

Anthropometric and bioimpedance equations for fat and fat-free mass in Chilean children 7–9 years of age

Gabriela Salazar^{1*}, Barbara Leyton¹, Carolina Aguirre², Aleyrina Anziani¹, Gerardo Weisstaub¹ and Camila Corvalán¹

¹*Institute of Nutrition and Food Technology (INTA), University of Chile, Santiago 7830490, Chile*

²*Departamento Ciencias de la Salud, Carrera de Nutrición y Dietética, Facultad de Medicina, Pontificia Universidad Católica de Chile, Santiago 8940000, Chile*

(Submitted 29 May 2020 – Final revision received 11 September 2020 – Accepted 24 September 2020 – First published online 8 October 2020)

Abstract

Assessing children's growth adequately is important due to the necessary prevention of adequate body composition, especially at pre-pubertal age. Simpler measurements such as anthropometry or bioimpedance, using equations validated in Caucasian children, have been demonstrated to overestimate or underestimate fat mass percentage (FM%) or fat-free mass (FFM) in Chilean children. In a sample of 424 children (198 boys and 226 girls) of 7–9 years old, the three component (3C) model was assessed, where total body water was determined by ²H dilution and body volume by air displacement plethysmography, in order to design and validate anthropometry and bioimpedance equations. The FM (%) equation specific for Chilean children was validated as $(1.743 \times \text{BMI } z\text{-score}) + (0.727 \times \text{triceps skinfold}) + (0.385 \times \text{biceps skinfold}) + 15.985$, against the 3C model (R^2 0.79). The new FFM equation (kg) generated was $(\log \text{FFM} = (0.018 \times \text{age}) + (0.047 \times \text{sex}) + (0.006 \times \text{weight}) + (0.027 \times \text{resistance}) + 2.071)$, with an R^2 0.93 (female = 1 and male = 2). The Bland–Altman analysis shows a mean difference of 0.27 (SD 3.5) for the FM% in the whole group as well as 0.004 (SD 0.9) kg is the mean difference for the bioelectrical impedance analysis (BIA) FFM (kg) equation. The new equations for FM (%) and FFM (kg) in Chilean children will provide a simple and valid tool for the assessment of body composition in cohort studies or to assess the impact of nutritional programmes or public policies.

Key words: Anthropometry: Bioimpedance: Child body composition

The assessment of body composition in childhood is relevant, as growth encompasses changes in several components of the body: total body water (TBW), fat mass (FM) and osseous mineral content which reflects weight change, also depending on sex, age, ethnic characteristics, food intake and physical activity⁽¹⁾. The rapid obesity increase in childhood since early age reinforces the need to have a simple and valid methodology for the evaluation of prevention efforts or clinical interventions⁽²⁾. In Chile, national data collected at public schools show an increment in obesity in first-grade children from 14% in 1996 to 24% in 2016⁽³⁾.

Most of these methods are limited to research because of their complexity and cost^(4–6). The four-component (4C) and three-component (3C) models of body composition constitute reference methods⁽⁷⁾. Both models make it possible to verify the degree of agreement for FM or fat-free mass (FFM), measured by simpler methods, such as anthropometry equations and bioelectrical impedance analysis (BIA). The advantage of the

three-compartment model is to minimise assessment error; thus, they increase the validity of FM or FFM equations, when using simpler methods⁽⁸⁾.

Skinfold thickness and BIA are techniques frequently used by health professionals to measure FM and FFM^(9,10). Expert panels have recommended the measurement of triceps and subscapular skinfold thickness, as a routine assessment of children and adolescents, whose conversion to FM will depend on sex, age, race and BMI⁽¹¹⁾. BIA is easy to measure and relatively cheap^(12–14) and requires less technical skill than skinfold assessment, which makes it useful where training opportunities may be limited. The main limitation of BIA studies is that each equipment utilises empirical equations provided by the manufacturer⁽¹⁵⁾, to convert the resistance measurement into TBW or FFM. The Tanita BIA segmental body composition analyser (BC-418MA) has been validated for FFM in some studies in Caucasian children⁽¹⁶⁾, compared with the reference method, although in other ethnic populations, it has underestimated FFM⁽¹⁷⁾ or overestimated it⁽¹⁸⁾.

