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Original article

Validation of bioelectrical impedance analysis for body composition assessment in children with obesity aged 8-14y

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SUMMARY

Background & aims: The aim was to generate a predictive equation to assess body composition (BC) in children with obesity using bioimpedance (BIA), and avoid bias produced by different density levels of fat free mass (FFM) in this population.
Methods: This was a cross-sectional validation study using baseline data from a randomized intervention trial to treat childhood obesity. Participants were 8 to 14y (n = 315), underwent assessments on anthropometry and BC through Air Displacement Plethysmography (ADP), Dual X-Ray Absorptiometry and BIA. They were divided into a training (n = 249) and a testing subset (n = 66). In addition, the testing subset underwent a total body water assessment using deuterium dilution, and thus obtained results for the 4-compartment model (4C). A new equation to estimate FFM was created from the BIA outputs by comparison to a validated model of ADP adjusted by FFM density in the training subset. The equation was validated against 4C in the testing subset. As reference, the outputs from the BIA device were also compared to 4C.
Results: The predictive equation reduced the bias from the BIA outputs from 14.1% (95%CI: 12.7, 15.4) to 4.6% (95%CI: 3.8, 5.4) for FFM and from 18.4% (95%CI: 16.9, 19.9) to 6.4% (95% CI: 5.3, 7.4) for FM. Bland–Altman plots revealed that the new equation significantly improved the agreement with 4C; furthermore, the observed trend to increase the degree of bias with increasing FM and FFM also disappeared.
Conclusion: The new predictive equation increases the precision of BC assessment using BIA in children with obesity.

1. Introduction

Adipose tissue has several functions, such as maintaining body temperature, regulating energy expenditure or releasing bioactive

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compounds playing an important role in appetite metabolism and energy homeostasis [1,2]. However, excess fat accumulation leads to adipose tissue dysfunction and to an increased risk of non-communicable diseases [3]. Although BMi is used worldwide as an index of adiposity for diagnosing and monitoring obesity, it has several limitations. The most important is that is not able to distinguish between fat mass (FM) and fat-free mass (FFM) [4]. During childhood, changes in BMI and body composition occur as part of the normal development. While increases in BMI in early infancy might be due mainly to changes in FM [5], the normal increase in BMI occurring during pre-puberty and puberty might be due to FFM in a higher proportion than FM [6]. Therefore, changes in BMI throughout childhood may not always be due to a change in adiposity.

There are many accurate techniques for assessing body composition; such as dual-energy X-ray absorptiometry (DXA), hydrometry by isotopic dilution, air-displacement plethysmography (ADP), ultrasonography, computed tomography, among others. However, these techniques are costly, time consuming and/or are only available in some clinical settings or specialized research centres. Bioelectrical impedance analysis (BIA) is a relatively inexpensive, non-invasive and safe technique and it does not require specialised training to perform. However, there have been several reports calling into question the accuracy of the predictive equations used to estimate body composition using BIA [7].

BIA is based on the relationship between total body water (TBW) and the electrical body impedance (Z). By estimating TBW, predictions for FFM and FM are made. BIA is based on the principle that tissues with a high electrolytic fluid composition, such as FFM, are conductors whereas fat and bone are not. However, BIA has several limitations. For example, BIA relies on the assumption that the body is a set of cylinders (trunk, upper-arms, forearms, upper-legs, lower-legs) with different percent contributions to both body weight (WT) and Z. The trunk contributes to nearly half of the body weight but contributes little to the whole-body Z, whereas the limbs contribute the most to whole-body Z. This disproportionality may confound the relationship between Z index (HT^2/Z) and TBW [8]. In addition, to predict FFM from TBW, the hydration factor of the FFM is assumed to be constant and it is known that many physiological variables (gender, age, ethnicity, hormone cycle, pregnancy, exercise, time of the day) and pathological (obesity, disease conditions, medication) circumstances influence the hydration status [9–11].

