RESEARCH PAPER

Validation of Bioelectric Impedance Analysis against Dual-energy *X*-Ray Absorptiometry for Assessment of Body Composition in Indian Children Aged 5 to 18 Years

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Objective: To validate body composition measurements by Bioelectric Impedance Analysis (BIA) against Dual-Energy *X*-ray Absorptiometry (DXA) as the reference method in healthy children and adolescents.

Design: Cross-sectional

Setting: Schools in and around Pune city, India.

Participants: A random sample of 210 (114 boys, 96 girls) apparently healthy Indian children and adolescents (5-18 y).

Methods: Weight, height, Tanner stage (TS) were recorded. Body composition measures: fat-free mass (FFM), fat mass (FM), lean mass (LM), bone mineral content (BMC) and body fat percentage (%BF) were assessed by BIA and DXA on a single day. Agreement between the methods was estimated by Pearson's correlation, and Bland and Altman analysis.

Main outcome measures: %BF, FM, FFM, LM, BMC.

Results: BIA underestimated %BF by 6.7 (3.7)% as compared to DXA. Mean FFM, BMC and LM by BIA were significantly higher than by DXA ($P<0.001$). These differences remained similar after adjusting for age, BMI and TS. Mean differences between FFM (-2.32 (1.39) kg), BMC (-0.18 (0.15) kg), and LM (-2.15 (1.34) kg) by DXA and BIA were significant ($P<0.01$). Correlations between BIA and DXA were 0.92 for %BF, 0.96 for LM and 0.98 for FFM and BMC. Both the methods were similar in identifying normal and overfat children as per their respective cut-offs.

Conclusion: BIA and DXA techniques are not interchangeable for assessment of body composition. However, BIA may be used in the field/clinical setting preferably with ethnicity specific references.

Keywords: *Adipose tissue, Body water, Bone density*.

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The prevalence of obesity, and its associated metabolic disorders, is increasing dramatically in developing countries, including India [1-3]. Although body mass index (BMI) is a simple indicator of overweight or obesity, body fat distribution plays a major role in cardio-metabolic health during childhood [4-7]. An increased proportion of fat mass and a decreased proportion of fat-free mass (FFM) during childhood have both been associated with increased risk of developing chronic disease in later life [8]. Thus, evaluating body composition is necessary to predict metabolic risk in childhood.

Amongst body composition assessment techniques, Bioelectric impedance analysis (BIA) and dual-energy *X*-ray absorptiometry (DXA) are the most commonly used. DXA provides acceptable accuracy in measuring body composition among children [9]. However, since measuring body composition using the DXA requires expertise, is expensive, and is often not available in clinical and epidemiological settings, the BIA is a preferred tool.

Accuracy of body composition estimation by BIA has been evaluated in Western or Asian populations in comparison with the DXA [10-13], but the results are inconsistent [10], presumably due to ethnic and phenotypic differences in the study cohorts. The present study therefore attempted to validate body composition measurements by BIA against DXA as the reference method in healthy Indian children and adolescents.

METHODS

A random sample of 210 children (114 boys; age 5-18 y) was selected from schools in and around Pune city, India. Stratified random sampling method was used in the selection of schools and subjects; participants were selected gender-wise over the age range of 5-18 years. A written informed consent from the parent and an assent from each participant were obtained. The study was approved by the Ethics Committee of the Hirabai Cowasji Jehangir Medical Research Institute.

Height and weight were measured with participants in light clothes and without shoes. Standing height was measured using a portable stadiometer (Leicester Height Meter, Child Growth Foundation, UK) to the accuracy of 1 mm. Weight was measured using an electronic digital scale to the nearest 0.1 kg (Salter India). Body mass index (BMI) was calculated (Weight (kg)/Height (meter)^2), and height for age z-scores (HAZ), weight for age z-scores (WAZ), and BMI for age z-scores (BAZ) were computed using recent Indian growth references [14]. A pediatric endocrinologist assessed Tanner stage (TS).

