM, with constant values for the hydration of lean tissue [7,8]. However, these methods need to be used in connection with prediction equations derived from a reference standard and are mostly developed from Caucasian populations. Because of differences in body composition, body proportions and bone geometry [9,10], these equations are valid only for a population of similar age, sex, ethnicity, and health status [11–13].

In Africa, many body composition prediction equations have been developed [14–16]. To date, in North Africa, only one study was conducted but in adult population [17]. So, the first specific purpose of the present study was to investigate the ability of the in-built equations from Tanita system to assess body composition of healthy children aged between 8 and 11 years old and from urban areas compared to D₂O technique as a reference method. The second specific aim was to develop and validate FM and TBW prediction equations using anthropometric variables, with D₂O technique.

2. Material and methods

2.1. Participants

A total of 134 school children aged between 8 and 11 years and enrolled from the first to the fifth year of three elementary public schools were assessed during 2014–2015. The sample selection was conducted randomly on two levels: first, in schools and then on children. Subjects were excluded if they were suffering from an acute illness that could cause abnormalities in body composition.

2.2. Ethics

The study protocols were approved by the scientific research and ethical committee of the National Institute of Nutrition and Food Technology and the agreement of the Ministry of Education and the Ministry of education and training were obtained before beginning the study. Meetings with the directors of three elementary schools to explain the objectives of our work were conducted. Written informed consent was also obtained from the children's parents.

2.3. Anthropometric measurements

Body weight was measured using a digital electronic scale (Seca, Hamburg, Germany, 896 (150 ± 0.1 kg)).

Height was measured using a mobile vertical anthropometer (ALTUREXATA®) graded in centimeters up to 2.13 m and with precision of 0.1 cm.

Waist circumference (WC) was measured with a 2-m long, flexible, inelastic anthropometric tape, divided into centimeters and subdivided into millimeters.

All assessments were performed in the morning 07.00 and 11.00 h in the same season.

2.4. Impedance analysis

A TANITA impedancemeter (TBF-401A, Tokyo, Japan) was used to assess body composition. It is presented as a pedestal analyzer and measuring is done in minutes. Data were measured according to the manufacturer's instructions. Each child must be standing in light clothing and bare feet on the metal imprints shaped soles which constitute the electrodes. Information on resistance (R), the percentage of fat mass (%FM), FM, FFM and TBW were provided. The resistance index (Ht^2/R) was calculated as the square of the height in cm and divided by the resistance in Ω .

2.5. Deuterium oxide dilution

The collection of the samples and the analyses were undertaken according to the guidelines of the International Atomic Energy Agency [18]. The plateau protocol was used for body composition measurement through the isotope dilution of deuterium oxide. In the morning, each child has to empty the bladder and provide a pre-dose saliva sample (to estimate the natural abundance of deuterium) using a cotton ball placed near the Stensen's ducts. The soaked cotton ball was introduced into a 20 ml needle-less syringe and the saliva squeezed out into a 4 ml vial. The children drank with a straw, a gravimetrically weighed amount of deuterium oxide 99.8% (0.5 g/kg of body weight). The bottle containing the dose was rinsed twice with 25 ml of drinking water. The second sample was collected 2 h 30 min after the administration of the dose (post-dose). All samples were stored at -20 °C and the analysis of deuterium enrichment was performed using a Fourier transform infrared spectrophotometer (FTIR Agilent 4500, Malaysia) in the Joint Unit on Nutrition and Food Research, Ibn Tofail University-CNESTEN, Rabat, Morocco. A standard solution of 1000 mg of D₂O/kg of local tap water was gravimetrically prepared and used to calibrate the FTIR.

TBW was determined by deuterium oxide dilution. According to this procedure, the volume of the compartment is equal to the amount of tracer added to it divided by the enrichment of the tracer in that compartment. The TBW was corrected, considering a 4.2% for deuterium exchange with non aqueous compartment in the body. FFM was calculated from TBW, assuming that FFM has an age and sex-specific values of hydration constant 0.732 [19]. FM was estimated from the difference between body mass and FFM.