Several studies have validated the use of bioelectrical impedance analysers in children, with some providing specific predictive equations [12]. However, most studies have reported an increased bias when using BIA in children and adults with obesity compared to normal weight [13,14]. BIA has an acceptable accuracy for normal weight healthy children, but previous research has shown that as FM increases, so does the level of underestimation [15]. Therefore, monitoring changes in body composition in children with obesity using BIA might be difficult, since the measurement error might be higher than the actual change [16]. Few longitudinal studies have validated the use of BIA to assess changes in body composition in children [17] and even less have been performed in children with obesity. However, previous reports support the hypothesis that specific equations were reliable for longitudinal assessment [16].

Most of the published equations have been obtained by comparison of BIA with isotope dilution [18,19], DXA [20,21] and the 4-component (4C) model [22]. However, when considering a special population such as children with obesity, equations for the normal weight population may not be appropriate [14,23]. One of the most important key points is that FFM in children with obesity has different properties (hydration and density) than normal weight children [11]. Therefore, if bioelectrical impedance equations are obtained by comparison to techniques that also assume a constant hydration of FFM, as in DXA, these predictive equations will always be adding bias to the analysis of children with obesity.

The aim of our study was to generate a novel predictive equation to assess body composition in children with obesity using BIA, but avoiding possible bias produced by altered hydration or density levels of this population.

2. Materials & methods

2.1. Design

This was a cross-sectional validation study, secondary to a randomized clustered clinical trial on a motivational intervention to treat children with obesity. To perform the present validation study, we used the baseline body composition data of the participants enrolled in the OBEMAT2.0 clinical trial [24].

2.2. Participants

Data from 315 children with obesity (170 males; 145 females) aged 8 to 14 were obtained from the clinical trial OBEMAT2.0 at baseline. Children were recruited from June 2016 to March 2018 from primary health care centres belonging to the "Camp de Tarragona" healthcare area. Obesity was considered according to BMI values equal or higher than the 97th percentile from Hernandez et al. [25] according to the National Clinical Practice Guidelines [26].

The overall sample was divided into two subsets for validation purposes: the test subset ($n = 66$), from whom body composition was assessed with the 4C model, and the training subset (the remaining 249 children).

2.3. Measurements

2.3.1. Anthropometry

Body weight was measured using a digital scale (SECA 703) to the nearest 0.5 kg in underwear or minimum clothing. Height was measured by a wall-mounted stadiometer (SECA 216) with 0.1 cm of precision. Body mass index (BMI) was calculated as weight (WT) over height squared (HT^2) in kg/m^2. BMI was then converted into standard deviation scores (SDS) using the current WHO 2007 reference data [27].

2.3.2. Body composition analyses

Body composition was assessed using Dual-energy X-ray absorptiometry (DXA), air displacement plethysmography (ADP) and bioelectrical impedance analysis (BIA) in the total sample of 315 subjects. From those, 66 individuals (35 males) were selected by order at arrival to perform a TBW assessment by deuterium dilution (DD) analysis. In this subsample, body composition by 4C was assessed. All examinations took place between 8:00 a.m. and 10:00 a.m. after an overnight fast.

The new proposed equation using raw impedance was generated in the training subset by comparison to calculations using body volume (BV) and FFM density (D_{FFM}) [28]. The predictive equation was then applied to the test sample subset to be validated against the 4C model.

2.3.2.1. Reference method: the 4-component model (4C). The 4C model divides the human body into fat, protein, mineral and water. Using the measures obtained from ADP, DXA and hydrometry (as detailed below). FM was calculated using the equation of Fuller [29]:

$$FM_{4C} = (2.747 \times BV) - (0.710 \times TBW) + (1.460 \times BMC) - (2.050 \times WT)$$

where FM = fat mass in kg; BV = body volume (L) from ADP; TBW = total body water volume (L) from deuterium dilution; BMC = bone mineral content (kg) from DXA and WT = body weight (kg).

FFM_{4C} was then calculated as the difference of FM from body weight, in kg.

2.3.2.1.1. Dual energy x-ray absorptiometry (DXA). To assess bone mineral content (BMC) (g), a whole body DXA scan was performed by a specialist trained technician using a General Electric Lunar Prodigy Advance (Madison, Wi, USA) instrumentation and the GE, Axial Lunar Prodigy Full Advance (encore 2014 version 15.20.002) software. Individuals wore underclothes during the test, laying in the supine position with arms at their side.