Body composition was assessed by GE-Lunar DPX Pro (GE Healthcare, Waukesha, WI, USA) Pencil Beam DXA scanner (software version encore 2005, 9.30.044) to measure total %BF, total Body Fat Mass (g), Fat free Mass (FFM) (g) and Bone mineral content (BMC) (g). Reproducibility of DXA measurements for %BF in children was 0.47 (2.78)% [15]. Daily quality assurance scans were run as per standard protocols.

Body composition of the subjects was also measured by BIA (Model BC-420MA, Tanita) after at least 3 hours of fasting and voiding before measurements, as per manufacturer's instructions to ensure equivalent hydration state. The Tanita Body Composition Analyzer measures body composition using a constant current source with a high frequency current (50 kHz, 90µA). The eight electrodes are positioned so that electric current is supplied from the electrodes on the tips of the toes of both feet, and voltage is measured on the heels of both feet. BIA measures body composition as fat%, fat mass, fat-free mass, total body water, bone-free lean tissue mass (LTM), bone mineral amount included in the entire bone (bone mass) by measuring bioelectrical impedance in the body. BIA measurements were tested for test-retest reliability on a pilot sample of ten subjects separately by measuring them on BIA at two different time points. Reliability coefficient was significant for body fat percent, fat mass, fat free mass, lean mass (intra class correlation coefficient = 0.99, 0.98, 0.99, 0.96, respectively P=0.0001).

Statistical analysis: All statistical analyses were performed using SPSS version 21.0. An independent *t* test was used to determine gender differences in the participants' physical characteristics, DXA measurements and BIA measurements. P values <0.05 were considered significant. Pearson's correlation coefficients between %BF, FM, FFM, LM predicted by BIA and that measured by DXA as also with BMI were estimated. Linear regression model analysis was performed to adjust the body composition parameters for age, BMI and TS. Differences in body composition measurements by BIA and DXA were examined using a paired *t*-test. Bland-Altman plots were used to determine the agreement between BIA and DXA measurements [16]. The agreement between methods is represented by the mean difference, and the SD of the differences along with the 95% limits of agreement as the mean difference ±1.96 SD of the differences between methods. Lin's concordance correlation coefficient (R_c) was used to measure the bivariate relationship of %BF and FFM obtained from DXA with those obtained by BIA. The degree of agreement by Lin's coefficient was judged by using McBride's scale for continuous variables; <0.90 poor, 0.90–0.95 moderate, 0.95–0.99 substantial, and >0.99 almost perfect [17].

RESULTS

Physical characteristics of the study cohort of 210 children and adolescents (114 boys) (mean (SD) age 11.3(2.5) yr) are presented in ***Table* I**. Almost all (94%) children and adolescents had normal *Z* scores for height, weight and BMI [14]. When compared with adult-equivalent cut-offs of BMI for Asians corresponding to 23 and 28 kg/m^2 [18], majority (78%) of the participants were in normal BMI category and 14% were overweight (***Table* II**).

TABLE I PHYSICAL CHARACTERISTICS OF THE STUDY PARTICIPANTS (N=210)

Parameter		Age group	
Boys	5-9 y	10-13 y	14-18 y
No.	28	67	19
Age (yr)	8.2 (1.5)	11.9 (1.1)	15.2 (1.1)
Weight (kg)	24.8 (6.0)	35.5 (9.6)	45.2 (9.2)
Height (cm)	125.0 (10.4)	143.7 (11.0)	159.4 (9.3)
BMI (kg/m^2)	15.6 (2.1)	16.9 (2.7)	17.7 (2.6)
HAZ	-0.3 (0.9)	-0.6 (1.1)	-0.7 (1.1)
WAZ	-0.3 (0.8)	-0.5 (1.0)	-0.8 (0.8)
BAZ	-0.1 (0.8)	-0.4 (0.9)	-0.6 (0.8)
Girls	5-9 y	10-13 y	14-18 y
No.	34	52	10
Age (yr)	8.5 (1.3)	11.9 (1.0)	15.0 (1.3)
Weight (kg)	25.4 (6.4)	35.2 (8.7)	42.1 (7.8)
Height (cm)	126.8 (10.0)	144.1 (9.2)	148.1(5.8)
BMI (kg/m^2)	15.5 (2.1)	16.8 (2.9)	19.1 (3.5)
HAZ	-0.2 (0.9)	-0.4 (1.0)	-1.1 (0.8)
WAZ	-0.2 (0.9)	-0.6 (0.9)	-0.8 (1.0)
BAZ	-0.2 (0.8)	-0.5 (0.9)	-0.3 (1.1)

