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Assessing Body Fat of Children by Skinfold Thickness, Bioelectrical Impedance Analysis, and Dual-Energy X-Ray Absorptiometry: A Validation Study Among Malay Children Aged 7 to 11 Years

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Abstract
This study aims to validate skinfold (SKF) and bioelectrical impedance analysis (BIA) against dual-energy X-ray absorptiometry (DXA) in determining body fat percentage (BF%) of Malay children aged 7 to 11 years. A total of 160 children had their BF% assessed using SKF and BIA, with DXA as the criterion method. Four SKF equations (SKF_{Bray}, $SKF_{Johnston}$, $SKF_{Slaughter}$, and SKF_{Goran}) and 4 BIA equations ($BIA_{Manufacturer}$, $BIA_{Houtkooper}$, BIA_{Rush}, and $BIA_{Kushner}$) were used to estimate BF%. Mean age, weight, and height were 9.4 ± 1.1years, 30.5 ± 9.9 kg, and 131.3 ± 8.4 cm. All equations significantly underestimated BF% ($P < .05$). BIA equations had reasonable agreement with DXA and were independent of BF% with $BIA_{Manufacturer}$ being the best equation. Although BIA underestimates BF% as compared with DXA, BIA was more suitable to measure BF% in a population that is similar to this study sample than SKF, suggesting a need to develop new SKF equations that are population specific.

Keywords
body composition, bioelectrical impedance analysis, children, dual-energy X-ray absorptiometry, skinfold measurement, validation study

Introduction

Globally, the prevalence of overweight or obese children and adolescents increased by nearly 50% between 1980 and 2013.[1] Obesity is significantly related to health problems during adolescence.[2] In Malaysia, the prevalence of overweight and obesity among children aged 6 to 12 years

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increased between 2002 and 2008 from 20.7% to 26.4% using World Health Organization (2007) cutoff points.[3] Recently, another study revealed 9.8% overweight and 11.8% obesity among children aged 7 to 12 years in 6 regions of Malaysia.[2] Even though body mass index (BMI) may be appropriate for distinguishing adults, it may not be as suitable in children as they are growing and experiencing body shape change.[3] In addition, BMI fails to distinguish between fat and fat-free mass (muscle and bone) and may falsely classify muscular children as obese.[3]

Methods of measuring body composition are important because body composition, specifically adiposity, is a more important health risk than excess body mass.[4] There is evidence that suggests that increased body fat is associated with higher risk for high blood pressure and dyslipidemia.[4]

There are a number of methods to measure body composition. Laboratory-based techniques such as hydrodensitometry, isotope dilution, and dual-energy X-ray absorptiometry (DXA) have been acknowledged as criterion methods that are acceptable and that produce valid measures of body composition.[5,6] The adoption of DXA as a criterion method is justified by validation against multicompartment models and against chemical analysis of animal carcasses.[5] Bioelectrical impedance analysis (BIA) has become one of the popular alternatives to DXA as it is attractive in terms of cost, equipment portability, and minimal need for personnel training, while skinfold thickness (SKF) measurement is a method that is cheap, quick, and suitable for children, although it needs technicians who are more skilled.[7]

Both methods, however, lack general validity as they depend on population specific prediction equations since there are ethnic differences in body composition.[6] Moreover, most of the body composition measurement techniques have often relied on instruments calibrated for adults or have used body composition constants derived from adult populations, and they may not be suitable to be applied to children.[7] Therefore, the aim of this study was to validate SKF and BIA methods in estimating body fat percentage with DXA as the criterion method among Malay children aged 7 to 11 years.

