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Original Article

Cross-calibration of multi-frequency bioelectrical impedance analysis with eight-point tactile electrodes and dual-energy X-ray absorptiometry for assessment of body composition in healthy children aged 6–18 years

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Abstract ***Background***: In diagnosis and treatment of obesity, body composition analysis including percent body fat (%BF) is useful in the clinical setting. Because bioelectrical impedance analysis (BIA) could be used quickly, easily and was non-invasive in clinical setting, the purpose of the present study was to evaluate the usefulness of multi-frequency BIA with eight-point tactile electrodes (MF-BIA8; InBody 720, Biospace) compared with dual-energy X-ray absorptiometry (DXA) in healthy children and adolescents.

Methods: A total of 166 children and adolescents under 18 (male, $n = 86$; female, $n = 80$) were recruited. Height, weight, body mass index (BMI) and Tanner stage were measured for each subject. The body composition such as fat-free mass (FFM), fat mass (FM), and %BF was measured on BIA and DXA and compared.

Results: On linear regression analysis, DXA FFM = 1.006(BIA FFM) + 0.554, $R^2 = 0.99$ and the standard error of the estimate (SEE) was 1.16 kg; DXA FM = 0.971(BIA FM) – 0.596, $R^2 = 0.93$; SEE, 1.34 kg; and DXA %BF = 0.940(BIA %BF) – 1.026, $R^2 = 0.858$; SEE, 3.03%. Limit of agreement in FFM, FM, and %BF was 0.7 ± 2.3 kg, –0.9 ± 2.9 kg and –2.2 ± 6.1%, respectively.

Conclusions: Although the %BF was not interchangeable with DXA, MF-BIA8 (InBody 720; Biospace) could be used to measure body composition of children and adolescents in the clinical field because of its high precision.

Key words bioelectrical impedance analysis, body composition, dual energy X-ray absorptiometry, Tanner stage, validation.

During the past two decades the prevalence of obesity in children has increased greatly worldwide, including in East Asian countries.[1] Because obesity in childhood is closely related to obesity in adulthood and causes a wide range of serious complications such as hypertension, dyslipidemia, type 2 diabetes and hyperinsulinemia, not only in later life but also in childhood, measurement of body composition including percent body fat (%BF) is important in pediatrics.[1–6]

Although anthropometric measurements such as body mass index (BMI), obesity index and skinfold thickness are used in the clinical field, they are not accurate and precise. The other established reference methods such as hydrodensitometry and deuterium (D_2O) distribution methods are not suitable for routine pediatric clinical practice.[7,8] Only bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DXA) could be used in the clinical setting because both methods are safe and easily accessible.[9,10]

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Validation studies have been done on DXA with other reference methods and it is known to have good accuracy and reproducibility including in pediatric populations.[10–14] It is still expensive, however, and not suitable for the bedside setting or epidemiological studies.

Bioelectrical impedance analysis has been widely used in clinical fields.[15,16] Several studies have compared predictions of BIA %BF with measurements made using DXA.[12,17–21] Although adult studies showed good agreement between BIA and DXA,[17,18] most pediatric studies indicated that BIA lacks precision and was not interchangeable with DXA.[12,19–21] We found that these discrepancies were due to small sample size, different ethnicity of study population and using BIA with single frequency in pediatric study.

The aim of the present study was to evaluate the validity of multi-frequency BIA with eight tactile electrodes (MF-BIA8; InBody 720, Biospace, Seoul, Korea) compared with DXA in a healthy pediatric population. The MF-BIA8 device is known to be very accurate and was found to be influenced little by age, height, weight or sex in previous adult studies.[17,18,22–24]

Methods

One hundred and sixty-six healthy children and adolescents were enrolled in the present study. There were 86 boys and 80 girls

Table 1 Subject characteristics (mean ± SD)