**Results are expressed as mean (SD), HAZ: Height for Age z-score, WAZ: weight for Age z-score, BAZ: BMI for Age z-score.*

TABLE II CLASSIFICATION OF CHILDREN ACCORDING TO BMI AND TANNER STAGE

	Boys (n=114)	*Girls (n=96)*	*All (N=210)*
Adult equivalent BMI	*Proportion of children (%)*		
Under weight	5.3	3.2	4.3
Normal weight	76.1	80.0	77.9
Over weight	15.9	11.6	13.9
Obese	2.7	5.3	3.8
Tanner stage			
I	45.5	30.5	38.6
II	22.3	20.0	21.3
III	17.0	14.7	15.9
IV	11.6	12.6	12.1
V	3.6	22.1	12.1

BMI: body mass index.

The comparison of body composition measurements by BIA and DXA in the study participants is shown in ***Table* III**. The estimation of body fat% by BIA was significantly lower than the body fat% measured by DXA in both boys and girls across all age groups (*P*<0.001) (***Table* III**). The estimates of fat-free mass, bone mineral content and lean mass by BIA were significantly higher than by DXA (*P*<0.001). These differences in estimates of FFM, BM, LM and %BF were of similar magnitude after predicting the adjusted means for age, BMI and TS by linear regression model (***Table* III**). The correlations between BMI and body composition measured on BIA were r=0.527, r=0.895, r=0.524 and r=0.847 (*P*< 0.01) for FFM, FM, LM and %BF respectively. Similarly, correlations between BMI and body composition measured on DXA were r=0.537, r=0.885, r=0.531 and r=0.767 (*P*<0.01) for FFM, FM, LM and %BF respectively. The correlations between BIA and DXA were r=0.98, r=0.965, r=0.98, r=0.941 and r=0.917 (*P*<0.01) for FFM, FM, LM, BM and %BF, respectively. The Lin's concordance correlation coefficients for %BF in boys and girls were low and showed a poor agreement between DXA and BIA measurements (R_c< 0.90) (***Web Table* I**). The FFM determined by DXA and BIA showed a moderate agreement (R_c between 0.90-0.95) in boys but poor

TABLE III BODY COMPOSITION OF THE STUDY PARTICIPANTS BY BIA AND DXA

Parameter	*BIA*		*DXA*	
	Boys	*Girls*	*Boys*	*Girls*
Age-group:5-9 years	(*n*=28)	(*n*=34)	(*n*=28)	(*n*=34)
Body fat %	11.5 (7.2)	16.3 (6.5)	17.6 (7.5)**	25.7 (11.7)**[a]
Fat free Mass (kg)[a]	21.4 (3.7)	20.4 (4.0)	19.6 (3.4)**	18.2 (3.4)**
Lean Mass (kg)	20.4 (3.5)	19.4 (3.7)	18.8 (3.2)**	17.3 (3.2)**
Bone mineral content (kg)	1.0 (0.2)	1.0 (0.3)	0.9 (0.2)**	0.8 (0.2)**
Age-group:10-13 years	(*n*=67)	(*n*=52)	(*n*=67)	(*n*=52)
Body fat %	13.2 (9.5)	20.5 (8.9)	21.1 (8.9)**	27.3 (9.3)**
Fat free Mass (kg)	29.5 (5.7)	27.9 (5.1)	26.9 (6.1)**	25.4 (5.2)**
Lean Mass (kg)	28.0 (5.4)	26.4 (4.7)	25.6 (5.8)**	24.1 (4.9)**
Bone mineral content (kg)	1.5 (0.4)	1.5 (0.4)	1.3 (0.3)**	1.3 (0.3)**
Age-group: 14-18 years	(*n*=19)	(*n*=10)	(*n*=19)	(*n*=10)
Body fat %	12.9 (9.7)	30.8 (12.2)	21.3 (9.8)**	35.2 (9.1)**
Fat free Mass (kg)	36.4 (7.2)	30.4 (3.4)	34.4 (6.5)**	28.4 (3.4)**
Lean Mass (kg)	34.6 (6.8)	28.8 (3.2)	(6.2)**	26.7 (3.0)**
Bone mineral content(kg)	1.9 (0.4)	1.7 (0.2)	1.6 (0.4)**	1.7 (0.4)**
Adjusted means[#]				
Adjusted Body fat %	13.6 (7.6)	20.0 (8.0)	20.0 (6.7)**	26.9 (6.8)**
Adjusted Fat free Mass (kg)	29.3 (7.6)	26.0 (4.2)	27.2 (7.2)**	23.6 (4.3)**
Adjusted Lean Mass (kg)	27.9 (7.1)	24.7 (3.9)	26.0 (6.9)**	22.4 (4.0)**
Adjusted Bone mineral content (kg)	1.4 (0.4)	1.4 (0.3)	1.2 (0.3)**	1.2 (0.3)**