Abbreviations: 3C, three component; BIA, bioelectrical impedance analysis; BMIZ, BMI z-score; FFM, fat-free mass; FM, fat mass; TBW, total body water.

* **Corresponding author:** Gabriela Salazar, email gabysal@gmail.com



These differences could be explained by the prediction equation of the equipment, predominantly developed in Caucasian population, or having different maturation status, physical activity level or extreme values^(11,12). Recently, authors have developed specific equations for FM, using BIA in Mexican children⁽¹⁷⁾ and also in a multiethnic group of young children⁽¹⁸⁾.

In a recent work, Aguirre *et al.*⁽¹⁹⁾ used a three-compartment model to determine FM% in 424 7–9-year-old Chilean schoolchildren, in order to assess the validity of published anthropometrical equations^(9,10) and BIA equations using the Tanita BC-418M⁽¹⁸⁾. High biases and large confidence limits were found, demonstrating that those equations were inaccurate in pre-pubertal Chilean children.

The importance of assessing body composition at pre-pubertal age is due to the adiposity rebound during this period^(20,21).

The main objectives of the present study are the development and validation of new equations for anthropometry and bioelectrical impedance, compared with the 3C model as the reference method, in order to have simpler methods to assess body composition in 7–9-year-old children.

Experimental methods

The study group was drawn from children participating in the Chilean Growth and Obesity Cohort Study, which started in 2006 in children between 3 and 4 years old, attending nursery schools of the National Nursery Schools Council Program (JUNJI), in the southeastern area of Santiago, Chile. All children were born in 2002, with birth weights between 2500 and 4500 g, having no physical or psychological conditions that could severely affect their growth or body composition^(22,23). The sample for the present study was obtained from verifying the interaction of maturation and body composition plus assuming a power of 0.8 and a two-tail $\alpha = 0.05$; this sample size makes it possible to detect small effect sizes ($d 0.23$, $r 0.1$, $f 0.01$).

The final sample for body composition studies consisted of 515 children participating in the Chilean Growth and Obesity Cohort study in the years 2010 and 2011. After excluding children with puberty stage 2 ($n 55$), twenty underweight and sixteen lacking completed data, the final sample size was 424 children (198 girls and 226 boys). The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethical Committee of the Institute of Nutrition and Food Technology (Act no. 19, 2009). A signed informed consent was obtained from the children's parents or guardians.

Anthropometry and body composition were measured in children participating in the Chilean Growth and Obesity Cohort study in the years 2010 and 2011. A standardisation procedure was performed by the two registered dietitians for weight, height and skinfold thicknesses. Weight was measured with a portable electronic scale (Seca 770) with a precision of 0.1 kg.

Height was measured with a portable stadiometer (Harpenden 603; Holtain Ltd) to the nearest 0.1 cm. BMI was determined as $\text{weight}/\text{height}^2$ (kg/m^2)⁽²⁴⁾.

BMI z-score (BMIZ) was calculated using the WHO 2007 growth reference in 5–19 years⁽²⁵⁾. Skinfold thickness (triceps and biceps) was measured in triplicate on the right side, with a Lange calliper to the nearest 0.5 mm and the mean value was used. The intra-observer technical measurement and the mean average bias of the observer were within the limits suggested by the WHO in the Growth Reference Study⁽²⁶⁾. Technical error of measurement in trained and standardised nutritionists was 4 % in skinfolds and 1 % in other measurements.

Body volume was measured by an air displacement plethysmography (BOD POD; Life Measurement Instruments), using standardised procedures. Children had to refrain previously from physical activity to avoid loss of water, and food ingestion was allowed 2 h before the measurement. The BOD POD equipment was calibrated daily, and measurements were conducted according to the manufacturer's guidelines. Children were assessed in tight-fitting bathing suits, to avoid air trapped in clothes, and hair was covered with swimming caps. Quality of data was assured by considering volume readings not differing >150 ml, and the measurement was repeated again, until compliance. The two closest values were averaged, according to the agreement criteria. Thoracic gas volume was predicted by the software, using a validated child-specific equation⁽²⁷⁾. The range of error for this test is 1–2.7 %, and precision was 0.56–1.34 %⁽²⁸⁾. The reproducibility of BOD POD is 1 % in measurements of children this age.

