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ORIGINAL ARTICLE

Evaluation of simple body composition methods: assessment of validity in prepubertal Chilean children

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BACKGROUND/OBJECTIVE: The aim of this study was to assess the validity of body fatness estimations based on skinfolds and bioelectrical iImpedance analyses (BIA) measurements compared to a three-component model (3C model) in prepubertal Chilean children, considering potential differences by sex and nutritional status.

SUBJECTS/METHODS: Four hundred and twenty four Chilean children (198 females and 226 males) were assessed for body composition. Body fat percentage (BF%) was evaluated by Skinfold equations (Slaughter, Ramirez and Huang) and Bioelectrical impedance (BIA: Tanita BC-418MA) using both the equipment and the Ramirez equation. Measurements based on a 3C model constructed from total body water estimates by isotope dilution and from body volume estimates by air displacement plethysmography were used as gold standard.

RESULTS: Coefficient of determination (R^2) values were higher in overweight and in the whole group of both gender. All slopes were differed significantly from 1, and most intercepts were significantly different from 0. *Skinfold Equations*: an underestimation of BF% was found for all equations, being higher with the Slaughter equation. *BIA:* Tanita underestimated BF% in all groups, whereas Ramirez equation shows an overestimation.

CONCLUSIONS: Skinfolds and bio-impedance equations serve well to rank children according to their BF%. However, these methods are not accurate for describing body composition in prepubertal Chilean children.

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INTRODUCTION

Body mass index (BMI) has been a valuable tool in monitoring trends in obesity as it is simple to measure; however, it does not distinguish between increments of fat or lean tissue.[1] This fact is important, considering that metabolic consequences of obesity are driven by excess adiposity.[2,3]

Body composition can be estimated by a variety of techniques. These methods vary in their sophistication, accuracy, feasibility, time, cost and availability. Multi-component models are the most accurate reference methods available; the three-component model (3C model) divides body weight into fat, water and remaining fat-free dry tissue, and requires measurements of body weight, total body water by hydrometrics (that is, isotope dilution), and body volume by densitometry (for example, air displacement plethysmography or hydrostatic weighing). However, these methods are unsuitable in epidemiological studies because of cost and limited availability. Additionally, these methods are difficult to use in large population groups, especially in non-clinical settings. Predictive methods that rely on assumptions to estimate body compartments and then body composition are considered a better option.

Skinfold thickness has been used extensively in clinical and epidemiological research to estimate changes in body composition, because of its simplicity; however, standardization and experience are required to achieve precise measurement. Multiple equations exist to estimate body fatness from skinfold thickness in children; however, most of them are highly population specific[4] and thus lack generalizability. Also, most equations were developed prior to the obesity epidemic. The widely accepted Slaughter equation[5] was developed in 1988; nevertheless, it is based on a sample of Caucasian children and has not been validated in children of Hispanic origin. For Hispanic populations, such as our sample, equations have been proposed by Ramirez[6] and Huang.[7]

Bioelectrical Impedance Analyses (BIA) is a simple, easy and inexpensive option to estimate body composition for epidemiological studies. There are now several instruments currently available that utilize empirical equations provided by the manufacturer to convert the resistance measurement into total body water or fat-free mass (FFM). The Tanita BC-418MA Segmental body composition has been validated. No significant differences in FFM compared with the reference method were found in some studies,[8] whereas in others, an underestimation[9] or overestimation[10] of body fat has been found. Impedance or resistance given by BIA equipment has been used to develop equations that might be more appropriate to Hispanic population.[6]

The Growth and Obesity Chilean Cohort Study (GOCS) is an on-going cohort study that aims to assess the relationship between early growth and the development of obesity and associated chronic conditions. As part of the GOCS, we have collected longitudinal anthropometric and BIA data in 1100 children since 4 years of age; in addition, we also assessed body composition using deuterium dilution and air displacement plethysmography in a subsample of children of 7–9 years of age. The aim of the present study is to assess the validity of body fatness estimations based on skinfolds and BIA measurements compared to a 3C model in Chilean prepubertal children, considering possible differences relates to sex and nutritional status.

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MATERIALS AND METHODS

Subjects

The study group was drawn from children participating in the Chilean GOCS, which recruited 3–4-year-old nursery school children who attended the National Nursery Schools Council Program (JUNJI) in Santiago, Chile in 2006. All children were singleton, born in 2002, weighing 2500–4500 g with no physical or psychological conditions that might significantly affect growth. In 2010, 504 children (out of the 1196 GOCS total) were evaluated with more detailed body composition measurements. Of these children, we further excluded 55 who had already entered puberty (only Tanner stage 1 were included) and 20 who were underweight; thus, the final sample size was 424 children (198 girls, 226 boys). Children included in the study were not different from those excluded in terms of age, gender, height and weight distribution.