Methods

Study Design

This validation study is part of the Malaysian South East Asian Nutrition Surveys (SEANUTS). SEANUTS is a multicenter study carried out among 16 744 children aged 0.5 to 12 years.[8] This project was registered in the Dutch Trial Registry as NTR2462. A sample of 160 children aged 7 to 11 years participated in this study, based on sample size calculation using G*Power version 3.1.3 software[9]: medium effect size 0.25; power 90%; level of significance 5%. Subjects were recruited from 4 randomly selected national primary schools with at least 1000 students in each school at Kuala Lumpur. The subjects of this validation study are a separate set from those who participated in the main SEANUTS Malaysia. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/patients were approved by the Medical Research Ethics Committee of Universiti Kebangsaaan Malaysia (Project code: NN-064-2012). Permission from the Ministry of Education and principals of the schools were also obtained.

Subjects

Subjects were Malay children aged between 7 and 11 years who were apparently physically and mentally healthy. Written informed consent from parents and verbal assent from the children were obtained before data collection commenced. Pubertal status of each subject was self-assessed using a questionnaire based on the criteria of Tanner Staging Scale using a printed poster of standardized series of drawings accompanied by explanatory text about the development of breasts, genitals, and pubic hair as guidance.[10,11] Subjects read the descriptions carefully and view themselves in a mirror in order to most accurately select their stage of development from the Tanner Staging poster.

Anthropometric Measurements

All measurements were done on the same day at the Universiti Kebangsaan Malaysia Medical Center. With the exception of the DXA scan, which was performed by a trained technician, all other measurements were done by the same researcher (NMJ). Weight in minimum clothing was measured using a SECA 880 electronic scale (SECA Corp, Hamburg, Germany) to the nearest 0.1 kg and height (without shoes) was measured using a SECA stadiometer Model 213 (SECA Corp, Hamburg, Germany) to the nearest 0.1 cm. Skinfolds were measured in duplicate to the nearest 0.2 mm following the ISAK procedure with a Harpenden skinfold caliper (Holtain Ltd, Bryberian, UK) at 6 sites (biceps, triceps, subscapular, suprailiac, thigh, and calf).[12] The technical error of measurements (TEM) for skinfolds (0.8% to 1.3%) were within target intratester TEM values (<7.5%).[13] BMI was calculated as the ratio of weight in kilograms to the square of height in meters (kg/m^2), and BMI-for-age *Z*-scores (BAZ) were calculated using WHO AnthroPlus software version 1.01 (World Health Organization, Geneva, Switzerland). Body fat percentage (BF%) was estimated using 4 prediction equations published in the literature (Table 1).

Bioelectrical impedance was measured using Bodystat Quadscan 4000 (Bodystat Ltd, Isle of Man, UK) and was calibrated using the calibrator provided by the manufacturer. Prior to measurement, the subjects were in the fasting state for at least 4 hours. Alcohol swabs were used to clean the skin on the right hand and foot where the electrodes were placed. While the children lay "spread-eagle" with their hands and legs not touching each other, electrodes were placed on the wrist and ankle as specified by the manufacturer. Fat-free mass (FFM) was determined using prediction equation and BF% was calculated as BF% = 100 × (weight − FFM/weight). Besides the BF% estimate by Bodystat Quadscan 4000 (manufacturer equation), 3 more equations published in the literature were also used to calculate BF% (Table 1).

Whole-body DXA scans were performed using Hologic QDR series model discovery W S/N 84687 (Hologic Inc, Waltham, MA, USA) with the subject in light clothing while lying supine. BF%, FFM and fat mass (FM) were determined using the pediatric medium scan mode. Each scan took approximately 10 minutes to complete. The instrument was calibrated daily using a phantom, as recommended by the manufacturer. All the scans were conducted and analyzed by the same trained technician according to standard operational procedures. The temporal machine precision (coefficient of variation, CV%) for this study was 0.27%.