2.6. BIA-based published prediction equations tested

We tested the validity of prediction equations previously published and mainly those made on children aged between 8 and 10 years. Three equations for the TBW and two equations for the FFM was tested [15,20–22] (Table 3). Most of the selected equations were developed in white populations except one prediction equation that was established in black Africans children.

2.7. Statistical analysis

The anthropometric data were analyzed using SPSS version 17.0.1 (2001. SPSS Inc., Chicago, USA). The variables were computed as means ± standard deviations (SD). The comparison of the general characteristics between subgroups was evaluated by t-tests.

BIA equations from the literature were cross-validated on our sample. Pearson's correlation coefficients were used to study the relation between the measured and predicted values of TBW. The difference between measured and predicted values (bias) was tested against zero using paired t-test. Error was determined as the SD of the bias. The accuracy of the new BIA equations was evaluated using pure error (PE), which was calculated as the square root of the

mean of squares of differences between measured and predicted body composition.

The approach of Bland and Altman [23] was used to compare the body FM as measured by the reference method with what was estimated from the prediction equations. In order to propose a new equation, multiple regression analyses were performed to assess the relation between the variables. The database were sorted by gender and randomly subdivided into two subgroups: a development group was allocated for the development of the equation (67 children) and a validation group to cross-validate the equation (67 children). The Precision of each proposed equation was evaluated using correlation coefficient (r), coefficient of determination (R^2) and standard error of the estimate (SEE). The level of significance was taken as $p < 0.05$.

3. Results

3.1. General characteristics

One hundred thirty four children (61 girls and 73 boys), aged between 8 and 11, were included in this study. The results of anthropometry and body composition of study participants of both the development and validation groups are presented in Table 1. There were no significant differences in all variables between the development groups ($n = 67$) and the validation group ($n = 67$).

The comparison between body compositions obtained directly by Tanita scales in-built prediction equations and by the D_2O technique is presented in Table 2. A significant difference was observed in body composition for overall population and for boys. The greater number of boys in the sample than girls may be

Table 1
General characteristics and body composition.

	Total subject (n = 134)	Development group (n = 67)	Validation group (n = 67)	p-value
Weight (kg)	32.44 ± 7.12	33.56 ± 7.61	31.32 ± 6.46	0.068
Height (cm)	136.83 ± 8.73	137.66 ± 9.00	136.01 ± 0.08	0.136
R (Ω)	605.75 ± 106.45	606.62 ± 106.77	604.86 ± 106.93	0.924
Ht ² /R (cm ² / Ω)	32.34 ± 8.90	32.65 ± 8.95	32.02 ± 8.92	0.684
% FM (imp)	21.19 ± 7.75	22 ± 8.65	20.38 ± 6.70	0.227
TBW D_2O (l)	17.97 ± 3.11	18.41 ± 3.24	17.52 ± 2.94	0.098
FFM D_2O (kg)	23.44 ± 4.1	24.02 ± 4.28	22.86 ± 3.92	0.104
FM D_2O (kg)	9.00 ± 4.03	9.53 ± 4.34	8.46 ± 3.66	0.125

D_2O : deuterium dilution technique; Ht²/R: Height²/resistance; TBW: total body water; FFM: fat-free mass; FM: fat mass; %FM (imp): percentage of fat mass obtained by impedance analysis, Values are mean ± SD; a T-Test between development and validation group.

Table 2
Comparison of body composition data obtained by impedance analysis and the deuterium oxide dilution method in children.