The study protocol was approved by the Ethical Committee of the Institute of Nutrition and Food Technology (INTA) of the University of Chile. Informed consent was obtained from all parents or guardians of the children after providing them with detailed information on potential risk and benefits.

Anthropometry

A registered and trained dietitian measured weight, height and five skinfold thicknesses (triceps, biceps, subscapular, suprailiac and abdominal) using standardized procedures. Weight was measured with a portable electronic scale (Seca 770; Seca, Hamburg, Germany) with precision of 0.1 kg. Height was measured with a portable stadiometer (Harpenden 603; Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. BMI (weight/height^2; kg/m^2), BMI z-score (BMI Z) and height-for age *Z*-score, were calculated using the World Health Organization 2007 growth reference 5–19 years.[11] Overweight was defined as BMI Z >1. Skinfold thickness was measured in triplicate on the right side, with a Lange caliper to the nearest 0.5 mm; the mean value was used for analysis. For all measurements, the intra-observer technical measurement and the mean average bias of the observer were within the range suggested by the World Health Organization in the Growth Reference Study.[12]

Bioelectrical impedance

BIA was measured using Tanita BC-418MA, eight-electrode, hand-to-foot system, manufactured by Tanita Corporation (Tokyo, Japan). BIA measurements were collected according to the manufacture's guidelines and using a frequency of 50 kHz. Height, sex and age were entered manually, whereas weight was recorded automatically. Measurements were taken during the morning, with limited physical exertion and with empty bladders.

Air displacement plethysmography

Body volume was measured in an air displacement plethysmography (BOP POD, Life Measurement Instruments, Concord, CA, USA), using standardized procedures. Children had to refrain from physical activity and food 2 h before the measurement. The BOD POD was calibrated daily and at each measurement according to the manufacturer's guidelines. Children were assessed in tight-fitting bathing suits with swimming caps to rule out air trapped in clothes and hair. If the first two readings for body volume differed by more than 150 ml, a third measurement was taken and the two values that were closest and within the criteria for agreement were averaged. Thoracic gas volume was predicted from anthropometric data by the software with a validated child-age-specific equation.[13]

Deuterium dilution

Total body water was determined by Deuterium dilution with a dose equivalent to 0.4 g D2O/kg body weight (98.9 atom % excess; Europa Scientific, Crewe, UK). Pre-dose deuterium abundance was obtained using absorbent saliva-collection material (cotton swabs) from a saliva sample and 3–4 h after dosing, samples were stored at $-20°$ and analysed in triplicate in an isotope ratio–mass spectrometry (HYDRA, Europe Scientific, Crewe, UK) using the equilibration method.

Body composition calculations

Three-component model. The 3C model was used as the reference method.[14] 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 to mineral of 0.35.[15] The advantage of this model over two compartment model is that it avoids the assumption of the water content of the FFM is constant between individuals. Fat mass (FM) was calculated as follows:

$$FM(kg) = ((2.220 \text{ X } BV) - (0.764 \text{ X } TBW)) - (1.465 \text{ X } BW)(14)$$

BV is body volume in liters, TBW in liter and BW, body weight in kilograms.

Skinfold thickness equations. Skinfold thickness were converted to body fat (%), using: (i) Slaughter equation, derived from caucasic children,[5] and two equations developed for Hispanic pre-pubertal children: (ii) Ramirez[6] and (iii) Huang equations.[7]

Bioelectrical impedance analysis. Body composition was derived from the standard equations included in the equipment. We also used whole body impedance (*Z*) to determined FFM using the Ramirez Equation.[6] Subsequently, FM was calculated subtracting FFM from body weight, then was multiplied by 100 and divided by body weight to obtain body fat percentage (BF%).

Statistical analyses

Descriptive statistics was used for presenting basic anthropometric characteristics of the sample; differences by sex were assessed using Student's *t* test (normal) and Mann–Whitney *U* test (non-normal variables).

To compare median percentage body fat derived from the 3C model and each of the skinfolds and BIA equations, we used a Kruskall–Wallis test with post hoc adjustments.

A regression analysis was undertaken to compare 3C model and simple methods BF%. Slopes and intercepts were assessed for the difference from 1 to 0, respectively, and the standard error of the estimate (SEE) was calculated.