TBW was measured by the ^2H dilution method, using a dose equivalent to 0.4 g $\text{D}_2\text{O}/\text{kg}$ body weight (98.9 atom % excess; Europa Scientific). Pre-dose ^2H abundance was obtained from 3 ml saliva sample, and the post-dose sample was collected 3–4 h after dosing, using absorbent saliva-collection material (cotton swabs). Samples were stored at -20° for later triplicate analysis, using the equilibration method in a HYDRA isotope ratio-MS (Europa Scientific). The D_2O method for measurement of TBW was 1.2 % and precision 2–3 %⁽²⁹⁾.

BIA was measured using Tanita BC-418MA, an eight-electrode hand-to-foot system, manufactured by Tanita Corporation, which in standard conditions has 2–4 % error⁽³⁰⁾. BIA measurements were made according to the manufacturer's guidelines at 50 kHz frequency. Height, sex and age were entered manually, while weight was recorded automatically. The parents were asked to limit their child's physical exertion during the day before measurements were taken at the laboratory at the Institute of Nutrition and Food Technology.

Two BIA recordings were obtained, one with elbows flexed at 90° and one with elbows extended at 180° (hereafter 90° or 180° arm positions), with the child standing in the anatomical position⁽³¹⁾. The measurement is influenced by age, sex, hydration status and bone maturation⁽³²⁾. The FFM considers the hydration coefficients, by sex and age.

All body composition methods were measured at a similar time in the morning, after children had emptied their bladders upon arrival. Children came to the laboratory, with only 100 ml of milk consumed at 07.00 hours, to avoid loss of normal hydration. The order of measurement was first collecting the D_2O background sample and dosing, then the BOD POD and finally BIA measurements. During the ^2H equilibration period (3 h), anthropometry data were collected. A light breakfast



(maximum 837 kJ) was provided after the BodPod measurement, 1 h after D₂O dosing and additional water intake was discounted from TBW and BIA assessment.

Age, sex, body height and especially body fat had a significant effect on the functional muscle:bone ratio. There was no sex difference in the bone mineral content:muscle ratio until pubertal stage 3^(33,34).

Body composition calculations

The 3C model was selected as the reference method⁽⁶⁾. This model divides the body into fat, water and the remaining fat-free dry mass, which is assumed to have a constant ratio of protein:mineral of 0.35⁽²⁸⁾. The 3C model takes into consideration the inter-individual variation in FFM hydration. If the various assumed densities are considered plus the constant ratio of protein:mineral, then FM may be calculated as follows⁽⁸⁾:

$$\text{FM (kg)} = ((2.220 \times \text{BV}) - (0.764 \times \text{TBW})) - (1.465 \times \text{BW}),$$

where BV is the body volume (litres), TBW is the total body water (litres) and BW is the body weight (kg).

The 3C model value for FM was compared with the FM (%) equation from anthropometry.

Statistical analyses

- (1) Descriptive statistics was used for analysing basic anthropometric characteristics; differences by sex were assessed using Student's *t* test (normal distribution) and the Mann-Whitney *U* test (for non-normal distributed variables).
- (2) The generation of new equations for FM and FFM was done by randomly splitting the total sample into 67% (*n* 284) and 33% (*n* 140), to generate a sampling for prediction and validation. For the FM (%) equation, the following variables were entered in the analysis, sex, BMIZ, subscapular, triceps, abdominal and bicipital skinfolds. They were selected as to having a significant association ($P < 0.05$) to FM (%). Variables that remained are part of the equation for body fat (%). For the FFM equation, variables that entered in the stepwise model were sex, age, height, resistance and impedance variables.
- (3) Variables selected to generate the FM (%) were BMIZ, triceps and biceps skinfolds, which represent habitual measurement of adiposity. In the case of the FFM (kg) equation using TANITA BC-418 MA, the selected variables were age (years), sex (female = 1 and 2 = male), weight (kg) and BIA resistance (ohms).

