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Predicting fat-free mass in children using bioimpedance analysis

Abstract Body composition assessment is a useful procedure for the study of nutritional status and water distribution. In adults, it is a predictor of morbidity and mortality, since body fatness is associated with risk factors for cardiovascular disease. Bioelectric impedance analysis (BIA) is a simple, safe, and inexpensive method for assessment of body composition both in pediatric and adult subjects. The aim of our study was to validate the impedance index, ZI (H^2/Z, height in cm^2/impedance), as a predictor factor of fat-free mass (FFM) and fat mass (FM) in a sample (n=75) of normal children. Dual-energy X-ray absorptiometry (DXA) was chosen as reference method. Despite some minor bias, DXA is considerably less expensive and easier to administer in pediatric subjects than other established gold standard reference methods for assessing body composition. ZI values were highly correlated with FFM measured with DXA. The following equations were obtained from the regression analysis: (a) male subjects, FFM_{DXA}=0.6375 (ZI)+5.9913, r^2=0.897, p<0.0001; (b) female subjects, FFM_{DXA}=0.7597 (ZI)+ 3.5853, r^2=0.903, p<0.0001. These data support the notion that BIA alone can be used as a surrogate to measure FFM in a pediatric sample.

Key words Pediatric • Fat mass • Fat-free mass • Bioimpedance analysis

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Introduction

Body composition assessment is a useful procedure for the study of nutritional status and water distribution in children. In adulthood, it is a predictor of morbidity and mortality, since body fatness is associated with risk factors for cardiovascular disease [1, 2].

It is important to have a reliable and accurate estimate of body composition when studying the various health correlates of diseases. Several methods are available, each with some advantages and limitations [3]. Underwater weighing (UWW), isotope dilution, and ^{40}K measurements are the established reference methods for body composition assessment [4]. However, all of them are very expensive, time-consuming, and need trained operators. In fact, UWW is not bias-free in young people, because the hydration of fat-free mass (FFM), which is assumed to be constant in the two-component model [5], can be different from the assumed value in young and very old subjects, thus impairing the reliability of FFM assessment [6, 7]. Therefore, FFM assessment from isotope dilution and ^{40}K could be biased in young people, because of hydration level variations [6].

Magnetic resonance imaging [8, 9] and computed tomography [10] are two additional established methods that are available for pediatric body composition research. However, their application is limited because of the high costs, and with computed tomography, the considerable

exposure to ionizing radiation. Another alternative for pediatric body composition analysis is dual-energy X-ray absorptiometry (DXA). Whole-body and regional body estimates in children and adolescents are possible with DXA system and radiation exposure is minimal. However, there are some concerns about the measurement under certain circumstances [11, 12].

A simple, safe, and inexpensive method is bioimpedance analysis (BIA). The direct evaluation of total-body impedance (Z) is possible following the standard tetrapolar procedure [13, 14]. The Z index (ZI, height^2/body impedance, cm^2/W_{50}) is a validated predictor of body fatness used in epidemiological research [15].

The aim of this study was to compare the accuracy of BIA measurement and DXA for predicting FFM in children aged 7–14 years. A predictive equation for FFM was developed.

Methods

Subjects

A total of 75 childrens aged 7–14 years were included in the study. Children were recruited during routine physical examinations. None had a history of endocrine, nutritional, growth, or renal problems. Clinical characteristics of the study population are shown in Table 1. Informed consent was obtained from parents and children, and ethical approval for the study was granted by the Ethical Committee of Tor Vergata University.

Each subject underwent an overnight fast. Body weight and height were measured to the nearest 50 g and 0.5 cm, respectively, on an electronic beam scale with a stadiometer (Invernizzi, Italy). Body mass index (BMI) was calculated as weight (kg)/height(m)^2. BIA was performed according to the standard tetrapolar procedure [13] using a Human-Im BIA (DS Medigroup, Milan, Italy). The direct evaluation of total-body impedance (Z) was performed at 50 kHz frequency, and ZI (height^2/body impedance, cm^2/W_{50}) was calculated for each child.