	Tanita System	D_2O Technique	p-value
Overall (n = 134)			
TBW (l)	18.93 ± 3.46	17.97 ± 3.11	0.018
FFM (kg)	25.63 ± 4.74	23.44 ± 4.1	<0.001
FM (kg)	7.44 ± 4.34	9.00 ± 4.03	0.002
Boys (n = 73)			
TBW (l)	19.48 ± 3.10	18.24 ± 2.81	0.012
FFM (kg)	26.49 ± 4.07	23.92 ± 3.75	<0.001
FM (kg)	5.88 ± 3.08	7.85 ± 3.22	<0.001
Girls (n = 61)			
TBW (l)	18.28 ± 3.77	17.63 ± 3.43	0.321
FFM (kg)	24.61 ± 5.29	22.87 ± 4.51	0.053
FM (kg)	9.28 ± 4.89	10.37 ± 4.49	0.202

D_2O : deuterium dilution technique; FFM: fat-free mass; FM: fat mass; TBW: total body water; Values are mean ± SD; a T-Test between data obtained by Tanita system and the D_2O technique.

responsible for this difference. Compared to D_2O technique, impedance analysis underestimates FM for overall population (82.67%) and for boys (74.9%). Tanita system overestimates FFM (109.34%) and TBW (105.34%) for all children compared to deuterium analysis. The same result was also observed for the boys with 110.7% for FFM and 106.8% for TBW.

The use of Bland–Altman approach shows a significant difference in FFM and TBW obtained by the D_2O dilution technique vs the Tanita system (Fig. 1A and B). The bias in the case of TBW was -0.968 with an IC 95% [-1.240 ; -0.697] and for FFM the bias was -2.19 with an IC 95% [-2.557 ; -1.824]. These results reflected an inaccurate estimation of Tanita in-built prediction equation compared to D_2O technique (see Fig. 2).

3.2. Comparison of TBW and FFM from the reference method and BIA-based published prediction equations

The cross-validation of equations from the literature in the validation group is presented in Table 4. All the tested published equations showed significant correlations in boys and in girls. TBW predicted by Wells et al. and Leman et al. equations was significantly overestimated in girls. However, in boys, Wells equation gave acceptable absolute bias of 0.36 ± 1.18 ($p = 0.075$). The bias was negative and significant in boys for Leman et al.

Liu et al. equations significantly underestimate TBW and FFM in males and females. Rush et al. equation showed the higher absolute value for the bias (-5.54 Kg for boys and -5.58 Kg for girls), significant differences displayed by the paired-sample t-test (<0.001), highest pure error and widest limits of agreement.

3.3. Development of the equations

The predictive equation was obtained by stepwise multiple regression and the regression statistics for the prediction equations are presented in Table 5. The FFM (kg) and TBW (l) were the dependent variables. BIA index (Ht²/R), Age, sex and weight were the significant predictors variables included in the equations. The waist circumference was the last variable entered in the model but it presented a high collinearity with a condition number (CN) = 45, meaning that there was no association between independent variables and it was not selected in the final equation.

In the development group, the following equations which presented the highest adjusted R and the lowest SEE value were selected (Table 5):

$$\text{TBW} = +2.456 + 0.083*(\text{Ht}^2/\text{R}) + 0.274*\text{Age} + 0.637*\text{sex} + 0.310*\text{Weight}; \text{ with a regression coefficient } R = 0.918 \text{ and SEE} = 1.342$$

$$\text{FFM} = +2.188 + 0.110*(\text{Ht}^2/\text{R}) + 0.451*\text{Age} + 1.097*\text{sex} + 0.403*\text{Weight}; \text{ with a regression coefficient } R = 0.918 \text{ and SEE} = 1.748$$

where TBW in Litre (l); FFM in kg; Ht²/R in cm²/ Ω ; age in year; Sex: female = 0 and male = 1 and Weight in kg.

3.4. Validation of the prediction equations

In the validation group, the use of the paired t-test showed that there was no significant difference between the TBW measured by isotope dilution technique (17.52 ± 2.94 l) and estimated with the new BIA equation (17.68 ± 2.79 l) validated in the present study ($p = 0.747$). The same observation was recorded for the FFM determined by isotope dilution technique (22.86 ± 3.92 kg) and estimated with the new BIA equation (23.06 ± 3.74 kg) ($p = 0.763$) (Table 6).