- (4) The two-sample *t* test showed no significant differences between the two sets ($\text{Pr}(T > t) = 0.76$) with respect to the selected variables chosen for the design of FM (%) and FFM (kg) equations. The distribution of residual data from the equations in both samples for FM (%) and FFM (kg) was assessed by the Shapiro-Wilk test⁽²⁹⁾, which indicated a normal distribution ($P > 0.9$).
- (5) In both equations, the variance of errors (homoscedasticity) was evaluated by the Kernel density test, indicating both samples were normally distributed ($P > 0.6$). Using the Durbin's alternative test ($P > 0.05$), no collinearity and similar variances were obtained⁽³⁵⁾.
- (6) The equations were similar in the two groups (cross-validation performance); thus, a single equation was regressed for FM (%) and FFM (kg) in the whole group. The error of measurement was 1–2% for ²H dilution and 3–4% for air displacement plethysmography.
- (7) A Bland-Altman⁽³⁶⁾ test was applied in the whole sample for both FM (%) and FFM (kg) equations to verify the difference between the 3C model and the generated equations. The Bland-Altman analysis calculated the mean difference between the reference (3C model) and each equation. The CI represented the 95% distribution, in FM (%) or FFM (kg).
- (8) The level of significance used was $P < 0.05$. All statistics were computed using SAS (version 8.2 for Windows: SAS), with an α value of 0.05.

Results

The anthropometric characteristics of the sample are shown in Table 1. Boys had higher age, but there were no differences in average weight and height, with girls. FFM (kg) and FM% differed significantly between sexes, with girls having a higher FM% and lower FFM ($P < 0.001$), in spite of the age difference. Furthermore, 50% of the sample had excess weight (BMIZ > 1), which agrees with the rapid increase in the obesity prevalence during the last 10 years in Chile.

In Table 2, TBW (litres) and BOD POD volume (litres) are also shown, values which are significantly different by sex, as expected.

The equation was derived into 2/3 of the population (*n* 254) out of the total of 424 children. In the other third, a cross-validation was conducted, with results showing that similar variables explained FM%.

Table 1. Anthropometric characteristics and body composition of the sample (197 girls and 224 boys) (Medians and ranges)

	Age (years)	Weight (kg)	Height (m)	BMI (kg/m ²)	BMI ≥ 1 (%)
Girls					
Median	7.9*	27.8*	1.27*	17.3	43
Range	7.6–8.2	24.8–33	1.23–1.37	16–20	
Boys					
Median	8.9*	31.1*	1.32*	18.0	52
Range	8.4–9.1	27.6–36.8	1.28–1.37	16.1–20.6	

* $P < 0.001$ (*t* test).



Table 2. Body compartmental values for girls and boys (Medians and ranges)

Variables	TBW (litres)	ADP body volume (litres)	3C FM (kg)	3C FFM (kg)
Girls				
Median	14.7*	27.3*	8.3	19.3*
Range	13.9–16.4	24.2–32.9	6.6–11.7	18.0–21.3
Boys				
Median	17.2*	30.3*	8.5	22.8*
Range	15.6–19.0	26.3–30	5.9–12.5	20.6–25.0

TBW, total body water; ADP, air displacement plethysmography; 3C FM, three component model fat mass; 3C FFM, three component model fat-free mass.
 * All of the variables, except 3C FM, were significantly different by sex ($P < 0.001$).

$$FM(\%) = (1.743 \times BMIZ) + (0.727 \times \text{triceps skinfold}) + (0.385 \times \text{biceps skinfold}) + 15.985 (R^2 0.79)$$

For the case of FM (%) equation, the R^2 in the cross-validation simple (0.77) had a difference < 0.1 when compared with the R^2 in the whole sample (0.78), which, according to Kleinbaum *et al.*⁽²⁹⁾, indicated that the final model was reliable.

The three-compartment data by sex on FM% and FFM (kg) are shown in Table 2.

In Fig. 1, the Bland–Altman plot shows a mean difference of 0.27 (SD 3.5) % for fat percentage in the whole group. The limits of agreement for the body fat (%) are C1 = 6.82 and C2 = -6.75. The FM (%) obtained with the new anthropometric equation differs against the 3C model, 1.0 (SD 3.2) % for boys and -1.8 (SD 3.4) % for girls ($P < 0.05$).

Dependent variables, such as the resistance, age, sex and weight, were regressed producing the following equation for Log FFM (kg), explaining 92 % of FFM variability:

$$\text{LogFFM (kg)} = (0.018 \times \text{age}) + (0.047 \times \text{sex}) + (0.006 \times \text{weight}) + (0.027 \times \text{resistance}) + 2.071 (R^2 0.93)$$

Girls = 1; boys = 2.