*Results are expressed as mean (SD); Level of Significance = ** P<0.001, a: Estimate of FFM by DXA; [#] means from linear regression analysis adjusting for age, BMI and TS; BIA: Bioelectric impedance analysis; DXA: Dual-energy X-ray absorptiometry.*

agreement in girls. Similar moderate agreement in boys and poor agreement in girls was seen for lean mass. Bone mineral content by DXA and BIA also showed poor agreement in both boys and girls. Overall, the mean difference between %BF by DXA and BIA was 6.7 (3.7)%. The 95% limits for differences between the two methods were (-0.8%, 14.2%). The width of the interval suggests that the degree of agreement is not acceptable for using the two measurement methods interchangeably (***Fig*.1a**). Percentage body fat by BIA was lower by 5.9 (3.5)% than the DXA estimate in overweight children.

BIA overestimated lean mass than the DXA with a mean difference of -2.15 (1.34) kg. The 95% limits of agreement between the two methods were (-4.82 kg, 0.51 kg) (***Fig*. 1b**). The mean difference between DXA estimate of FFM and BIA was -2.32(1.39) kg. The 95% limits of agreement between the two methods were (-5.11 kg, 0.46 kg) (***Fig*. 1c**).

The mean difference between BMC by DXA and BIA was -0.18 (0.15) kg. The 95% limits of agreement between the two methods were (- 0.48kg, 0.12 kg) (***Fig*. 1d**). The bias for BIA estimates of BMC as compared to DXA estimates was lower in children with normal bone mass for bone area (*n* = 169, -0.15 (0.14) kg), than those with low bone mass for bone area (*n* = 32, -0.26 (0.15) kg) or children with poor bone mass for bone area (*n* = 9, -0.34 (0.16) kg) as per DXA 85^{th} and 95^{th} cut offs (14), (*P*<0.001) (***Fig*. 2**). Thus, BIA overestimated lean mass, FFM and bone mass as compared to DXA.

When children were classified as normal fat, over fat and excess fat using DXA body fat percentile cut-offs [7] and cut-offs for BIA by McCarthy, *et al* (of 85th and 95th percent body fat percentile) [21], 93% children were below 85th percentile for DXA cut-offs as also below 85th percentile by McCarthy, both indicating normal percent body fat. However, 64% of excess fat children by McCarthy's cut-offs were overfat (between 85th and 95th percentile) or excess fat (>95th percentile) by DXA cut-offs.