2.3.2.1.2. Air-displacement plethysmography (ADP). BV was measured by ADP using a BODPOD device (Life Measurements, Inc, Concord, CA). Measurements were taken following the manufacturer's instructions and recommendations, wearing tight fitting swimsuits or underclothes and swimming caps. Each test performed two body volume measures. If these duplicate measures of BV differed more than 150 ml, a third measurement was performed. The average of the two measurements (or the closest two when a third measure was needed) was then used in subsequent calculations. The thoracic gas volume remaining in lungs was predicted by children's equations [30], and subtracted from total body volume in subsequent calculations.

2.3.2.1.3. Hydrometry by deuterium oxide dilution (D_2O). The first sixty-six participants who agreed to participate in this sub-study had an oral dose equivalent to 1 g/kg body weight of deuterium oxide (^2H_2O). Participants collected six urine samples: one sample before dosing at the study site and then daily for five days, preferably at the same time of day, avoiding the first urine in the morning. The samples were refrigerated until the families brought them back to the study site 6–10 days after dosing where they were stored at −20 °C. Samples were shipped to the Medical Research Council Elsie Widdowson Laboratory (MRC EWL, Cambridge, UK) for their analysis. For ^2H enrichment, samples of 0.4 ml were placed in 3.7 ml glass vials and flush-filled with hydrogen gas, and then equilibrated for 6 h in the presence of a platinum catalyst. The headspace of the samples was then analysed using a continuous flow IRMS (Sercon ABCA-Hydra 20–22, Sercon Ltd, Crewe, UK). All measurements were made relative to V-SMOW (Vienna Standard Mean Ocean Water) using calibrated laboratory standards. Analytical precisions (SD) were better than ± 1.3 ppm for ^2H.

TBW (kg) was calculated using the zero-time intercept of ^2H turnover and corrected for non-aqueous exchange within the body.

2.3.2.2. Bio-electrical impedance analysis (BIA). BIA was measured using the octopolar TANITA BC–418MA (Tanita Corporation, Tokyo, Japan) device. Subjects, wore minimal clothing, stood barefoot on the metal footplates and held hand grips. Outputs from the device were whole-body impedance and predicted FM (FM_{TANITA}) and FFM (FFM_{TANITA}) by using the manufacturer's internal equations. Measurements were taken twice, and the average was then used in further calculations.

We compared the results of the BIA analyser (FM_{TANITA} and FFM_{TANITA}) to the results of the 4C model (FM_{4C} and FFM_{4C}). Additionally, we used the raw whole-body impedance to create a new predictive equation.

2.3.2.3. Method used to generate the new equation from raw whole-body impedance. FM was used as a dependent variable in a predictive model to create a new equation was obtained using body volume from ADP and density of fat-free mass (predicted) following the procedure detailed below (to avoid the bias that could be produced by changes in hydration and density in obesity).

D_{FFM} was calculated using the following predictive equation [11]:

$$D_{FFM} = 1.0791 + (0.009 \times \text{age}) + (0.0021 \times \text{gender}) - (0.0014 \times BMI_Z)$$

where age is given in years; gender 1 = male and 2 = female; BMI_Z = body mass index in z-scores.

Derived values for density of the fat-free mass (D_{FFM}) were used with an assumed constant density of fat mass to generate age-specific constants (C1 and C2) [31]:

$$C1 = \frac{(D_{FFM} \times D_{FM})}{(D_{FFM} - D_{FM})} \quad C2 = \frac{(D_{FM})}{(D_{FFM} - D_{FM})}$$

where D_{FM} = 0.9007 kg/L (assumed to be constant).

These constants (C1 and C2) were used in the generic equation of Siri [32] to calculate body fat percentage:

$$BF\% = \left(\frac{C1}{BD} - C2\right) \times 100$$

where BF% = Body Fat percentage and BD = body density and was calculated as:

$$\text{Body Density}\left(\frac{kg}{L}\right) = \frac{\text{Body weight}(kg)}{\text{Body Volume}(L)}$$

where Body Volume was obtained from ADP output.