The concordance between 3C model and each of the skinfolds and BIA equations estimations was further verified using Bland–Altman analysis[16] and intra class correlation (ICC) coefficients. Bland–Altman analysis was calculated as the mean difference value between the reference (3C model) and each of the methods and the 95% distribution (confidence intervals). Level of significance used was $P<0.05$. Analysis were performed using Stata 10.1 statistical package.[17]

RESULTS

The sample anthropometric characteristics are shown in Table 1. Boys and girls had similar *Z* scores for weight and height. Almost half of the sample had excess weight (BMI Z >1), overweight was particularly high in boys. FFM and BF% differed significantly by gender with girls having a higher BF% and lower FFM than boys ($P<0.001$).

Comparisons of median BF% estimated by 3C model versus simpler methods, by gender and nutritional status are shown in Table 2.

Table 1. Anthropometric characteristics of the sample, by gender

	Girls (n = 198)	*Boys* (n = 226)	P-*value*
Age (y)	7.9 (7.6–8.2)	8.9 (8.4–9.1)	< 0.001
Weight (kg)	27.8 (24.8–33.0)	31.1 (27.6–36.8)	< 0.001
Weight-for-age *Z* score	0.74 (0.06–1.62)	0.8 (0.02–1.9)	0.69
Height (cm)	127.1 (122.9–130.7)	132.0 (128.0–137.0)	< 0.001
Height-for-age *Z* score	0.26 (−0.37–0.73)	0.13 (−0.50–0.76)	0.39
BMI (kg/m^2)	17.3 (16.0–20.0)	18.0 (16.1–20.6)	0.09
BMI-for-age *Z* score	0.82 (0.22–1.84)	1.01 (0.13–2.10)	0.30
Total fat (%) 3C model	30.8 (26.7–37.0)	27.6 (21.7–34.5)	< 0.001
FM (kg)	8.3 (6.6–11.7)	8.5 (5.9–12.5)	0.53
FFM (kg)	19.3 (18.0–21.3)	22.8 (20.6–25.0)	< 0.001
IFM (kg/m^2)	5.2 (4.3–7.2)	4.9 (3.4–7.1)	0.0094
IFFM (kg/m^2)	12.2 (11.5–12.8)	13.0 (12.4–13.7)	< 0.001
Normal (% (n))			
BMI-for age *Z* score ⩽ 1SD	57.0 (113)	47.8 (108)	0.056
Overweight (% (n))			
BMI-for age *z* score > 1SD	43.0 (85)	52.2 (118)	0.056

Abbreviations: BMI, body mass index; FM, fat mass; FFM, fat-free mass; IFM, fat mass index; IFFM, fat-free mass index; 3C model, three component model. Values are Median, range.

Skinfolds equations: When compared with the 3C model, median BF% by Huang equation was the best equation for girls, whereas Ramirez was the best for boys. In both genders and nutritional status, Slaughter equation was the equation with the highest underestimation of BF%. *BIA equations*: In girls, Tanita on average underestimated BF% in all groups, being greater in overweight girls, whereas when using Ramirez's equation, the median values were similar in overweight girls, but higher in the normal and in the whole group. Similar results were found in boys, with the exception of the use of Tanita in the normal nutritional status group, with a median similar to the 3C model.

Table 3 shows R^2 values, intercept and slopes for the regression of 3C BF% on every simple method data, together with the SEE stratified by gender and nutritional status. *Skinfolds equations*: in girls, R^2 values were higher in the overweight group and for all girls, however, each equation only accounted for 34–68% and 56–77% of the variance in BF% in overweight and the whole group, respectively. In boys, R^2 accounted for 65–70% and 75–81% of variance in overweight and all together, respectively. All slopes and intercepts were significantly different from 1 and 0 ($P < 0.05$), with the exception of Ramirez equation in overweight and in the whole group of boys. The smallest SEE values were observed for the whole group of girls and boys. *BIA equations*: like in skinfolds equations, higher R^2 values were observed in overweight and in the whole group for both gender. All slopes differed significantly from 1, and most intercepts were significantly different from 0, with the exception of Tanita equation for both genders. Linearity was confirmed for all models revealing that none of the equations had systematic errors.

Bland–Altman analysis

We carried out Bland–Altman analyses for all the combinations of methods previously described (3C model versus skinfolds and BIA equations) and the results were basically the same in magnitude and direction (Figures available as supplementary files).