The Bland and Altman analysis revealed a good agreement between the two techniques. Indeed, the bias expressed as the mean of the difference in TBW or FFM measured by isotope dilution using

Table 3
Published bioelectrical impedance analysis (BIA)–based prediction equations tested in the study population.

References	Prediction equation	Ages (years)	Countries	RMSE (SEE)	r ²
Wells et al. [20]	$\ln \text{TBW} = -2.952 + 0.5551 \ln (\text{Weight}) + -0.796 \ln (\text{Height}) + 0.008 (\text{Age}) - 0.047 (\text{Sex})$	1–19	London,UK	0.78 l	0.31
Leman et al. [15]	$\text{TBW} = 1.67 + 0.35 (\text{Height}^2/\text{resistance}) + 0.24 (\text{weight}) - 0.74 (\text{Sex})$	5–18	south-western Nigeria	0.7 l	0.987
Liu et al. [21]	$\text{TBW (kg)} = 0.231 (\text{height}^2/\text{resistance}) + 0.066 (\text{height}) + 0.188 (\text{weight}) + 0.128 (\text{age}) - 0.500 (\text{sex})$ $\text{FFM (kg)} = 0.299 (\text{height}^2/\text{resistance}) + 0.086 (\text{height}) + 0.245 (\text{weight}) + 0.260 (\text{age}) + 0.901 (\text{sex})$	8–10	From the five countries: (China, Lebanon, Malaysia and The Philippines Thailand)	1.3 l 1.7 5 kg	0.88 0.883
Rush et al. [22]	$\text{FFM} = 0.622 (\text{height}^2/\text{resistance}) + 0.234 (\text{weight}) + 1.166$	5–14	European, Maori and Pacific Island	2.44 kg	0.96