In the regression for FFM (kg), R^2 was 0.93 and in the validation sample, R^2 was 0.92, which was also < 0.1 ; thus, according to Kleinbaum *et al.*⁽²⁹⁾, the final model was reliable.

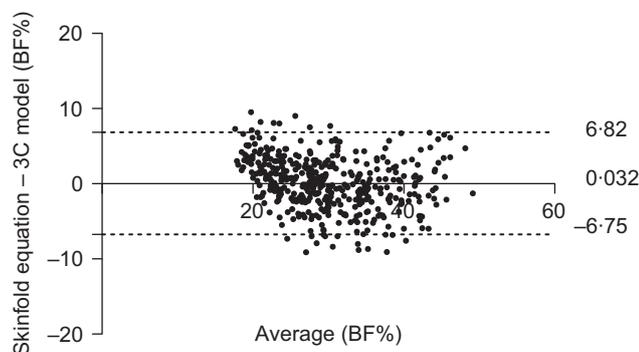


Fig. 1. Body fat % (BF%) anthropometrical equation agreement to three component model (3C model) data. 2 SD = 6.82 and -2 SD = -6.75.

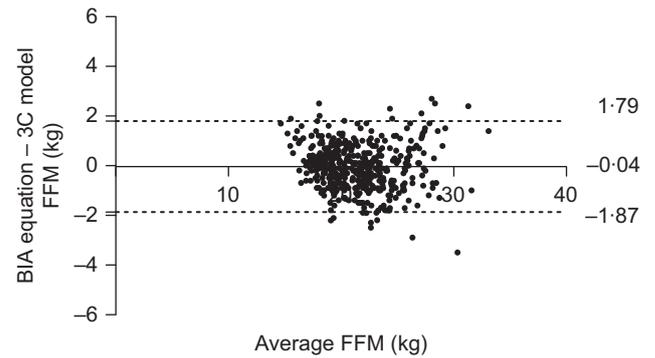


Fig. 2. Fat-free mass (FFM) (kg) bioimpedance equation agreement to three component model (3C model) data. BIA, bioelectrical impedance analysis. 2 SD = 1.79 and -2 SD = -1.87.

In Fig. 2, the Bland–Altman analysis for the comparison of 3C model FFM (kg) and BIA FFM is shown. The limits of agreement for FFM are C1 = 1.79 and C2 = -1.87. These equations are valid for group measurement due to the high limits of agreement. The equation leads to a 0.004 (SD 0.92) kg of FFM difference. When the differences to the 3C model are considered by sex, these differences were -0.02 (SD 1.0) and 0.02 (SD 0.8) kg in boys and girls, respectively, indicating that the equation has no bias by sex. These values are shown in Table 3.

Discussion

The present study is one of the few estimating body compositions in children of Hispanic origin (7–9 years old). We proposed new equations for FM, based on anthropometry and FFM using bioimpedance.

Our results for the FFM equation are similar to those found in Jemaa *et al.*⁽³⁷⁾, where they measure 8–11-year-old children. In spite of age difference, BIA provided a valid equation for FFM. The results of the study done in Mexican children, for body fat and FFM, differed substantially from ours, due to a high obesity prevalence which was not similar to the present study.

Results provided by the BIA equipment are also prone to error in children, as the Tanita BC 418 MA may utilise an adult hydration factor, which is lower than those seen in children⁽²⁹⁾. Considering these factors, we have generated new anthropometrical and BIA equations for FM (%) and FFM (kg), taking into account these factors (Hispanic origin, sexual maturation, hydration factors and having an excess weight similar to our national data).

In Chilean children, mainly of Hispanic origin, the Slaughter equation clearly underestimated FM (%) by over 12 %. This huge difference may be explained by the fact that it was developed in 1988 in Caucasian children⁽³⁸⁾. Thus, the Slaughter's anthropometric equation should not be used for Chilean children or of Hispanic origin. Additionally, the sex distribution in the Slaughter' equation is not similar to ours, which may affect the estimation of FM in girls. Other anthropometrical equations developed for Mexican children⁽¹⁷⁾ failed to provide good results in 7–9-year-old Chilean children, due to differences in obesity prevalence, sample composition or methodological issues. Anthropometrical equations validated