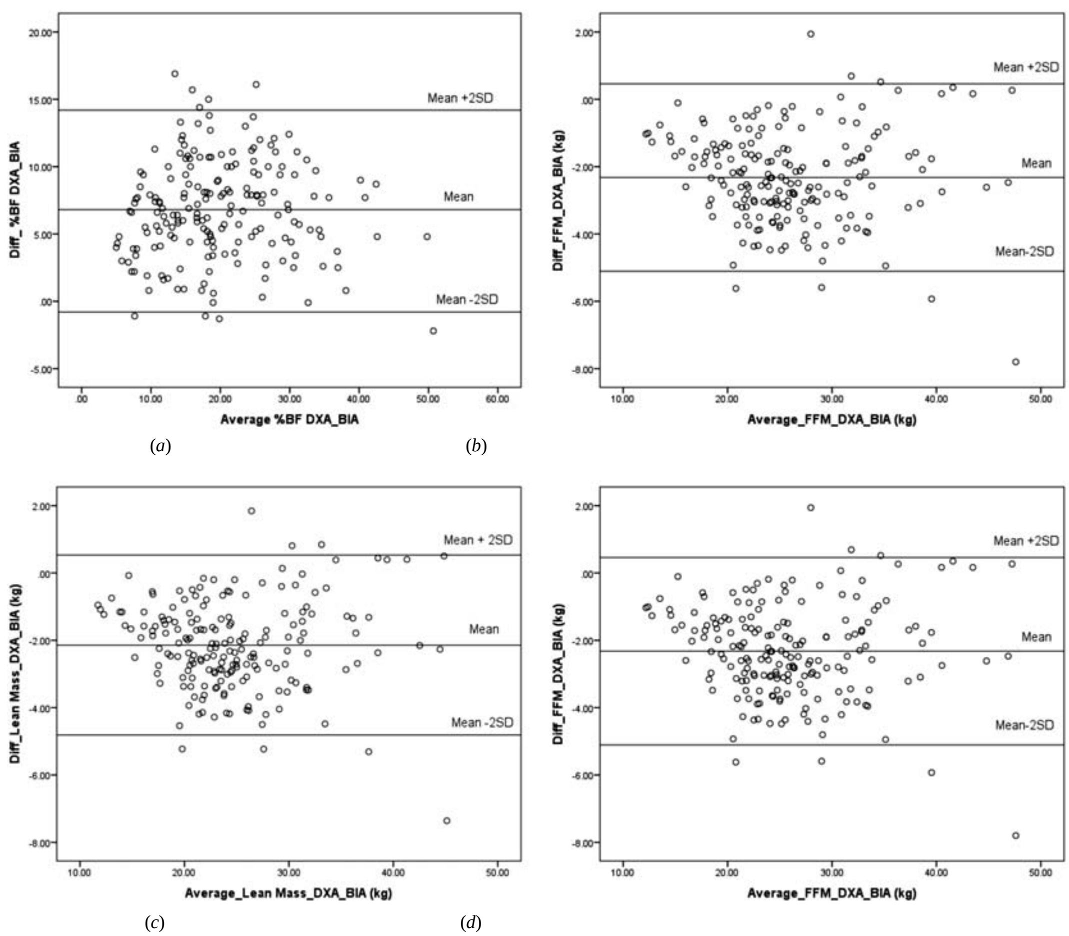


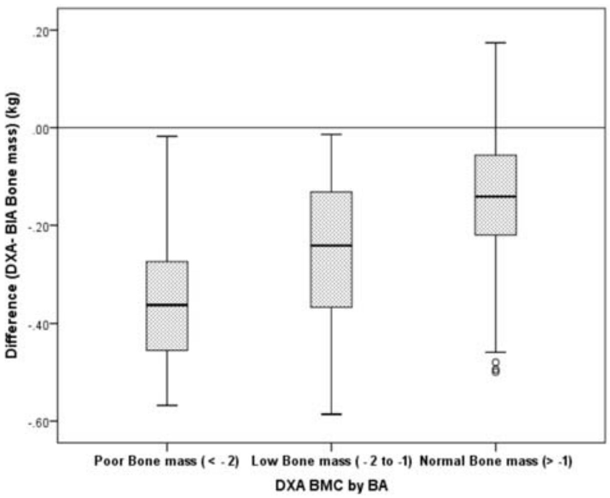
FIG. 1 *Comparison of BIA with DXA by Bland-Altman plots for (a) percent body fat, (b) fat-free mass, (c) lean mass, (d) bone mass in children and adolescents.*

WHAT IS ALREADY KNOWN?

- DXA is used to assess body composition due to its precision although BIA is widely used in clinical settings.

WHAT THIS STUDY ADDS?

- BIA and DXA techniques are not interchangeable for assessment of body composition in children.
- BIA may be used for the assessment of body composition in the field/clinical setting preferably with the use of ethnicity specific references.