DXA total-body analysis was performed immediately after BIA measurement using a Lunar DPX-L scanner (Lunar Corp., Madison, WI, USA) equipped with pediatric software (version 1.5e). Technical details of DXA have been described previously [16, 17]. Scans were performed with subjects in a supine position. The entire body of each subject was scanned, beginning at the top of the head and moving in a rectilinear pattern down the body to the feet. Mean measurement time was 15 min; radiation exposure was less than 8 mSv. Body fat was expressed in kilograms; lean body mass was expressed in kilograms, and bone mineral content was expressed as total mass in kilograms. FFM in kilograms was evaluated as the sum of lean body mass (kg) and bone mineral content (kg). Daily quality-assurance tests were performed according to the manufacturer's instructions. All scans were performed and analyzed by the same operator. Skinfold thickness measurement was performed by a trainer operator using a Holtain caliper (Holtain, Bryberian, UK), according to an established protocol [18]. The triceps skinfold is measured in the midline of the posterior aspect of the arm, over the triceps muscle, at a point midway between the lateral projection of the acromion process of the scapula and the inferior margin of the olecranon process of the ulna [19]. The triceps skinfold is measured more commonly than any other skinfold, and it is well correlated with percentage of body fat both in children and in adults [19].

Statistical analyses

Correlation and regression analyses were used to assess the validity of our hypothesis. Zero-order correlations were performed first to assess the unadjusted association between ZI, FFM, and FM. Two sets of multiple regression analyses were also performed, one using FFM as the criterion-dependent variable and the other using FM as the criterion-dependent variable [20]. These analyses allowed us to assess the association between ZI, FFM, and FM with sex and other potential covariates. Significance levels were based on two-tail tests; a value of $p<0.05$ was considered statistically significant. SSPS for Windows 6.0 statistics software was used for all analyses.

Table 1 Physical characteristics of the study sample (data are shown as mean SD)

Variables	Female (25)	Male (50)	Total (75)	t (p)*
Age, years	10.2±1.6	9.7±1.3	9.9±1.4	t=1.45 (0.15)
Weight, kg	33.3±12.4	35.4±8.4	34.7±9.8	t=-0.86 (0.38)
Height, cm	138.0±12.6	138.7±8.6	138.5±10.1	t=-28 (0.77)
BMI, kg/m^2	16.9±3.4	18.2±2.5	17.7±2.8	t=-1.87 (0.06)
Z, Ω_{50}	737.0±76.8	631.2±60.2	666.7±82.9	t=6.53 (<0.0001)
ZI, cm^2/Ω_{50}	26.6±7.6	31.0±5.7	29.6±6.7	t=-2.81 (0.006)
Tricep, mm	7.2±4.1	10.5±5.8	9.4±0.4	t=-2.54 (0.01)
FM $_{DXA}$, kg	8.5±7.1	9.6±6.3	9.2±6.5	t=-0.68 (0.49)
Lean $_{DXA}$, kg	22.6±5.6	24.3±3.6	23.7±4.4	t=-1.59 (0.11)
FFM $_{DXA}$, kg	23.8±6.1	25.7±3.8	25.1±4.7	t=-1.65 (0.10)

*Student's *t* tests comparing female versus male subjects
BMI, body mass index; *FM*, fat mass; *FFM*, fat-free mass

Results

The characteristics of the study population are presented in Table 1. Significance levels between mean values of the sample were assessed using *t* test. Male and female subjects were similar in age, weight, and height. BMI, FM, and FFM values were not significant. The male subjects in the sample had a greater ZI (p=0.006) and triceps skinfold value (p=0.01) than the female subjects. Table 2 shows the zero-order correlation matrix for the study variables presented by gender; a highly significant association was found between FFM and ZI in male and female subjects. There was no relationship between triceps skinfold and ZI in male subjects (p=0.09), whereas there was in female subjects (p<0.0001).