Table 3. Comparison of the three component model body fat (%) and fat-free mass (FFM) (kg) with the anthropometrical (ANTHRO) and bioelectrical impedance analysis (BIA) generated equations values by sex (Mean values and standard deviations)

Variables	All		Girls (n 197)		Boys (n 224)		P
	Mean	SD	Mean	SD	Mean	SD	
ANTHRO (%)							
FM (equations)	29.8	6.7	30.1	6.5	29.5	7.0	<0.01
FM (reference)	29.9	7.6	31.5	6.7	28.2	7.8	
Difference	0.27	3.5	-1.4	3.4	1.3	3.0	
BIA (kg)							
FFM (equations)	21.6	3.2	19.8	2.4	23.1	3.0	<0.01
FFM (reference)	21.5	4.4	19.8	2.5	23.1	3.0	
Difference	0.004	0.9	0.02	0.8	-0.02	1.0	

FM, fat mass; FFM, fat-free mass

for Latino children⁽¹⁰⁾ have overestimated or underestimated FM in other populations⁽³⁹⁾. The new proposed equations for FM (%) in 7–9-year-old Chilean children utilise BMIZ and skinfolds and may be used in the group of children, due to its standard deviation (3.5%) of the difference in the Bland–Altman analysis⁽⁴⁰⁾. These equations are valid for group measurement due to the high limits of agreement. For FFM in both boys and girls, the Huang equation showed the best agreement for boys (r 0.73) and the Ellis equation had the best agreement for girls (r 0.92) compared with the 3C BIA FFM equation^(41,42).

Previous research assessed the validity of habitual equation used for 7–9-year-old children, it was found that BIA works well for TBW and FFM assessment in healthy subjects, although in chronic diseased subjects or children, a specific BIA equation should be which is applied appropriate with regard to age, sex and race^(11–14). An important issue is that BIA was designed to measure the impedance across TBW, but BIA usually does not provide the equations to estimates FFM.

The present proposed equation for FFM has an R^2 0.92, using height, resistance and anthropometrical variables, which can be applied in 7–9-year-old Chilean children, and its validity should be tested if applied to children of different Hispanic origin.

Ethnic-specific impedance-based equations for body composition are justified because of differences in body build among ethnic groups⁽¹⁸⁾. Of special interests are relative leg lengths, frame size and body build which may be factors responsible for ethnic differences in the relationship of BMI to FM. On the other hand, FFM hydration decreases with age, an osseous content increases^(7,27,28).

One of the strengths of this study is the use of the 3C model to validate FM (%) and FFM equations, needing fewer assumptions than the two-compartment model (2C model). That approach has to rely on assumptions, about the FFM density and hydration of TBW within the FFM which may vary substantially during child growth. In fact, from infancy to childhood and through adolescence, TBW decreases, whereas bone mass increases^(7,28). Therefore, 2C models tend to overestimate FM and underestimate FFM in children and are less accurate as a criterion method for developing anthropometric-based model or from BIA^(7,43). To the best of our knowledge, few studies have assessed differences and validity in Latino children, using

BIA or anthropometric equation measurements against the 3C model^(10,17).

The other advantage of this work is the sample size, which allowed for an adequate representation of the FM (%) and FFM (kg) variables for the equations in the 7–9-year-old children. With respect to weaknesses, we identified the limited age range studied, the amount of overweight in children in this work and the standard deviation for the FM (%) equation, which indicates that the equation should be applied to groups, rather than individuals.

In conclusion, the proposed equation for anthropometry and BIA should be used preferentially in children of Hispanic origin with similar age, ethnicity, obesity prevalence and maturation status, in order to diminish errors in the estimation of FM (%) or BIA FFM (kg) in the study of body composition of children 7–9 years of age.

Acknowledgements

We thank the children participating in the study and their parents.

We appreciate the support of Fondecyt Project grants no. 1090252 and 1100206 (Chile), which financed the study.

G. S. directed the collection of data and wrote the paper. B. L. performed the statistics of the paper. C. A. contributed to the writing up. A. A. measured samples in the mass spectrometer and BOD POD. G. W. contributed to the writing up. C. C. revised the paper and contributed to the writing.

The authors declare no conflicts of interest.