BMC: Bone Mineral content; BA: Bone Area. BMC by BA: Z score calculated using DXA measurements. Data are presented as the mean difference ±SE. Mean difference among three groups of BMC by BA was statistically significant (P< 0.1).

FIG. 2 *Bone mineral content-dependent bias of BIA compared with DXA in children and adolescents.*

DISCUSSION

Our findings indicate that while BIA underestimated percentage body fat by 6.7 (3.8)% as compared to DXA measurements in apparently healthy children and adolescents, it overestimated fat-free mass, lean mass (muscle mass) and bone mass as compared to DXA. These differences were of similar order after adjusting for influence of age, BMI and Tanner stage. The accuracy and correlations between BIA and DXA for FFM, FM, and %BF were higher than those between BMI and DXA. Even so, both methods were similar in identifying normal fat children and children with increased fat as per the respective available cut-offs.

One of the limitations of the present study was that majority of the children and adolescents in the study were normal weight children and therefore, comparison of the lean and obese children and adolescents for the same age and gender could not be performed. However, amongst overweight children and adolescents, underestimation of %BF by BIA and DXA was of similar order; 5.9% in boys and 5.8% in girls.

Measurement of body composition may be performed by several methods such as by underwater weighing, air-displacement, dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging (MRI) and computerized tomography (CT). However, either anthropometry (mainly BMI) or BIA is a more practical method of assessing body composition in the field setting [22]. The body mass index (BMI), although commonly used as a surrogate measure for BF%, the relationship between BF% and BMI is different is ethnic groups [23]. Thus, BIA maybe a more preferable method for measuring body fat in the field setting.

An underestimation of 5% by BIA over DXA body fat%, as we observed, is also reported in adults [12] and by 2% to 12% in children [13,19]. The difference in percentage body fat estimates was variable with different models of BIA devices [11] and also across body fat ranges. A moderate agreement for FFM with different models of BIA machines in comparison with the Hologic DXA has also been reported [11]. The underestimation by BIA may also be due to the use of non-population-specific prediction equations by BIA models for estimating fat and fat free mass from total body water [20].

Considering the cut-offs for body fat percentiles for normal or excess body fat percentage [7] for the DXA and BIA (as per 85th and 95th percent body fat percentile) [21], 93% children were below 85th percentile of DXA as also below 85th percentile by McCarthy, both indicating normal percent body fat. However, 64% of excess fat children by McCarthy's cut-offs were overfat (between 85th and 95th percentile) or excess fat (>95th percentile) by DXA cut-offs. Apart from the difference in method of assessment, this also could be because the cut-offs for the DXA that we have used are based on Indian data while the reference data for the BIA is based on Caucasian children. Hence, more children were possibly classified as excess fat by the BIA cut-offs than by the DXA cut-offs. This underlines the need for generating ethnic specific BIA reference curves for identifying at risk children and adolescents.

In conclusion, BIA and DXA techniques are not interchangeable for % BF, FFM, lean mass and bone mass in children. However, BIA may be used for the assessment of body composition in the field/clinical setting preferably with the use of ethnic specific references.

Contributors: SC, AK: concept and designed the study, analyzed data and drafted the manuscript; NK: helped in data analysis and manuscript writing; VE, LP, RM: collected data and helped in data analysis; VK: analyzed data and manuscript writing.

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WEBTABLE I LIN'S CONCORDANCE COEFFICIENTS BETWEEN BODY COMPOSITION PARAMETERS ASSESSED BY DXA AND BIA MEASUREMENT

DXA	*BIA*	
	Boys	*Girls*
%BF	0.679 (95% CI: 0.59, 0.75)	0.706 (95% CI: 0.62, 0.77)
FFM	0.938 (95% CI: 0.91, 0.96)	0.887 (95% CI: 0.85, 0.92)
Lean Mass	0.939 (95% CI: 0.92, 0.96)	0.889 (95% CI: 0.85, 0.92)
BMC	0.868 (95% CI: 0.82, 0.90)	0.812 (95% CI: 0.75, 0.86)

DXA: measured by dual-energy X-ray Absorptiometry; BIA: measured by bioelectrical impedance analyser; %BF: body fat percentage; FFM: fat-free mass; BMC: bone mineral content.