Data Analysis

Statistical analyses were conducted using the Statistical Package for Social Science (SPSS) version 16 (SPSS Inc, Chicago, IL, USA). Distributions of BF% by each equation for SKF and BIA, and by DXA were tested for normality using the Kolmogorov-Smirnov test. BF% was normally distributed, therefore parametric tests were employed. Descriptive statistics were calculated for subject's characteristics and independent Student's *t* tests were carried out to examine the difference between sexes. The Bland-Altman technique was used to examine the agreement between BF% measured by DXA and other body composition techniques (4 SKF equations and 4 BIA-based equations).[21] Individual biases were computed as predicted BF% from SKF or BIA minus BF% from DXA. Student's *t* test was performed to examine whether the mean bias were significantly different from zero. To test the agreement between methods, bias for BF% (example: $\text{BIA}_{\text{Manufacturer}}$ minus DXA) was plotted against the mean value of the 2 respective methods

Table 1. Skinfold Thickness (KF) and Bioelectric Impedance Analysis (BIA) Prediction Equations Used to Derive Body Fat Percentage (BF%).

No	Reference	Age	Equation
SKF prediction equation			
1	Bray et al (2001)[14]	10-12 years	Male and female: Fat % = 7.66 + (0.22 × subscapular) + (0.21 × thigh) + (0.64 × biceps) + (0.31 × calf)
2	Johnston et al (1988)[15]	8-14 years	Male: Density = 1.166 – 0.07[log(biceps + triceps + subscapular + suprailiac)]
			Female: Density = 1.144 – 0.06[log(biceps + triceps + subscapular + suprailiac)]
	Lohman et al (1984)[16]	Prepubescent	Male and female: Fat % = (530/density) – 489
3	Slaughter et al (1988)[17]	Children and adolescents	Male: Fat% = 0.735(triceps + calf) + 1.0
			Female: Fat % = 0.61(triceps + calf) + 5.1
4	Goran et al (1996)[5]	4-10 years	Male and female:
			Fat mass (kg) = (0.23 × subscapular) + (0.18 × weight) + (0.13 × triceps) – 3.0
BIA prediction equation			
1	Manufacturer	Not avalaible	Not published
2	Houtkooper et al (1992)[18]	10-19 years	Fat-free mass = 1.31 + (0.61 × height²/resistance) + (0.25 × weight)
3	Kushner et al (1992)[19]	Infants to adults	Fat-free mass = [0.04 + (0.593 × height²/resistance) + (0.065 × weight)]/0.73
4	Rush et al (2003)[20]	5-14 years	Fat-free mass = 0.622(height²/resistance) + (0.234 × weight) + 1.166

(example: [DXA + $BIA_{Manufacturer}$]/2). Limits of agreement were determined using the equation [mean difference ± 2 × standard deviation (SD)].

Results

Physical characteristics of the subjects are shown in Table 2. Boys and girls had similar age, weight, height, BMI and z-score for BMI-for-age, but girls had significantly higher BF% than boys. Most of the subjects (63%) were in the normal BMI category. Some 93% of the subjects were in prepubertal stage (Table 3).

All mean biases for SKF and BIA had negative values, indicating that SKF and BIA methods underestimated BF% when compared with DXA. The 4 SKF equations showed similar SDs of the bias ranging from 2.7 to 3.7, which indicates that they are closely related to each other while BIA had a wider range of SD for bias, ranging from 3.9 to 5.3. The means of bias and 95% limits of agreement between prediction methods and DXA are shown in Table 4.

Although the lowest SD of the individual bias between SKF and DXA was for $SKF_{Johnston}$, the mean bias for this equation was the highest (Table 4, Figure 1). The scatter of the biases for SKF_{Goran} was proportionally lower at lower BF%. This shows that the Goran equation tends to underestimate body fat in subjects with high BF% and overestimates body fat in subjects with low BF%. A similar trend was also seen for SKF_{Bray} and $SKF_{Slaughter}$ where these formulas had high biases for subjects with low and high BF% but had lower bias for subjects with normal values of body fat.

Table 2. Physical Characteristics of Subjects.