References

1. Wells JC & Fewtrell MS (2006) Measuring body composition. *Arch Dis Child* **91**, 612–617.
2. Ogden CL, Carroll MD, Kit BK, *et al.* (2012) Prevalence of obesity and trends in body mass index among US children and adolescents, (1999–2010). *JAMA* **307**, 483–490.
3. JUNAEB, Ministry of Education (2016) Nutritional status in children attending state schools.
4. Siervo M & Jebb SA (2010) Body composition assessment: theory into practice: introduction of multicompartiment models. *IEEE Eng Med Biol Mag* **29**, 48–59.
5. Rush EC, Bristow S, Plank LD, *et al.* (2013) Bioimpedance prediction of fat-free mass from dual-energy X-ray absorptiometry



- in a multi-ethnic group of 2-year-old children. *Eur J Clin Nutr* **67**, 214–217.
6. Velazquez M, Salazar G, Vio F, *et al.* (2008) Validation of body composition equations using anthropometric data in Chilean preschool children. *Rev Med Chile* **136**, 433–441.
 7. Wells J, Fuller N, Dewitt O, *et al.* (1999) Four-component model of body composition in children: density and hydration of fat-free mass and comparison with simpler models. *Am J Clin Nutr* **69**, 904–912.
 8. Fuller NJ, Jebb SA, Laskey MA, *et al.* (1992) Four-component model for the assessment of body composition in humans: comparison with alternative methods, and evaluation of the density and hydration of fat-free mass. *Clin Sci* **82**, 687–693.
 9. Slaughter MH, Lohman TG, Boileau RA, *et al.* (1988) Skinfold equation for estimation of fatness in children and youth. *Hum Biol* **60**, 709–723.
 10. Huang T, Watkins M & Goran M (2003) Predicting total fat mass from anthropometry in Latino children. *Obesity Res* **11**, 1192–1199.
 11. Haroun D, Taylor J, Viner R, *et al.* (2010) Validation of bioelectrical impedance analysis in adolescents across different ethnic groups. *Obesity* **18**, 1252–1259.
 12. Brown CL & Perrin EM (2018) Obesity prevention and treatment in primary care. Review. *Acad Pediatr* **18**, 736–745.
 13. Xiao J, Purcell SA, Prado CM, *et al.* (2017) Fat mass to fat-free mass ratio reference values from NHANES III using bioelectrical impedance analysis. *Clin Nutr* **37**, 2284–2287.
 14. Moon JR (2013) Body composition in athletes and sports nutrition: an examination of the bioimpedance analysis technique. *Eur J Clin Nutr* **67**, Suppl. 1, S54–S59.
 15. Montagnese C, Williams JE, Haroun D, *et al.* (2013) Is a single bioelectrical impedance equation valid for children of wide ranges of age, pubertal status and nutritional status? Evidence from the four-component model. *Eur J Clin Nutr* **67**, Suppl. 1, S34–S39.
 16. Barreira TV, Staiano AE & Katzmarzyk PT (2013) Validity assessment of a portable bioimpedance scale to estimate body fat percentage in white and African-American children and adolescents. *Pediatr Obesity* **8**, e29–e32.
 17. Ramirez E, Valencia M, Bourges H, *et al.* (2012) Body composition prediction equations based on deuterium oxide dilution method in Mexican children: a national study. *Eur J Clin Nutr* **66**, 1099–1103.
 18. Sluyter JD, Schaaf D, Scragg RK, *et al.* (2010) Prediction of fatness by standing 8-electrode bioimpedance: a multiethnic adolescent population. *Obesity (Silver Spring)* **18**, 183–189.
 19. Aguirre CA, Salazar GC, Lopez de Romaña D, *et al.* (2015) Simpler methods to evaluate body composition: assessment of validity in prepubertal children. *Eur J Clin Nutr* **69**, 269–273.
 20. Ayyavoo A, Derraik JG, Hoffman P, *et al.* (2014) Metabolic, cardiovascular and anthropometric differences between prepubertal girls and boys. *Clin Endocrinol (Oxf)* **81**, 238–243.
 21. González L, Corvalán C, Pereira A, *et al.* (2014) Early adiposity rebound is associated with metabolic risk in 7-year-old children. *Int J Obes (Lond)* **38**, 1299–1304.
 22. Corvalán C, Uauy R, Stein AD, *et al.* (2009) Effect of growth on cardiometabolic status at 4 y of age. *Am J Clin Nutr* **90**, 547–555.