Then, FM (kg) derived from D_{FFM} and body volume measurements (FM_{ADP}) was calculated as:

$$FM_{ADP} = \frac{BF\% \times Weight}{100}$$

where BF% = percentage of body fat; weight in kg.

Then, FFM_{ADP} was calculated as the difference of FM_{ADP} from body weight, in kg.

Whole-body impedance (Z) was used in a regression model to predict FFM_{ADP} to create a new equation. The results from applying the new equation were FFM_Z (kg) (and FM_Z was calculated as the difference between body weight and FFM_Z).

2.4. Statistical analysis

All statistical analysis was performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). The sample was analysed separately as two sampled groups: the training sample (n = 249) and the test sample (n = 66). Descriptive characteristics for the training, testing and the overall sample are shown as means ± standard deviation (SD). Kolmogorov–Smirnov test for normality was applied and Student's T-test was performed to assess differences in continuous variables between sample groups (training and test subsets). We used a Chi squared test to assess differences in gender distribution between the training and test subsets.

A bootstrap linear regression analysis of 1000 sample replications from the training sample (n = 249) was undertaken to derive predictive equations for fat-free mass. The independent variables introduced using the enter method in the linear regression model

were impedance index (HT^2/Z), age, gender, body weight or BMI (to find out the one with the highest goodness of fit). The obtained predictive equation was applied to the test sample (n = 66) to externally validate it.

We assessed the association between body composition obtained from BIA (FFM_{TANITA}, FM_{TANITA}, FFM_Z and FM_Z) and the reference method (4C) by Pearson correlation coefficients after applying Kolmogorov–Smirnov test for normality. Reliability was obtained from Cronbach's α analysis. Concordance was given as an intraclass correlation coefficient (ICC) with a confidence interval (CI) of 95%. Percentage of the differences between methods and 4C are shown as mean ± SD with a 95% CI. Bland and Altman plots were performed and the limits of agreement calculated, to assess the agreement of the methods with the reference (4C model). The trend to increase under o overestimation by the composition results obtained from BIA and by those obtained from the new equation compared to the 4C model were tested with Pearson correlations.

2.5. Ethics

The study followed the rules of the Declaration of Helsinki [33]. Ethical committees of all involved study centres approved the study. All parents or legal guardians signed informed consent prior to study enrolment. Children aged 12 years or above signed informed assent to participate in the study as well.

3. Results

Table 1 shows the characteristics of the training and test subjects. There were no statistically significant differences in the gender distribution, average age, anthropometry nor body composition measures between the training and the test subsets.

Linear regression analysis was performed to predict FFM_{ADP} from HT^2/Z in the training sample (n = 249) bootstrapping 1000 samples (Table 2). The first model, without adjustments, explained 85.7% of the FFM_{ADP} variance. Adding age, gender and BMI, the goodness of fit increased up to 87.7%. The obtained predictive equation to assess body composition from impedance in children with obesity was:

$$FFM_Z = -9.012 + \left(0.818 \times \frac{HT^2}{Z}\right) + (0.742 \times Age) + (0.648 \times gender) + (0.235 \times BMI)$$

where HT^2/Z is the raw impedance measure obtained from the BIA device, age is given in years, gender is 1 for males and 2 for females, and BMI is provided in kg/m^2. The standard error of this equation was 2.7 kg.

FM_Z (kg) was obtained from subtracting FFM_Z from total body weight (kg). The results from body composition obtained through the new predictive equation (FFM_Z and FM_Z) and those obtained directly from the device (FFM_{TANITA} and FM_{TANITA}) were then tested in the test subset (n = 66) against 4C.

The output from TANITA overestimated FFM by 14.1% ($p < 0.001$) and underestimated FM by 18.4% ($p < 0.001$) (Table 3). The difference compared to the reference method was reduced to 4.6% for FFM_Z and 6.4% for FM_Z when using the generated predictive equation (Table 3).

FFM_{TANITA} and FM_{TANITA}: FM and FFM (kg) obtained from the impedance device internal algorithms; FFM_Z and FM_Z: FM and FFM (kg) obtained from the impedance equation generated for children with obesity.