Variables	TS 1	TS 2	TS 3	TS 4	TS 5	Total
Boys	$n = 37$	$n = 10$	$n = 10$	$n = 11$	$n = 18$	$n = 86$
Age (years)	8.7 ± 1.5	11.1 ± 1.5	12.9 ± 1.1	14.9 ± 1.2	15.5 ± 1.1	11.7 ± 3.2
Height (cm)	132.4 ± 8.7	142.9 ± 6.6	158.7 ± 8.6	169.4 ± 5.9	172.5 ± 4.6	149.8 ± 18.9
Weight (kg)	31.3 ± 7.4	36.8 ± 6.0	53.2 ± 10.0	56.1 ± 7.9	63.8 ± 12.2	44.4 ± 16.2
BMI (kg/m^2)	17.9 ± 2.6	18.6 ± 1.9	21.4 ± 3.2	19.8 ± 2.5	21.8 ± 3.9	19.5 ± 3.3
Girls	$n = 25$	$n = 17$	$n = 8$	$n = 12$	$n = 18$	$n = 80$
Age (years)	8.2 ± 1.2	9.7 ± 1.2	11.0 ± 1.2	12.8 ± 1.8	15.2 ± 1.5	11.1 ± 3.0
Height (cm)	125.5 ± 7.6	137.6 ± 4.8	147.2 ± 6.8	155.2 ± 7.2	159.3 ± 4.6	142.3 ± 15.0
Weight (kg)	24.0 ± 3.4	31.6 ± 4.3	40.6 ± 8.2	46.1 ± 10.3	52.8 ± 5.2	37.1 ± 12.8
BMI (kg/m^2)	15.7 ± 1.3	16.9 ± 1.9	19.2 ± 3.5	19.2 ± 3.1	21.0 ± 1.8	18.0 ± 3.0

The mean height, weight and BMI of the subjects did not differ significantly from the Korean standard for the same age.
BMI, body mass index; TS, Tanner stage.

between the ages of 6 and 18 years (mean, 11.4 ± 3.1 years). Subjects with chronic disease or medications that would affect body composition were excluded. Weight was measured to the nearest 0.1 kg on electronic scale (150A, Cas, Seoul, Korea) and height was measured to the nearest 0.1 cm using a stadiometer (DS-102, Dong Sahn Jenix, Seoul, Korea). The pediatric endocrinologist assessed Tanner stage (TS). The characteristics of the study subjects are presented in Table 1. The mean height, weight and BMI of the subjects did not differ significantly from the Korean standard for the same age.[25]

Bioelectrical impedance analysis was performed using multi-frequency BIA with eight tactile electrodes (MF-BIA8; InBody 720, Biospace), after at least 3 h of fasting and voiding before measurements. This analyzer uses an alternating current of 250 mA at a multi-frequency of 1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz and 1000 kHz. It measures segmental impedances at the right arm, left arm, right leg, left leg and trunk for all frequencies, and total body impedance value is calculated by summing the segmental impedance values. It automatically displays measurements of fat-free mass (FFM), fat mass (FM), and %BF. FFM is estimated from total body water, using a prediction equation developed for Asian subjects. The %BF is then calculated using the following equations: FM (kg) = weight (kg) – FFM (kg); and %BF = FM/weight × 100%. The measures were made as previously described.[17,18] The subject stood on the footplate with bare feet and held both hand electrodes. It takes 2 min and no specific skills are needed. The precision error of FFM, FM, %BF is <than 2% in 30 subjects.

Whole-body DXA scans were performed using Lunar Prodigy advance with pediatric software version enCore 2005 9.15.010 (GE Lunar, General Electric, Madison, WI, USA). Each scan provided bone mineral content (BMC), FM, and lean mass (LM) in grams. The %BF is then calculated using the following equations: FFM = BMC + LM; %BF = FM/(FFM + FM) × 100%. A trained technician performed the measurements based on the manufacturer's guidelines. Both DXA and BIA measured body composition of each subject within 1 h. The Institutional Review Board of Korea Cancer Center Hospital approved the present study. Informed consent was obtained from all parents and subjects.

Statistical analysis

Statistical analysis was performed using SPSS 13.0 (SPSS, Chicago, IL, USA). Results are expressed as mean ± SD except for limit of agreement, which is expressed as mean ± 2 SD. Data were analyzed using linear regression after adjusting gender and TS. In regression analysis the DXA values were the dependent variable and the BIA values were the independent variable. The Bland and Altman method was used to determine the limits of agreement.[26] $P < 0.05$ was considered to be statistically significant.

Results

The mean FFM, FM and %BF calculated with the instrument's software for DXA and BIA are summarized in Table 2. No difference in FFM, FM and %BF between the two methods was found according to TS adjusted by sex. No difference in FFM, FM or %BF between the two methods was found in either genders. Only %BF difference between BIA and DXA was larger in TS 1 compared to TS 2 and higher (–2.96 ± 2.99 vs –1.81 ± 3.03, $P < 0.05$). Thus, all subjects were grouped in subsequent analyses.