The regression model with FFM as a dependent variable for male and female subjects is presented in Table 3 (model A). FFM was regressed onto ZI and sex. Results indicated that ZI was significantly associated with FFM (p<0.0001), with ZI and sex explaining approximately 90% of between-subject variance. The following equations were obtained from the regression analysis separately for male and female subjects:

Table 2 Zero-order correlation matrix of study variables for male (upper triangle) and female subjects (lower triangle)

	Tricep	FFM	FM	ZI
Tricep	1.00	0.15	0.91	0.24
	(0.295)	(<0.0001)	(0.096)	
FFM	0.69	1.00	0.35	0.95
	(<0.0001)	(0.012)	(<0.0001)	
FM	0.86	0.85	1.00	0.42
	(<0.0001)	(<0.0001)	(<0.0001)	
ZI	0.65	0.95	0.84	1.00
	(<0.0001)	(<0.0001)	(<0.0001)	

Male subjects, $FFM_{DXA} = 0.6375\ (ZI) + 5.9913$
r=0.897, p<0.0001 (Eq 1)

Female subjects, $FFM_{DXA} = 0.7597\ (ZI) + 3.5853$
r^2=0.903, p<0.0001 (Eq 2)

The triceps skinfold measure was next added to the multiple regression model as a covariate, but because it did not add significance to the model (p=0.89) we decided to maintain the most parsimonious model.

The regression model with FM as a dependent variable for male and female subjects is presented in Table 3 (model B). FM was regressed onto ZI, triceps skinfold, and sex. Results indicated that ZI was significantly associated with FM (p<0.0001), with ZI, triceps skinfold, and sex explaining approximately 86% of between-subject variance. We also analyzed male and female subjects separately. The following equations were obtained from the regression analysis:

Male subjects, $FM_{DXA} = 0.330\ (ZI) + 0.942\ (triceps) - 7.543$
r^2=0.879, p<0.0001 (Eq 3)

Female subjects, $FM_{DXA} = 0.441\ (ZI) + 0.972\ (triceps) - 10.234$
r^2=0.876, p<0.0001 (Eq 4)

Discussion

There are many methods available for pediatric body composition analysis in research laboratories. There is a need for estimating adiposity in field settings such as private clinics and epidemiology studies. BIA is a commonly used and validated measure of FFM among adults [21] and children [22]. In a previous study on 43 adolescents with celiac disease and 30 matched healthy controls, De Lorenzo et al. [23] found that BIA can be considered a valid alternative to DXA for the

Table 3 Fat-free mass regression model* (model A) and fat mass regression model* (model B)

Variable	β	SE_β	p	Intercept	r^2	SE	p model
Model A							
ZI	0.694	0.812	<0.0001				
Sex	-1.097	0.398	0.007				
Overall model				5.344	0.898	5.12	<0.001
Model B							
ZI	0.330	0.047	<0.0001				
Sex	-3.542	0.636	<0.0001				
Tricep	0.956	0.058	<0.0001				
Overall model				-7.1443	0.867	1.27	<0.001

* β, Unstandardized regression coefficient; *p model*, significance level for model; *SE*, standard error for model

assessment of FFM. To expand on this previous study, we used DXA as a reference method to assess FFM in a pediatric age group. In our sample of healthy children, ZI value and FFM were highly correlated ($p<0.0001$). We presented our results separately for male and female subjects. However, when using multiple regression analysis we pooled males and females together, and when controlling for gender, we found no differences. We also added the triceps skinfold measurement to our model, but it did not improve the significance. Therefore, we maintained the most parsimonious model. According to these results, we can conclude that BIA alone can be used as a surrogate measurement of FFM in a pediatric sample. Using an accurate measurement method as reference (i.e., DXA), this study confirms prior investigations demonstrating a good association between FFM and ZI in healthy Italian children. Thus, the technique appears to be a reliable and robust indicator of FFM in children. On the other hand, our results showed that BIA is a better measurement of FFM than triceps skinfold in children, while the latter is a more reliable measurement of FM.

One of the limitations of BIA is that this approach provides an estimate of total body water, which must then be transformed into FFM. A further limitation of our study was that we had no access to specific hormonal measurements. We are now extending our cross-sectional study results to a broader sample with the aim of examining longitudinal body fat changes in relation to specific developmental stages.