The limits of agreement were narrower when using the generated predictive impedance equation (Fig. 1B and D) (limits of agreement were −2.5 kg–4.2 kg for FFM_Z and −4.2 kg–2.5 kg for FM_Z) than the direct outputs from the BIA device (Fig. 1A and C) (limits of agreement were 0.8 kg–8.3 kg for FFM_Z and −8.0 kg to −0.6 kg for FM_Z). The Bland & Altman plots of the direct outputs from the impedance device showed a bias trend: the higher the FFM, the greater the overestimation (Pearson correlation $r = 0.364$, $p < 0.001$), and the higher the fat mass, the greater the underestimation (Pearson correlation $r = -0.517$, $p < 0.001$). Furthermore, there was no significant trend to increase under nor overestimation with increase of FM or FFM using the new equations.

Table 4 shows the correlations and reliability coefficients of the BIA methods and the reference 4C model. FFM measures obtained from both the new equation and the device outputs were highly correlated to 4C assessment and showed similar values of reliability. However, the FFM_Z showed higher concordance than FFM_{TANITA} with the gold standard.

FFM_{TANITA}: FFM (kg) obtained from the impedance device internal algorithms; FFM_Z FFM (kg) obtained from the impedance equation generated for children with obesity.

4. Discussion

In this article, we showed a method to assess body composition, which offers an improvement in the estimation of body composition in children with obesity and it is feasible for both research and clinical practice, at low cost, by using a measure of whole body impedance from BIA, BMI, age and gender.

The accurate determination of body composition usually requires expensive equipment, complex and time-consuming methods and well-trained technicians (e.g., DXA, MRI, ADP, UW, DD, etc.). These circumstances hinder the use of accurate methods to evaluate body composition in clinical practice and limit its use to research. Hence, clinicians use simpler and cheaper methods to evaluate body composition in children with obesity even though precision is compromised with BMI and skinfold thicknesses.

Some authors have proposed DXA as a criterion method to assess body composition [34]. Despite DXA having been demonstrated to be a safe and accurate method to assess body composition, it is worth being cautious when using DXA as a reference method in paediatric studies [35] and, in addition, DXA presents some limitations when assessing both children and adults with obesity [36,37] and longitudinal body composition changes [38]. The main disadvantages of DXA are that DXA includes a small amount of radiation, which limits its reproducibility in a short time for an individual; the equipment is very expensive, needs a large space for storage, is not portable and requires a trained specialist technician to perform the test. Thus, DXA is limited to research studies and diagnosis related to bone health.

Although there is a lack of evidence about ADP accuracy in children and adolescents with obesity, some authors have recently used ADP as the criterion method to validate BIA and other body composition measurements in children [39,40]. ADP (nowadays performed by a BODPOD device) is accurate, reliable and precise [41], but it is expensive, needs to be placed in a room with specific conditions and requires an exhaustive preparation before each use. We recently published a methodological approach to reduce the bias produced by the ADP by assuming a constant hydration and density of FFM in children with obesity [11,28]. Thus, this was the method used in the present work to generate a new equation to estimate body composition from BIA in children with obesity.

BIA has been proposed by many investigators, as a feasible option to assess body composition when others of higher precision are not available, due to its advantages: BIA is quick, inexpensive, non-

Table 1
Description of anthropometry and body composition of overall sample and train and test samples.