	Boys (n = 77)		Girls (n = 83)		All (n = 160)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	9.3	1.0	9.5	1.1	9.4	1.1
Height (cm)	130.4	6.6	132.1	9.7	131.3	8.4
Weight (kg)	29.9	8.9	31.0	10.8	30.5	9.9
BMI (kg/m^2)	17.4	4.1	17.4	4.0	17.4	4.1
BAZ	0.19	1.74	0.04	1.59	0.11	1.66
DXA BF%	29.8	8.3	33.4*	7.6	31.7	8.1

Abbreviations: BMI, body mass index; BAZ, BMI-for-age *Z*-scores; DXA, dual-energy X-ray absorptiometry.
**P* < .05 for sex difference.

Table 3. Classification of Subjects According to Body Mass Index (BMI) and Tanner Stage, n (%).

	Boys (n = 77)	Girls (n = 83)	All (n = 160)
BMI-for-age			
Severe thinness	2 (2.6)	2 (2.4)	4 (2.5)
Thinness	3 (3.9)	4 (4.8)	7 (4.4)
Normal	52 (67.5)	49 (59.0)	101 (63.1)
Overweight	6 (7.8)	18 (21.7)	24 (15.0)
Obese	14 (18.2)	10 (12.1)	24 (15.0)
Tanner stage			
Prepuberty (stage 1 and 2)	77 (100)	71 (85.5)	148 (92.5)
Puberty (stage 3 and 4)	—	12 (14.5)	12 (7.5)
Postpuberty (stage 5)	—	—	—

All BIA equations showed reasonable agreement with DXA. The best agreement was seen for $BIA_{Manufacturer}$ that had a relatively small mean bias and acceptable limits of agreement with no apparent extreme bias compared with other BIA equations (Figure 2). As can be seen in Figure 2, prediction equations using BIA sometimes resulted in extreme individual biases, leading in turn to larger SD of the bias.

Discussion

Using the skinfold prediction equations to Malay children resulted in significant underestimation of BF%, although the bias had a relatively small SD. This, together with the high correlation of SKF and DXA measured BF%, suggests that the underlying principle of skinfold measurement, in that subcutaneous fat is representative for total body fat, is met. However, the ratio of subcutaneous fat to total fat is different in Malay children. Compared with the Caucasian children in the study of Johnston et al,[15] the Malay children in our study are likely to have more internal fat or a different subcutaneous fat pattern, causing the extreme high underestimation. The suggestion that Malay children have more internal fat is supported by the higher waist circumference found in Malay children compared with children from other countries.[22] As prediction equations are population specific, any selection or bias in the sample in which the equation is developed will result in biased estimates when applied to another population sample.

The difference may be due to in methodological differences between the other studies and this study.[23] For example, Johnston et al[15] used the Montreal Olympic Games Anthropological Project

Table 4. Bias Between Different Methods in Measuring Body Composition and the Limits of Agreement.

	SKF_{Bray}-DXA		$SKF_{Johnston}$-DXA		$SKF_{Slaughter}$-DXA		SKF_{Goran}-DXA		$BIA_{manufacturer}$-DXA		$BIA_{Houtkooper}$ -DXA		$BIA_{Kushner}$-DXA		BIA_{Rush}-DXA	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bias	−6.4	3.1	−14.6	2.7	−9.5	3.1	−9.5	3.7	−4.9	5.3	−9.5	3.9	−4.8	4.8	−8.3	4.0
Limits of agreement	−12.6, −0.2		−20.0, −9.1		−15.7, −3.2		−16.9, −2.0		−15.6, −5.7		−17.4, −1.5		−12.8, 4.7		−16.3, −0.3	

Abbreviations: BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry; SKF, skinfold thickness.