 23. Kain J, Corvalán C, Lera L, *et al.* (2011) Association between body mass index (BMI) and height from birth to 5 years in Chilean preschool children. *Rev Med Chile* **139**, 606–612.
 24. de Onis M & Habicht JP (1996) Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. *Am J Clin Nutr* **64**, 650–658.
 25. WHO (2006) Child Growth Standards based on length/height, weight and age. *Acta Paediatr Suppl* **450**, 76–85.
 26. WHO Multicentre Growth Reference Study Group (2006) Reliability of anthropometric measurements in the WHO Multicentre Growth Reference Study. *Acta Paediatr Suppl* **450**, 38–46.
 27. Fields DA, Hull HR, Chelene AJ, *et al.* (2004) Child-specific thoracic gas volume prediction equations for air-displacement plethysmography. *Obesity Res* **12**, 1797–1804.
 28. Collins AL, Saunders S, McCarthy HD, *et al.* (2004) Within- and between-laboratory precision in the measurement of body volume using air displacement plethysmography and its effect on body composition assessment. *Int J Obes Relat Metab Disord* **28**, 80–90.
 29. Kuriyan R (2018) Body composition techniques. *Indian J Med Res* **148**, 648–658.
 30. Talma H, Chinapaw MJ, Bakker B, *et al.* (2013) Bioelectrical impedance analysis to estimate body composition in children and adolescents: a systematic review and evidence appraisal of validity, responsiveness, reliability and measurement error. *Obesity Res* **14**, 895–905.
 31. Devakumar D, Grijalva-Eternod CS, Roberts S, *et al.* (2015) Body composition in Nepalese children using isotope dilution: the production of ethnic-specific calibration equations and an exploration of methodological issues. *Peer J* **3**, e785.
 32. Lopez-Sanchez GL, Sgroi M, D'Ottavio S, *et al.* (2019) Body composition in children and adolescents residing in Southern Europe: prevalence of overweight and obesity according to different international references. *Front Physiol* **19**, 130.
 33. Locquet M, Beaudart C, Durieux N, *et al.* (2019) Relationship between the changes over time of bone mass and muscle health in children and adults: a systematic review and meta-analysis. *BMC Musculoskelet Disord* **20**, 429.
 34. Duran I, Martakis K, Hamacher S, *et al.* (2018) Are there effects of age, gender, height, and body fat on the functional muscle-bone unit in children and adults? *Osteoporos Int* **29**, 1069–1079.
 35. Kleinbaum DG, Kupper LL & Muller KE (1988) *Applied Regression Analysis and Other Multivariable Methods*, 2nd ed. Boston, MA: PWS-KENT Publishing Company.
 36. Bland JM & Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **i**, 307–310.
 37. Jemaa HB, Mankai Sarra A, Minaoui Dhekra M, *et al.* (2019) Development and validation of impedance-based equations for the prediction of total body water and fat-free mass in children aged 8–11 years. *Clin Nutr* **38**, 227–233.
 38. Ogden, CL, Carroll MD, Lawman HG, *et al.* (2016) Trends in obesity prevalence among children and adolescents in the United States, 1988–1994 through 2013–2014. *JAMA* **315**, 2292–2299.
 39. Bellizzi A & Roche AF (2005) Anthropometry and echography. In *Body Composition*, 2nd ed., pp. 109 [SB Heymsfield, TG Lohman, ZM Wang and SB Going, editors]. Mexico D.F.: McGraw-Hill.
 40. Freedman DS, Ogden CL & Blanck HM (2013) The abilities of body mass index and skinfold thicknesses to identify children with low or elevated levels of dual-energy X-ray absorptiometry-determined body fatness. *J Pediatr* **163**, 160–166.
 41. Huang TT, Watkins MP & Goran MI (2003) Predicting total body fat from anthropometry in Latino children. *Obesity Res* **11**, 1192–1199.
 42. Ellis KJ (2001) Selected body composition methods can be used in field studies. *J Nutr* **131**, 1589S–1595S.
 43. Osborne DL, Weaver CM, McCabe LD, *et al.* (2012) Body size and pubertal development explain ethnic differences in structural geometry at the femur in Asian, Hispanic, and white early adolescent girls living in the U.S. *Bone* **51**, 888–895.