	Whole sample (n = 315)		Train sample (n = 219)		Test sample (n = 66)		p-value[a]
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Gender (males/females)	170/145	–	135/114	–	35/31	–	0.851
Age (y)	10.8 ± 1.6	8.0–14.25	10.9 ± 1.6	8.0–14.25	10.7 ± 1.5	8.0–13.3	0.275
Weight (kg)	58.0 ± 12.5	35.9–105.3	58.5 ± 12.8	35.9–105.3	56.2 ± 11.2	31.0–83.1	0.188
Height (cm)	148.7 ± 10.5	124.6–177.0	149.2 ± 10.6	124.6–177.0	146.9 ± 10.2	125.5–170.3	0.099
BMI kg/m2	26.0 ± 2.8	20.7–36.9	26.0 ± 2.9	20.7–36.9	25.9 ± 2.5	21.7–32.5	0.879
BMI z-score	2.60 ± 0.48	1.40–4.77	2.59 ± 0.5	1.40–4.77	2.62 ± 0.40	1.86–4.20	0.636
Impedance (m^2/ohms)	34.7 ± 7.2	21.3–59.4	34.9 ± 7.3	21.41–59.44	33.9 ± 6.6	21.3–47.5	0.351
Body Volume (L)	57.8 ± 12.6	35.7–105.7	58.3 ± 13.0	35.7–105.7	56.0 ± 11.2	36.1–83.7	0.178
D_{FFM} predicted (kg/L)	1.088 ± 0.002	1.083–1.093	1.088 ± 0.002	1.083–1.093	1.088 ± 0.002	1.083–1.092	0.445
FFM_{ADP} (kg)	34.4 ± 7.5	29.1–38.0	34.6 ± 7.7	29.3–38.7	33.6 ± 6.9	28.7–37.8	0.325
Total Body Water (kg)	–	–	–	–	24.8 ± 5.0	15.8–36.7	–
Bone Mineral Content (kg)	1.71 ± 0.41	1.43–1.94	1.73 ± 0.41	1.44–1.98	1.66 ± 0.38	1.37–1.88	0.248
FM_{4C} (kg)	–	–	–	–	23.3 ± 5.8	11.6–38.7	–
FFM_{4C} (kg)	–	–	–	–	32.9 ± 6.7	20.3–50.6	–

[a] p-value for Student's T-test between the test and the training samples.

Table 2
Predictive models for impedance to predict fat-free mass (using FFM_{ADP}, which is fat free mass predicted from body volume and adjusted by density of fat free mass).

		B	SE	p value	95% CI	r^2	s.e.e.
Unadjusted model	Constant	0.496	1123	0.651	(−1.817, 2.911)	0.857	2927
	Impedance index (HT^2/Z) (m^2/Ω)	0.978	0.035	0.001	(0.907, 1.044)		
Adjusted model	Constant	−9.012	1726	0.001	(−12.263, −5.785)	0.877	2712
	Impedance index (HT^2/Z) (m^2/Ω)	0.818	0.060	0.001	(0.700, 0.922)		
	Age (years)	0.742	0.144	0.001	(0.426, 1.051)		
	Gender	0.648	0.298	0.037	(0.065, 1.242)		
	BMI (kg/m^2)	0.235	0.098	0.014	(0.058, 0.442)		

Table 3
Analyses of differences (%) of impedance methods against the four-component model.

	Mean (95% CI); p-value	SD	Minimum	Maximum
FFM_{TANITA}	14.1% (12.7,15.4); p < 0.001	5.4	1.3%	29.3%
FM_{TANITA}	18.4% (16.9, 19.9); p < 0.001	6.1	1.0%	29.3%
FFM_Z	4.6% (3.8, 5.4); p < 0.001	3.3	0.0%	15.7%
FM_Z	6.4% (5.3, 7.4); p < 0.001	4.2	0.1%	16.9%

invasive, safe, easy to store, portable, and it is suitable for a large range of populations and requires little training to use which makes it an appropriate technique for routine clinical use. Many publications have evidenced that BIA had poor accuracy due to the use of non-specific population equations [16,42–44]. Actually, BIA has shown greater bias associated with greater BMI [15]. Our work also identified TANITA's manufacturer's equation biases when compared to the gold standard (4C), according to previous studies performed with paediatric populations [16,45,46]. The main inconvenience is that BIA results are biased for those populations with altered hydration levels, such as pregnancy, fasting, exercise prior to the test, pharmacological treatments, diseases, obesity, pubertal stage, etc. Thus, these BIA biases could be due to the assumed constant values of fat-free mass properties, more specifically, the water fraction of FFM.

Published reference data for the hydration [47] and density of FFM [31] were obtained from general population studies. Thus, we found that body composition measurements in children with obesity from TANITA's outputs were highly biased when compared to body composition calculations with the 4C. These results were consistent with those found by other investigators [44]. In 1996, Deurenberg [48] discussed the validity of BIA in severely obese subjects and concluded that an increased relative TBW, as well as different fat distribution, would result in underestimations of FM predicted by manufacturer's equations; especially in those subjects with severe abdominal obesity, who have a big proportion of fat and water located in the trunk (part of the body which contributes poorly to impedance).