References

1. Faith MS, Pietrobelli A, Allison DB, Heymsfield SB (1996) Prevention of pediatric obesity. Examining the issues and forecasting research direction. In: Bendich A, Deckelbaum RJ (eds) Preventive nutrition. Humana Press, Totowa, NJ, pp 471–486
2. Bandini LG, Shoeller DA, Dietz WH (1990) Energy expenditure in obese and nonobese adolescents. Pediatric Res 27:198–203
3. Goran MI (1998) Measurement issues related to studies in childhood obesity: assessment of body composition, body fat distribution, physical activity and food intake. Pediatrics 101:505–518
4. Roche AF, Heymsfield SB, Lohman TG (1996) Human body composition. Human kinetics, Champaign, IL
5. Siri WE (1956) Gross composition of the body. In: Lawrence JH, Tobias CS (eds) Biological and medical physics. Academic Press, New York, pp 1–19
6. Lohman TG (1986) Applicability of body composition techniques and constants for children and youth. Exerc Sport Sci Rev 14:325–357
7. Guo S, Roche AF, Houtkooper L (1989) Fat-free mass in children and young adults predicted from bioelectric impedance and anthropometric variables. Am J Clin Nutr 50:435–43
8. Brambilla P, Manzoni P, Sironi S et al (1994) Peripheral and abdominal adiposity in childhood obesity. Int J Obes 18:795–800
9. de Ridder CM, de Boer RW, Seidell JC et al (1992) Body fat distribution in pubertal girls quantified by magnetic resonance imaging. Int J Obes 16:433–449
10. Goran MI, Kaskoun MC, Shulman W (1995) Intra-abdominal fat in young children. Int J Obes 19:279–283
11. Ellis K, Shypailo R, Pratt J, Pond W (1994) Accuracy of dual X-ray absorptiometry for body composition measurement in children. Am J Clin Nutr 60:660–665
12. Roubenoff R, Kehayias JJ, Dawson-Hughes B, Heymsfield SB (1993) Use of dual energy X-ray absorptiometry in body composition studies: not yet a gold standard. Am J Clin Nutr 58:589–591
13. Lukaski HC, Bolonchuk WW, Hall CB, Siders WA (1986) Validation of tetrapolar bioelectric impedance method to assess human body composition. J Appl Physiol 60:1327–1332
14. Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB (1988) Lean body mass estimated by bioelectrical impedance analysis; a four site cross-validation study. Am J Clin Nutr 47:7–14
15. De Lorenzo A, Sorge SP, Iacopino L, Andreoli A, De Luca PP, Sasso GF (1998) Fat-free mass by bioelectrical impedance vs dual-energy X-ray absorptiometry (DXA). Appl Radiat Isot 49(5–6):739–741
16. Pietrobelli A, Formica C, Wang Z, Heymsfield SB (1996) Dual-energy x-ray absorptiometry body composition model: Review of physical concepts. Am J Physiol 34:941–451
17. Goran MI, Driscoll P, Johnson R, Nagy TR, Hunter G (1996) Cross validation of body composition techniques against dual-energy X-ray absorptiometry in young children. Am J Clin Nutr 63:299–305
18. Lohman TG, Roche AF, Martorell R (1988) Anthropometric standardization 22. Reference manual. Human kinetics, Champaign, IL
19. Harrison GG, Buskirk ER, Carter JEL, Jonston FE, Lohman TG, Pollock ML, Roche AF, Wilmore J (1988) Skinfold thicknesses and measurement technique. In: Lohman TG, Roche AF, Martorell R (eds) Anthropometric standardization reference manual. Human kinetics. Champaign, IL, pp 55–70
20. Allison DB, Paultre F, Goran MI, Poehlman ET, Heymsfield SB (1995) Statistical considerations regarding the use of ratios to adjust data. In J Obes 19:644–652
21. Yanovski SZ, Heymsfield SB, Lukaski HC (1996) Bioelectrical impedance analysis. Am J Clin Nutr 64 (3S):387–532
22. Gutin B, Litaker M, Islam S, Manos T, Smith C, Treiber F (1996) Body composition measurement in 9–11-y-old children by dual-energy X-ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. Am J Clin Nutr 63:287–292
23. De Lorenzo A, Di Campli C, Andreoli A, Sasso GF, Bonamico M, Gasbarrini A (1999) Assessment of body composition by bioelectrical impedance in adolescent patients with celiac disease. Am J Gastroenterol 94(10):2951–2955