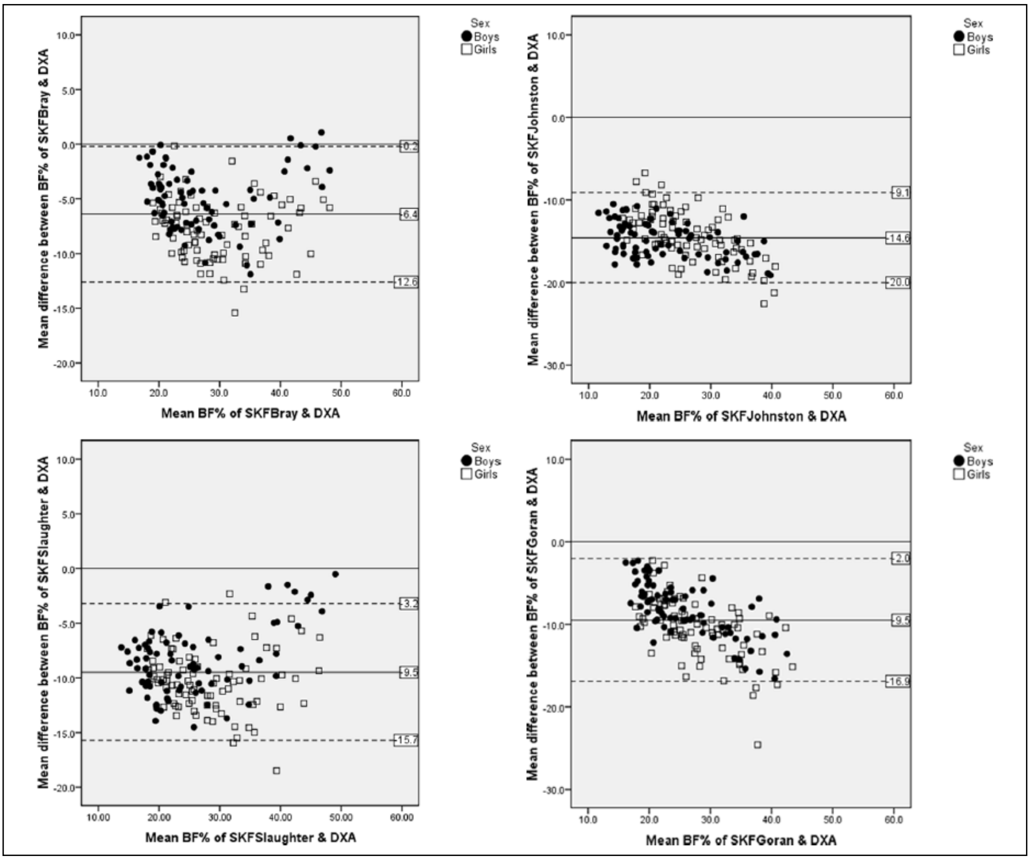

Figure 1. Comparison of predicted body fat percentage (BF%) between skinfold thickness (SKF) equation and dual-energy X-ray absorptiometry (DXA) by Bland-Altman plots. Central line represents mean bias between methods. The dotted line represent upper and lower limit of agreement.
*Y-axis represents predicted BF% minus $BF\%_{DXA}$.

(MOGAP) procedures to perform the SKF measurements, while we used the ISAK method,[12] nevertheless, it seems unlikely that this would result in such huge differences.

In addition, a likely explanation for underestimation of body fat is using BF% formula that relies on body density.[16] The prediction equation by Johnston et al[15] was developed for the estimation of body density in Caucasian children. Results may be biased because of the conversion from body density to BF% and also account for lower estimates of BF% in Malay children based on body density in Caucasian children for a given skinfold measurement.

None of the 4 SKF equations showed good agreement when compared with DXA in our subjects. Nasreddine et al[24] also found similar results when using the SKF_{Bray}, $SKF_{Slaughter}$ and SKF_{Goran} equations in Lebanese children aged 8 to10 years. A study done by Rodriguez et al[25] found that the accuracy of most of the equations including SKF_{Bray}, $SKF_{Johnston}$, and $SKF_{Slaughter}$ for assessment of body fatness at the individual level was poor in adolescents aged 13 to 17 years. Similarly, Reilly et al[23] also found that $SKF_{Johnston}$ also had the lowest estimates of BF% for children aged 6 to 11 years in the United Kingdom.