Agreement of 3C model with air displacement plethysmography and deuterium dilution estimates. In addition to the simpler methods, the BF% agreement was assessed in comparison to the reference methods, like air displacement plethysmography (Bod Pod) and deuterium dilution. Results show that agreement with deuterium was good (bias from −0.63 to 0.1 and limits of agreement around ±4%)

Table 2. Comparison of body fat (%), estimated by three-compartment model versus simpler methods, by gender and nutritional status

	3C model	*Skinfolds equations*			*BIA equations*	
		Slaughter	*Huang*	*Ramirez*[a]	*Tanita*	*Ramirez*[b]
Girls						
Normal (*n* = 113)	27.5 (24.1–30.7)	15.8[c] (14.1–18.3)	25.0 (21.8–28.6)	22.9[c] (20.4–26.6)	23.3[c] (21.6–24.9)	32.1[c] (29.9–34.4)
Overweight (*n* = 85)	38.0 (33.9–40.9)	24.2[c] (20.2–28.0)	36.3 (33.6–41.1)	32.5[c] (28.2–36.7)	29.7[c] (26.8–33.1)	38.1 (34.9–41.3)
All children (*n* = 198)	30.8 (26.7–37.0)	18.6[c] (15.4–23.3)	29.6 (24.2–35.7)	26.6[c] (22.5–31.9)	25.3[c] (22.7–28.9)	34.3[c] (31.3–38.0)
Boys						
Normal (*n* = 108)	21.9 (19.5–24.6)	13.4[c] (12.0–16.2)	15.9[c] (12.4–19.4)	20.1 (18.1–23.6)	20.0 (18.6–22.0)	29.9[c] (27.4–32.6)
Overweight (*n* = 118)	33.7 (29.0–37.8)	24.8[c] (20.2–28.5)	30.8[c] (25.9–35.7)	31.2 (28.1–34.1)	28.9[c] (25.1–32.4)	37.4[c] (34.4–40.6)
All Children (*n* = 226)	27.6 (21.7–34.5)	18.6[c] (13.3–25.1)	22.7[c] (16.1–30.9)	26.1 (20.1–31.4)	23.6[c] (20.0–29.2)	33.8[c] (29.7–37.9)

Abbreviaiton: BIA, bioelectrical impedance analyses. [a]Ramirez equation using skinfolds stickness. [b]Ramirez equation using Tanita BC-418MA resistance. [c]Significantly different from 3C model, $P < 0.001$. Kruskal–Wallis test. Values are Median, range.

Table 3. Regression analysis for 3C model BF% and simple methods

	Normal				*Overweight*				*All children*			
	R^2	*Intercept*	*Slope*	*SEE*	R^2	*Intercept*	*Slope*	*SEE*	R^2	*Intercept*	*Slope*	*SEE*
Girls												
Skinfolds equations												
Slaughter	0.52	9.85	1.08	0.09	0.68	16.46	0.85	0.06	0.77	10.76	1.05	0.04
Huang	0.14	18.85	0.34	0.08	0.34	13.94	0.63	0.09	0.56	11.46	0.66	0.04
Ramirez	0.48	10.04	0.73	0.07	0.54	12.86	0.75	0.08	0.72	6.66	0.91	0.04
BIA equations												
Tanita	0.30	2.9	1.05	0.15	0.78	1.55	1.18	0.07	0.75	−2.33	1.29	0.05
Ramirez	0.42	−1.6	0.90	0.10	0.73	−6.06	1.14	0.08	0.73	−12.46	1.27	0.06
Boys												
Skinfolds equations												
Slaughter	0.55	7.30	1.06	0.09	0.70	10.84	0.92	0.06	0.84	8.16	1.02	0.03
Huang	0.19	16.39	0.37	0.07	0.65	9.31	0.79	0.05	0.75	11.16	0.72	0.03
Ramirez	0.47	6.54	0.76	0.08	0.66	0.72	1.06	0.07	0.81	1.09	1.04	0.03
BIA equations												
Tanita	0.47	−0.02	1.09	0.11	0.80	−0.08	1.16	0.05	0.86	−2.9	1.25	0.03
Ramirez	0.46	0.37	0.73	0.08	0.72	−10.5	1.19	0.07	0.78	−13.87	1.25	0.04

Abbreviations: BIA, bioelectrical impedance analyses; SEE, standard error of the estimate. The 3C model BF% regressed on each simple method. All slope are significantly different from 1 ($P < 0.05$).

whereas with Bod Pod were lower (bias from −5.1 to −3.4%), even within the ranges of agreement observed with simpler methods.