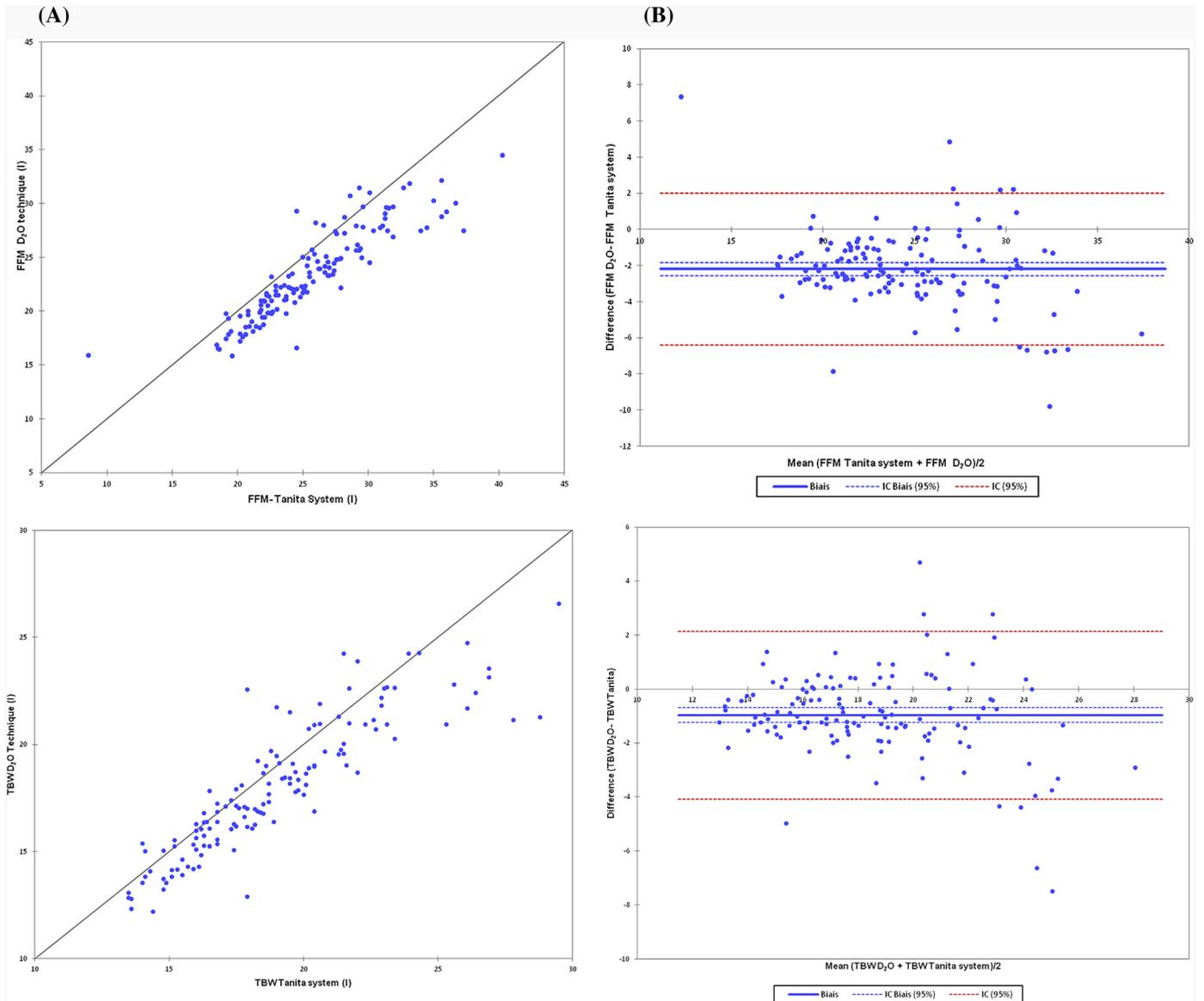


Fig. 1. Bland and Altman plots. (A) Plots of FFM (Kg) and TBW (l) determined by D₂O technique (y-axis) against FFM and TBW from Tanita system for (x-axis). (B) Bland and Altman plots between FFM and TBW measured by D₂O technique and those determined with Tanita system.

FTIR and estimated from the new BIA equation was 0.168 ± 1.269 l for TBW and 0.212 ± 1.656 kg of FFM with a confidence interval at 95% equal to $[-0.144; 0.480]$ for TBW and $[-0.195; 0.619]$. For the models pure errors, it was 1.263 for the TBW equation and 1.646 for the FFM equation (Table 7).

Furthermore, in all samples (134 children) of the present study, the FFM, the body fat and the percent of body-fat values estimated with the new validated BIA equation among girls and boys did not differ from what was measured by the isotope dilution technique ($0.37 \leq p \leq 0.93$) (Table 8).