The correlations between BMI and body composition measured on DXA were $r = 0.704$ ($P < 0.01$), $r = 0.907$ ($P < 0.01$) and $r = 0.729$ ($P < 0.01$) for FFM, FM and %BF, respectively. The correlations between BIA and DXA were $r = 0.995$ ($P < 0.01$), $r = 0.981$ ($P < 0.01$) and $r = 0.926$ ($P < 0.01$) for FFM, FM and %BF, respectively. Linear regression analysis comparing BIA FFM with DXA FFM is shown in Figure 1(a). The R^2 for this relationship was 0.990 and the standard error of the estimate (SEE) was 1.16 kg. The equation was DXA FFM = 1.006(BIA FFM) + 0.554. Although the relationship between FFM on both methods was affected by age and TS, the equation including those variables only increased the R^2 by 0.001. Linear regression analysis of FM is shown in Figure 1(b). The R^2 was 0.934 and the SEE was 1.34 kg. The equation was DXA FM = 0.971(BIA FM) – 0.596. Linear regression analysis of %BF is shown in Figure 1(c). The R^2 was 0.858 and the SEE was 3.03%. The equation was DXA %BF = 0.940(BIA %BF) – 1.026. Although the relationship between both methods for FM and %BF was affected by weight and BMI, the equation including those variables only increased the R^2 by 0.019 and 0.046, respectively.

The differences for FFM, FM and %BF between BIA and DXA were analyzed as Bland–Altman plots (Fig. 2). The limits

Table 2 DXA and BIA results of body composition (mean ± SD)

Variables	TS 1	TS 2	TS 3	TS 4	TS 5	Total
Boys	$n = 37$	$n = 10$	$n = 10$	$n = 11$	$n = 18$	$n = 86$
DXA FFM (kg)	25.5 ± 4.0	29.4 ± 2.1	41.1 ± 7.0	48.8 ± 4.9	53.1 ± 6.2	36.5 ± 12.7
BIA FFM (kg)	24.7 ± 4.0	29.1 ± 2.5	41.1 ± 6.7	47.3 ± 5.7	52.1 ± 6.7	35.7 ± 12.7
DXA FM (kg)	5.5 ± 4.0	7.1 ± 4.2	12.0 ± 5.8	7.3 ± 3.9	11.1 ± 7.8	7.8 ± 5.7
BIA FM (kg)	6.6 ± 4.2	7.7 ± 4.9	12.1 ± 6.0	8.8 ± 3.0	11.7 ± 7.3	8.7 ± 5.6
DXA %BF	15.9 ± 8.4	18.5 ± 7.8	22.0 ± 8.7	12.5 ± 5.6	15.9 ± 8.7	16.5 ± 8.3
BIA %BF	19.5 ± 8.6	19.7 ± 9.5	22.1 ± 8.9	15.4 ± 3.8	17.2 ± 7.9	18.8 ± 8.2
Girls	$n = 25$	$n = 17$	$n = 8$	$n = 12$	$n = 18$	$n = 80$
DXA FFM (kg)	20.5 ± 2.7	25.4 ± 2.4	32.3 ± 5.5	34.7 ± 4.3	38.5 ± 3.9	28.9 ± 8.0
BIA FFM (kg)	20.1 ± 2.8	24.9 ± 2.2	31.8 ± 6.2	34.4 ± 4.5	37.3 ± 3.5	28.3 ± 7.8
DXA FM (kg)	3.4 ± 1.4	5.8 ± 2.5	8.7 ± 5.2	11.0 ± 6.2	13.9 ± 3.2	8.0 ± 5.4
BIA FM (kg)	3.9 ± 1.5	6.7 ± 2.8	8.8 ± 3.2	11.7 ± 6.2	15.5 ± 3.0	8.8 ± 5.5
DXA %BF	14.0 ± 4.6	18.1 ± 5.6	20.2 ± 7.8	22.5 ± 8.4	26.4 ± 4.6	19.6 ± 7.4
BIA %BF	16.1 ± 5.2	20.6 ± 5.8	21.5 ± 5.8	23.8 ± 7.6	29.2 ± 4.1	21.7 ± 7.3

BIA, body impedance analysis; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass; %BF, percent body fat; TS, Tanner stage. No difference of FFM, FM, and %BF was observed between the DXA and BIA according to Tanner stage.

of agreement (mean ± 2SD) for FFM for both methods were –0.69 ± 2.27 kg. The limits of agreement for FM and %BF were 0.85 ± 2.82 kg and 2.25 ± 6.06%, respectively.