Although all prediction equations based on bioelectrical impedance also underestimated BF% compared to DXA, the estimates had a lower systematic bias compared to skinfolds. The correlation with BF% from DXA was lower compared with skinfolds and the SD of the bias was higher.

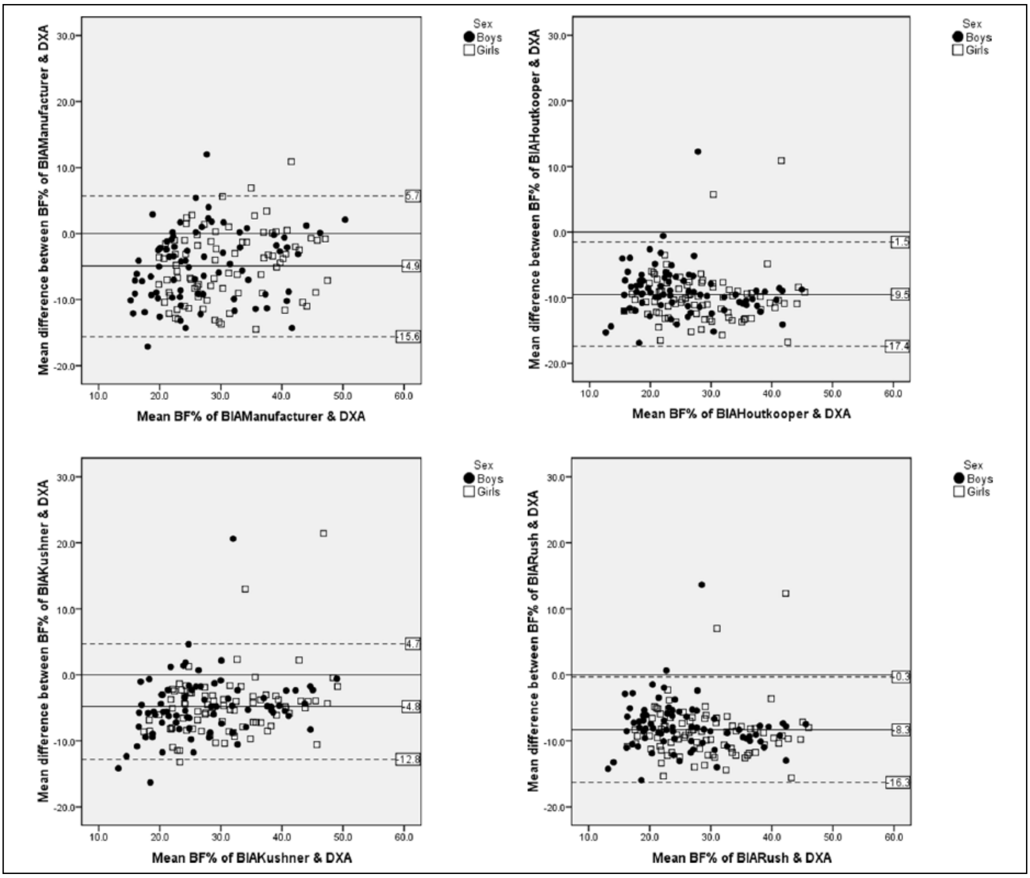

Figure 2. Comparison of predicted body fat percentage (BF%) between bioelectric impedance analysis (BIA) equation and dual-energy X-ray absorptiometry (DXA) by Bland-Altman plots. Central line represents mean bias between methods. The dotted line represent upper and lower limit of agreement. *Y-axis represents predicted BF% minus $BF\%_{DXA}$.