These findings are very important to consider when monitoring weight loss treatment or performing longitudinal studies where individual changes in body composition might not be reliably detected. Furthermore, there are several conditions in which analysing body composition rather than simple anthropometry may have several advantages in terms of diagnosing and performing interventions. For example, in sarcopenic obesity, body composition measures allow focused nutritional interventions, or fat free mass has shown to be a predictor of hospital stay duration in children while BMI not [49]. That is why there are several predictive equations population-specific published to estimate body composition from BIA.

Many predictive equations for specific populations have been published [50,51], but not so many specifically for children with obesity, and few equations have been compared to multi-component models. The most recent approaches including BIA and children with obesity were from Lazzer et al. (2008) [46], Haroun et al. (2009) [16], Clasey et al. (2011) [45] and Seo et al. (2018) [52]. Lazzer et al. found that BIA underestimated FM % by 5.8% (±4.6%) when compared to DXA in a study which comprised 58 adolescents with obesity [46]. Clasey et al. [45] published in 2011 a predictive equation obtained from a sample of 361 boys and girls (obese and non-obese) aged 5–11 years, and tested the equation in a sample of 75 children. The criterion method used was DXA. They obtained a high degree of agreement with DXA. They concluded that this equation was suitable for children, including those with obesity. However, this study had a reduced sample of subjects with obesity in their validation analysis. Seo et al. [52] published a validation study of BIA against DXA and compared the agreement between both techniques depending on the degree of

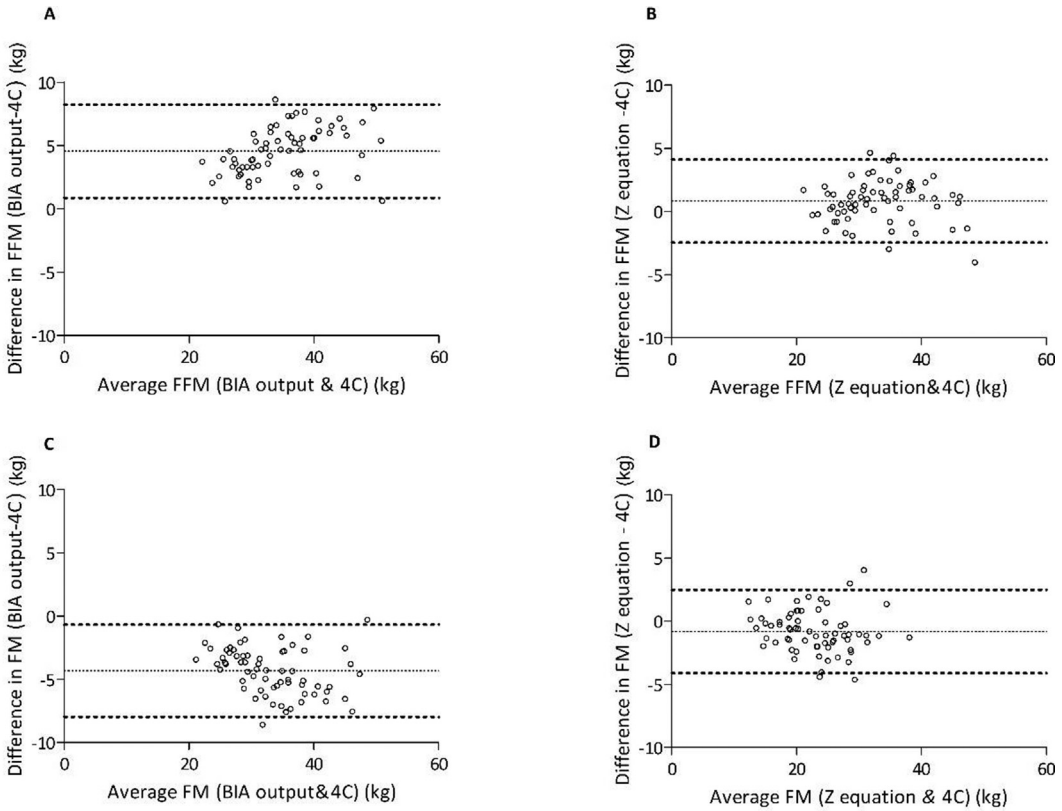

Fig. 1. Bland and Altman plots of the difference between fat-free mass and fat mass (kg) as obtained by TANITA'S output (A and C) and obtained with the new impedance predictive equation (B and D) both compared to the reference method (4 components model).