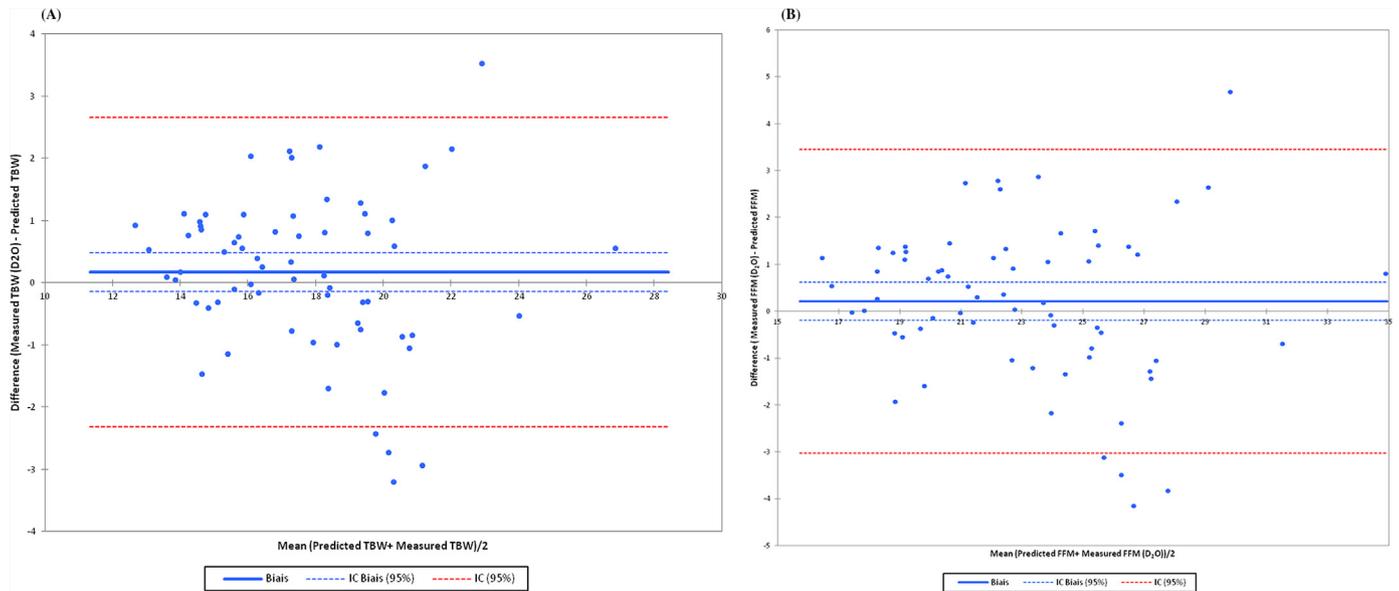


Fig. 2. Bland and Altman plots. (a) Bland and Altman plots between TBW predicted by the new equation and those measured by D₂O technique. (b) Bland and Altman plot between FFM predicted by the new equation and those measured by D₂O technique.

4. Discussion

Little information is available on body composition in non-Western children. Most of techniques developed for the evaluation of the body composition were conceived for the adults, and modifications must be generally applied to the infants. For technical, theoretical and ethical reasons, most of the methodologies are not practical for the measure of body composition in children. Consequently, reliable measures of body composition in children remain a technically challenging area [24]. The BIA is a simple and rapid method, but their specific formulae need to be adjusted [25].

The technique of isotopic dilution is a well established methodology for the measure of human body composition. It is considered as a reference method for the evaluation of TBW, which

is safe, non-invasive and adapted to a pediatric use [26]. To our knowledge, this is the first study carried out in North Africa to determine body composition of children by deuterium dilution technique.

The results of the comparison between body composition from deuterium oxide dilution and those from BIA machine demonstrated clearly, for Tunisian children, that the original Tanita equation measured body composition with a significant bias comparing to D₂O technique. A similar result was reported by Khan et al. in Bangladeshi children [27]. However, other study reported that the Tanita BIA system agrees well with reference methods in Caucasian populations [28].

This variability was probably due to differences in physical and body geometry between the children ethnicities which is, in our knowledge, not taken into consideration, in Tanita equation [29].

In our study, the TBW and FFM measured by D₂O technique was compared to that predicted by BIA-based published prediction equations for the same age range and showed a significant correlation. However, Bland Altman approach revealed high values of

Table 4
Comparison of TBW and FFM from the reference method and published prediction equations.