Discussion

This comparison study of body composition measured using both BIA and DXA is one of the largest studies of children and adolescent with a wide age range and the same ethnicity. The main finding was that there were significant correlations between FFM, FM and %BF measured on MF-BIA8 and DXA in healthy Korean children. Although the methods were not interchangeable for %BF measurements, both methods are useful and complement each other in the clinical field.

Body composition analysis, especially %BF, is important for the evaluation of nutritional status and for measuring the effect of intervention in obesity. In the clinical field only BIA and DXA are safe and precise methods. Although BIA is widely used in the bedside setting and in epidemiological studies due to low cost, safety, rapidity and portability,[15,16] there was controversy as to its reliability and validity, especially in children.[12,19–21]

In the present study, the accuracy and correlations between MF-BIA8 and DXA for FFM, FM, and %BF were greater than those between BMI and DXA. The relationships between MF-BIA8 and DXA were influenced little by sex, age, TS, weight, BMI, %BF compared with other previous studies.

On linear regression for DXA FFM by BIA FFM, the R^2 was 0.990 and the SEE was 1.16 kg. The slope of regression line was not different from 1 and the intercept was only 0.55. In the Bland–Altman plots, the mean difference between the two methods was –0.69 ± 1.16 kg, which was only 2.23 ± 3.33% difference. For FM the R^2 was 0.934 and the SEE was 1.34 kg. While the R^2 of %BF was decreased to 0.858 and the SEE was 3.03%. The limits of agreement for %BF in both methods were increased up to 2.25 ± 6.00%. Thus the two methods were not interchangeable in %BF. In the present study the %BF difference between the two methods was more remarkable in prepubertal children. Considering that %BF is the ratio of FM and bodyweight, the lower bodyweight of the subjects means that greater %BF error could occur. Eisenmann *et al.*, reported very poor correlation between BIA and DXA for 3–8 year old children.[21] It was suggested, however, that SEE of 3–4% body fat and 2.0–2.5 kg FFM in body composition is considered ideal.[27,28]

Bioelectrical impedance analysis is based on electrical impedance measurements as an index of total body water (TBW). TBW is the sum of extracellular water (ECW) and intracellular water (ICW). Previous single-frequency BIA estimated TBW from estimated ECW. Thus many empirical equations are used and it could be influenced by race, sex, age, TS, weight, BMI, %BF and height.[29,30] The impedance is influenced not only by the ratio of ECW and ICW but also by the volume of the body, trunk and extremity lengths.[7] Therefore previous BIA with fewer than four electrodes could not distinguish trunk and extremity impedance. Thus calculated whole body impedance might have error in estimating FFM, considering that the trunk has as much as 50% whole body mass but only influences 10% of total impedance.[31] Considering that children, especially adolescents, have rapid change of height, weight and body composition according to sex, errors would be expected calculation of body composition on single-frequency BIA or with whole body impedance, which estimates FFM from a multiple regression equation using impedance, weight, height and age as independent variables. The recently developed MF-BIA8 (InBody 720, Biospace) solves those problems.[17,18,22–24] It directly calculates ECW and TBW from impedance of low- and high-frequency data and is not influenced by body proportion because it divide the body into five conductors. It is known to be very accurate compared with the other reference methods including hydrodensitometry, deuterium (D_2O) distribution and DXA in adults.[17,18,22]

The limitation of the present study was that we did not compare the lean and obese children and adolescents for the same age or TS. However, Sartorio *et al.* reported that MF-BIA8 accurately estimated TBW and ECW in women with a wide range of BMI (19.1–48.2 kg/m^2).[24]

The major application of BIA is obesity research and management, and many recent studies reported that compared with DXA, BIA measurement overestimate FM in lean subjects while FM is underestimated in obese subjects.[20,32,33] In the present study the