Sensitivity analysis. In addition to the Bland–Altman analysis, the ICC and the Kappa coefficient were calculated (data not shown). The results were similar to those obtained with the regression equations with the highest values for Huang skinfolds equation and the lowest for Slaughter skinfolds equations for both groups of girls and the highest values for Ramirez Skinfolds equation and the lowest for Slaughter equation for both groups of boys. In relation to BIA analysis, the lowest values were for Tanita equation and the highest for Ramirez equation for both groups of girls group, whereas in boys the opposite was found, with the highest values for Tanita and the lowest for Ramirez equations.

DISCUSSION

The epidemic rise in childhood obesity and its associated metabolic and health consequences has led to the need to determine body adiposity using simple, valid and easy-to-use measurements. In this study, we found that there is poor agreement when comparing skinfold and BIA equations to the 3C model in prepubertal children showing that these methods have major limitations in describing body composition. However, in the whole group of girls and boys, results were highly correlated, indicating that skinfolds and bio-impedance equations are adequate to rank children according to their BF%, but are not able to properly assess body fat in different nutritional status, applying the chosen equations and methods.

Skinfold thickness can be converted into BF% using published parameters. In this study, we compared the 3C model for body fat with equations by Slaughter *et al.*,[5] Huang *et al.*[7] and Ramirez *et al.*[6] As observed in other studies,[18] the Slaughter equation underestimated BF% by −12 and −9% in girls and boys, respectively, independently of nutritional status. The lack of validity of Slaughter equations for children in this age range can be partially explained by the fact that the equation was developed in 1988 (prior to the rapid increase in obesity) and derived from only 50 boys and 16 girls. Moreover, the Slaughter equation exclusively used data from Caucasian populations and thus it may not be applicable for other ethnic groups such as ours. However, we also found poor agreement when we used the Huang and Ramirez equations that were originally developed in Hispanic populations. We believe that this is largely because of the fact that Huang and Ramirez based their findings on populations with different obesity and fat distribution than ours.[6,7]

Bioimpendance analysis allows the determination of body composition, when using appropriate population, age or pathology-specific BIA equations and established procedures.[19] Our results indicate that overall for Chilean girls and boys, the Tanita equation underestimated BF%. However, when the group was categorized by nutritional status, the underestimation was higher in the overweight groups. This result may be explained by the ethnic origin of the population in which equations were constructed, probably because of differences in body composition, body proportions, bone geometry and pubertal maturation.[20–22] Data measured with BIA by Bray[23] and Mitsui *et al.*[24] found underestimation at high values of body fat, which may explain the differences in results found in our population, which has a high prevalence of overweight and thus, higher body fat. Additionally, body fat determined by the Ramirez equation, using Tanita impedance, showed an overestimation of BF%, with acceptable agreement only in overweight girls, although with large limits of agreement. This result could be explained by the higher BF% of children in the Ramirez study.

The study group was divided by gender for the present analysis, considering the sexual dimorphism in human body composition;[25] on average, girls have a higher BF% relative to boys even before the onset of sexual maturation. In agreement with these observations, our study found that the equations that gave the best agreement and correlation for skinfolds and BIA measurements varied by gender. Another factor that may influence validity of body composition assessments is the sample fat distribution represented by nutritional status. Federico *et al.*[26] showed that there is a curvilinear relationship between BMI-for-age *Z* score and BF% in 6–12-year-old boys, with a stronger association with body fat, among overweight/obese children than among normal and underweight subjects. Correlations between simpler methods and 3C model were stronger in the overweight group, with lower means bias in both Hispanic skinfolds equations and BIA Ramirez equation. The Tanita equation showed the best bias in the normal nutritional status group, probably because of the original sample composition in which body fat equation was generated (mostly caucasian population).

One of the strengths of this study includes the use of a multicomponent model as a reference method, the 3C model, which is considered close to 4C and likely one of the most accurate *in vivo* method, for a relatively large sample of subjects. However, a potential limitation may be given by the narrow age range of the group studied.

In conclusion, an ideal method to estimate body composition should be accurate, precise, accessible and acceptable.[26] Skinfold thickness and BIA are accessible and may be precise. Our results show that their BF% estimates show high correlation with 3C model, suggesting that these methods could be used to classify prepubertal children according to BF% and to assess associations with other variables such as lipid profile or insulin sensitivity. However, because of the high bias and large confidence limits, both methods are inaccurate and should not be used to describe body composition in prepubertal children.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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