Equation	Mean	r	Bias	Error	Limits of agreement	Pure error
Males (n = 37)						
TBW D₂O	18.21 ± 2.90					
Wells et al.	17.85 ± 2.58	0.914	0.36 (0.075)	1.18	-1.95; 2.67	1.21
Leman et al.	20.95 ± 4.03	0.805	-2.74 (<0.001)	2.42	-7.48; 2.00	3.63
Liu et al.	16.38 ± 3.08	0.820	1.83 (<0.001)	1.80	-1.70; 5.36	2.55
FFM D₂O	23.88 ± 3.85					
Liu et al.	29.41 ± 6.27	0.830	3.64 (<0.001)	2.25	-0.77; 8.05	4.27
Rush et al.	20.23 ± 3.87	0.773	-5.54 (<0.001)	4.10	-13.58; 2.50	6.86
Females (n = 30)						
TBW D₂O	16.67 ± 2.81					
Wells et al.	18.72 ± 3.31	0.948	-2.05 (<0.001)	1.14	-4.21; 0.11	2.31
Leman et al.	18.97 ± 4.65	0.838	-2.30 (<0.001)	2.75	-7.69; 3.10	3.55
Liu et al.	14.99 ± 3.51	0.863	1.68 (<0.001)	1.78	-1.81; 5.17	2.43
FFM D₂O	21.60 ± 3.69					
Liu et al.	27.18 ± 7.05	0.863	1.57 (0.001)	2.21	-2.76; 5.90	2.68
Rush et al.	29.42 ± 5.72	0.988	-5.58 (<0.001)	4.68	-14.75; 3.59	7.23

r: Correlation coefficient.

Error: Standard deviation of the absolute bias.

Limits of agreement: Mean absolute bias ± 1.96 SD.

Bias: Mean measured-predicted value (a negative value of the bias reflects an overestimation by the prediction equation) (significance at 0.05 level).

Pure error: (Σ (Measured-predicted)²/n).

Table 5
Regression models for the prediction of TBW and FFM.

Variables included in the model	Regression coefficient (SE)	R	SEE	p-value	Collinearity statistics	
					CN	VIF
TBW						
Constant	+2.456	0.620	2.558	0.000	0.737	1.356
H ² /R	+0.083	0.761	2.132	0.144	0.632	1.583
Age	+0.274	0.761	2.149	0.062	0.960	1.041
Sex	+0.637	0.916	1.342	0.000	0.489	2.046
Weight	+0.310					
FFM						
Constant	+2.188	0.619	3.391	0.000	0.737	1.356
H ² /R	+0.110	0.769	2.781	0.066	0.632	1.583
Age	+0.451	0.770	2.799	0.015	0.960	1.041
Sex	+1.097	0.918	1.748	0.000	0.489	2.046
Weight	+0.403					

FFM: fat-free mass (Kg); TBW: Total body water (l); SEE: standard error of the estimate (kg or l); Sex: male = 1, female = 0; CN: condition number; VIF: variance inflation factor.

Table 6

Comparison between TBW and FFM measured by isotope dilution using FTIR and by new BIA equation in the cross-validation sample.

	Mean \pm SD	p-value
TBW by isotope dilution	17.52 \pm 2.94	0.747
TBW by new BIA equation	17.68 \pm 2.79	
FFM by isotope dilution	22.86 \pm 3.92	0.763
FFM by new BIA equation	23.06 \pm 3.74	

FFM: fat-free mass (kg); TBW: Total body water (l).
SD: Standard Deviation.

Table 7

Cross-validation of the new equation with isotope dilution for prediction of TBW and FFM.

Equations	BIAIS	IC BIAIS	Pure error
TBW	0.168 \pm 1.269	[−0.144; 0.480]	1.263
FFM	0.212 \pm 1.656	[−0.195; 0.619]	1.646

FFM: Fat-free mass (kg); TBW: Total body water (l).

Table 8

Comparison of TBW and FFM from the reference method and prediction equations and according gender.

		D ₂ O technique	TBW equation – tanita system	p-value
TBW Equation				
Boys (n = 73)	FFM (kg)	23.92 \pm 3.75	23.87 \pm 3.48	0.93
	FM (kg)	7.85 \pm 3.22	7.90 \pm 3.00	0.92
	FM%	24.02 \pm 5.64	24.12 \pm 4.62	0.91
Girls (n = 61)	FFM (kg)	22.87 \pm 4.51	23.19 \pm 4.26	0.69
	FM (kg)	10.38 \pm 4.49	10.05 \pm 4.02	0.67
	FM%	30.29 \pm 6.93	29.33 \pm 4.63	0.37
FFM Equation				
Boys (n = 73)	TBW (l)	18.24 \pm 2.81	18.18 \pm 2.57	0.89
	FM (kg)	7.85 \pm 3.22	7.92 \pm 3.02	0.89
	FM%	24.02 \pm 5.64	24.16 \pm 4.63	0.87
Girls (n = 61)	TBW (l)	17.64 \pm 3.43	17.87 \pm 3.26	0.70
	FM (kg)	10.38 \pm 4.49	10.07 \pm 3.10	0.69
	FM%	30.29 \pm 6.93	29.39 \pm 4.59	0.40