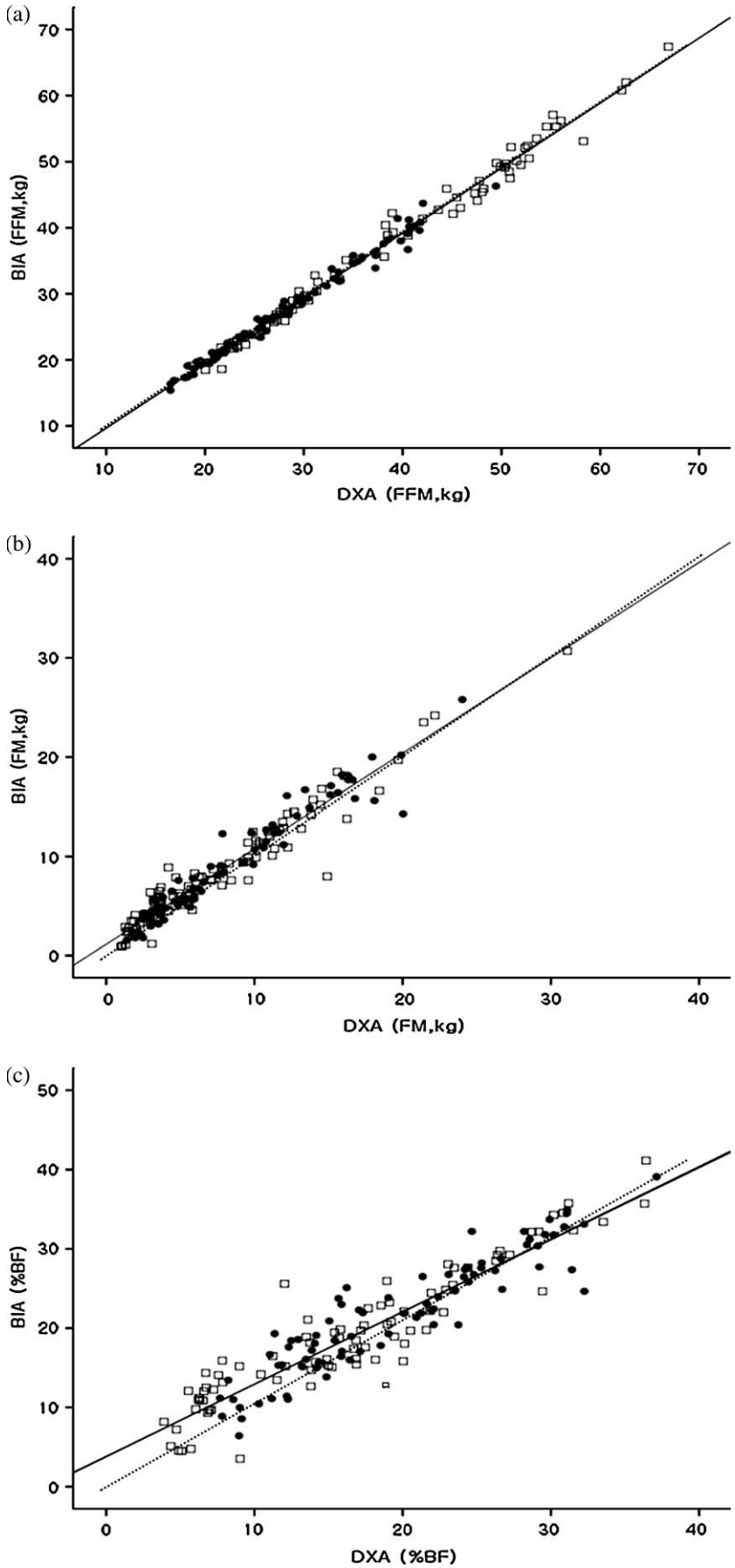

Fig. 1 Linear regression analysis comparing body compositions by BIA with by DXA in 166 children and adolescents. (a) DXA FFM = 1.006(BIA FFM) + 0.554; R^2 = 0.990; standard error of the estimate (SEE) = 1.16 kg. (b) DXA FM = 0.971(BIA FM) – 0.596; R^2 = 0.934; SEE = 1.34 kg; (c) DXA %BF = 0.940(BIA %BF) – 1.026; R^2 = 0.858; SEE = 3.03%. BIA, bioelectrical impedance analysis; %BF, percent body fat; DXA, dual-energy X-ray absorptiometry; FM, fat mass; FFM, fat-free mass.