Table 4
Correlation coefficients (Pearson) and reliability of fat free mass assessments against the four-component model.

	Correlation coeff. (p-value)	Cronbach's α	ICC (95% CI); p-value
FFM_{TANITA} vs. FFM_{4C}	0.969 ($p < 0.001$)	0.982	0.886 (−0.101,0.973); $p < 0.001$
FFM_{Z} vs. FFM_{4C}	0.968 ($p < 0.001$)	0.984	0.980 (0.957, 0.989); $p < 0.001$

obesity. They included 316 obese participants from Korea aged 6–17 years classified in two groups depending on the degree of obesity: mild to moderate obesity and severe obesity. They found a good agreement of their method in both groups. Weaknesses of these previous studies were that they compared their results with DXA, which has some limitations when assessing body composition both in adults and children with obesity [33,36], and used the same method to generate the predictive equation and to test it.

Haroun et al. [16] validated an impedance index predictive equation for children and adolescents with obesity. The training sample consisted of 77 participants and the test sample consisted of 17 participants (aged 5–22 years, all of them with obesity). They compared TANITA's body composition outputs to 3C model measurements and found that TANITA manufacturer's equations overestimated FFM, and thus underestimated FM. Then, they derived a predictive equation adjusted to impedance index which did not show significant bias neither in FM or FFM, nor in changes over time [16].

A possible limitation of our work is that BV obtained from BODPOD was used in the model to calculate D_{FFM} and therefore to create the new predictive equation for FFM from bioimpedance (FFM_Z). It was also used in the 4C model. This fact might influence the correlation between the two equations. However, considering that both models include additional variables that makes the approach different, and thus ensures a reduced the bias produced by reduced density of FFM in obesity, we consider the new equation to be very robust. A factor introducing some possible selection bias was the fact the first 66 participants who agreed to take part in the deuterium dilution study could have certain characteristics different than those who did not agree (as predisposition to participate in studies or desire to improve their body composition). However, the results showed that there were no significant differences in the body composition outcomes between the two groups.

The strengths of our study, are: first, a large sample size was used to generate and to test our predictive equation in children and adolescents with obesity; second, a different model was used to create the equation and to test it; third, the method to create the equation took into account the changes in density of FFM that occur with different degrees of obesity; and fourth, the body composition results calculated with our proposed equation show good agreement with the *in vivo* gold standard method (4C). Therefore, we demonstrate the potential of BIA to predict body composition when population-specific equations are applied, explaining nearly 90% of the variability.

A spreadsheet template has been provided as supplementary online material to ease body composition calculations with this method.

5. Conclusion

In conclusion, the new predictive equation increases the precision of body composition assessment in children and adolescents with obesity by using bioelectrical impedance analysis. This facilitates body composition assessment both in research and clinic, due to the ease and speed of calculation, with no expensive equipment nor exhaustive training necessary. Nonetheless, further studies are required to evaluate the accuracy of the predictive equation in longitudinal studies and in non-obese populations.

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Author contributions

Conceptualization: DG and VL; Data curation: DG and VL; Formal analysis: DG and VL; Funding acquisition: RC, JE, VL, JB; Investigation; NF, PS, JM, MZ, MG, CR, MA, MN, AF, RG, MD, OS, AP; Methodology: VL, MV; Project administration: VL, Resources: RC, JE, JB, MV; Supervision: JE, RC, JW, MV, JB; Writing - original draft: DG; Writing - review & editing: VL, MV, JW, PS. All authors reviewed and agreed with the content of the manuscript.

Conflict of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2021.02.001.

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