FFM: fat-free mass (kg); TBW: total body water (l); FM: Fat mass(kg); Values are mean \pm SD.

bias. When compared against zero the differences between measured and predicted values were significant which indicated the inaccuracy of these equations. The Wells et al. equation performed on a Caucasian population was the most accurate one with the smallest error and pure error. This result can be explained by the sufficiently large number of subjects used in this study (n = 672). However, the equation of Wells is not valid in our population because it overestimated the TBW in girls with a negative bias value (−0.5, (<0.001)). Liu et al. and Rush et al. equations developed in mixed population were not valid in our sample. This finding confirmed that mixed population equations do not guarantee the validity of prediction in specific populations. Thereby, previous reports suggested that population-specific prediction equations might be developed for body composition assessment [10,30].

When developing novel equations for body composition prediction, children were divided into two groups: one for generating the equation and one for validating it. There were no differences in the general characteristics between the two groups. The former fact indicated that the randomization procedure was adequate. TBW and FFM were used as our outcome variables rather than FM because of the functional relationship between resistance and the hydrated lean tissue of the body [21]. The prediction equations for TBW and FFM were developed using the BIA index (Ht^2/R), sex, age

and weight as possible predictor variables. In practice, BIA index and weight were considered, in previous report, as the strongest predictors of body composition and the inclusion of age, gender and anthropometric parameters improved the predictability of TBW or FFM [5,16,17].

BIA equations developed in this study ($r = 0.918$; $SEE = 1.342$ l and $r = 0.918$; $SEE = 1.748$ kg respectively for TBW and FFM) showed similar statistical parameters to/or better than those obtained with other equations used for the same population, such as that of Schaefer et al. based on total body potassium ($R^2 = 0.975$, $SEE = 1.98$ kg) [31], De Lorenzo et al. based on DEXA ($r = 0.96$, $SEE = 1.0$ kg) or Cordain et al. based on hydrodensitometry and total body potassium ($r = 0.83$; $SEE = 4.08$) [32,33] or Sun et al. based on a multicomponent model based on densitometry, isotope dilution and DEXA ($R^2 = 0.90$ for males and 0.83 for females; $SEE = 3.9$ for males and 2.9 for females) [34].

Our validation results indicated that the predicted values correlated very highly and the Bland and Altman approach showed a good agreement between the predicted and the measured values of TBW and FFM. The pure error recorded on the model was 1.263 for the TBW and 1.646 for the FFM. This result was similar or better than those from the previous study, that indicated a pure error of 1.34 l for the TBW and 1.84 kg for the FFM [5].

4.1. Limitations of the study

The most important limitation of our study is age range which is limited between 8 and 11 years. But even in this case, studying body composition in this age range has some relevance. There is a good evidence that the trajectories of growth during infancy and childhood are a major risk factor for a group of chronic diseases that includes coronary heart disease and diabetes [35]. Finally it is important to point out that all body composition methods are an indirect measure based on assumptions which can be considered to actually accurately measure body composition [36].

5. Conclusion

The assessment of body composition in children is essential to monitor nutritional status. Since body composition prediction equations are population specific, there is a need for a valid equation in Tunisian children.

In this study, we have generated new prediction equations for FFM and TBW based on BIA index, weight, sex and age measurements. These equations provided a better agreement with the isotope dilution and could be used for Tunisian and north African children between 8 and 11 years.

Conflict of interest

The authors declare no conflict of interest.

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