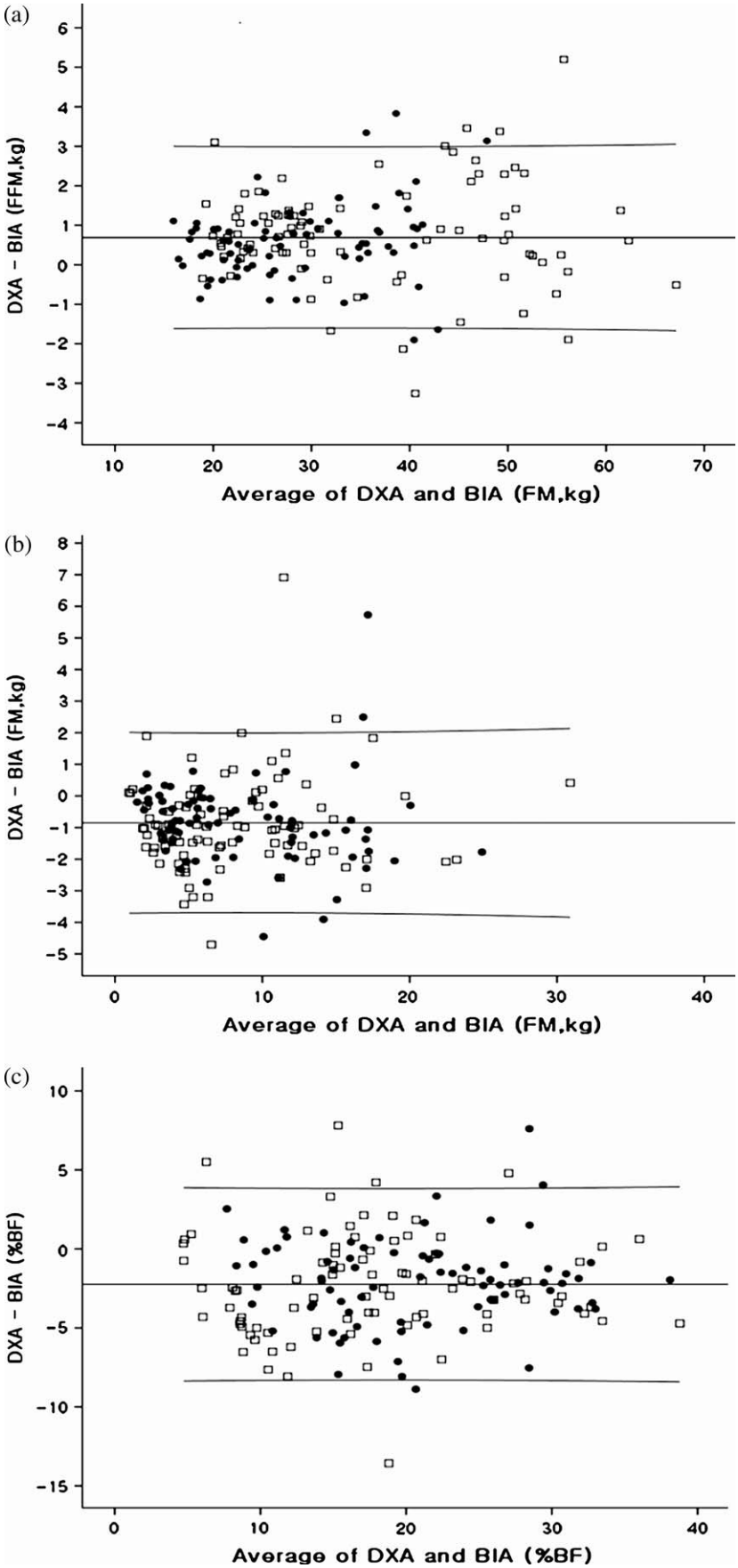

Fig. 2 Bland-Altman plots depicting the difference between DXA and BIA. BIA, bioelectrical impedance analysis; %BF, percent body fat; DXA, dual-energy X-ray absorptiometry; FM, fat mass; FFM, fat-free mass.

subjects with TS 1 who had lower BMI compared with TS 2 and higher had higher %BF on BIA compared to DXA. Thus further study comparing lean and obese subject at the same age or TS is needed.

In conclusion, although BIA and DXA technique are not interchangeable in %BF, these two methods for measuring body composition provided similar estimates of FFM, FM and %BF in healthy children. Both could be used as complementary methods. BIA could be used in screening, population study, and the bedside setting. DXA could be used for definite diagnosis and management of intervention. The next step of research should be to determine the cut-off for %BF related to complications of obesity such as metabolic syndrome in both methods.

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