The best prediction was from the Bodystat Quadscan 4000 incorporated equation ($BIA_{Manufacturer}$), which provided consistent estimates of BF% with no apparent extreme individual bias from DXA as compared with other BIA prediction equations. Similarly, BIA prediction equations (Schaefer et al[26] and Houtkooper et al[18]) were validated against DXA by Liew[27] among Malay teenagers aged 13 to 17 years, and it was observed that none of the BIA prediction equations tested had strong agreement to DXA in estimating the BF% of subjects. These results suggest the possibility of ethnic differences in hydration level of FFM.[14] Therefore, ethnic-specific BIA prediction equations may be required because of different coefficients in the relationships between bioelectrical data and body composition.[28]

A recent study have reported that no ethnic-specific BIA prediction equation is required for children aged 5 to 11 years, suggesting that ethnic differences in body size, composition and proportions may be lower in young children.[28] However, applying the 3 BIA prediction equations to Malay children in the current study is likely to overestimate their FFM and underestimate %BF. Previous studies have also demonstrated that BIA may accurately predict %BF if an appropriate BIA prediction equation is used.[18-20]

We found that BF% from SKF equations correlated better with DXA (*r* value ranging from 0.91 to 0.95) than BIA equations (*r* value ranging from 0.82 to 0.88), resulting in a lower SD of biases for skinfold equations than for BIA equations. This suggests that SKF may be a better tool to measure BF% than BIA in young children. According to the study by Rodriguez et al,[25] SKF thickness is accepted as body fatness predictor because subcutaneous fat (40% to 60% of total body fat) can be directly measured with a caliper. An experienced technician can perform reliable skinfold measurements with little error while BIA is a machine dependent method hence less experience is needed from researcher.

With wider limits of agreement and significant underestimation as compared with the criterion method, the present findings showed that the 3 methods SKF, BIA, and DXA were not interchangeable. As reported by Lloret et al,[29] BIA is useful in describing mean body composition for groups of individuals, but the sometimes large errors for an individual, limit its clinical application and among the obese. However, BIA is still useful in assessing body composition at population level with the narrowest agreement limits and a high correlation to DXA among children in this study. Meanwhile, although SKF had very good correlation with DXA, none of the prediction equations showed good agreement with DXA based on the Bland-Altman plots. This calls for the development of SKF prediction equations derived from this population of children, which is supported by literature on ethnic disparities in the ability of published SKF-based equations to accurately predict body fat.[14]

The strength of this study was the use of DXA as the criterion method. Previous studies have examined the accuracy of the technique using carcass analysis in animal models and found that DXA had good precision.[5] Hence, DXA has been acknowledged as a gold standard for body composition measurement. Moreover, Pritchard et al[30] demonstrated that the precision of DXA for BF% estimation was greater than that of the underwater weighing method. In addition, actions have been taken to minimize possible measurement errors by having only one observer doing all the anthropometric measurements using a standardized protocol and daily calibration of instruments. Further studies on validation of SKF and BIA techniques are needed for the other ethnicities living in Malaysia in order to determine similarities or differences within a multiethnic Malaysian population. A limitation of the current study is the relatively small sample of subjects who were of Malay origin and recruited from Kuala Lumpur only. As a result, the present sample may not be considered as representative of Malaysian children.

Conclusion

This finding showed that SKF- and BIA-based prediction equations from the literature underestimate BF% when compared with DXA. None of the SKF prediction equations used in this study had good agreement with DXA while BIA-based prediction equation from the manufacturer had better agreement with DXA and can be used to measure body composition at population level in Malay children. Hence, there is a need for the development of population specific SKF prediction equations for estimating body fat percentage of Malay children.

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Authors' Note

B. K. Poh is National Coordinator, the SEANUTS Study Group. This study was conducted according to the guidelines of the Declaration of Helsinki and all procedures involving human subjects/patients were

approved by the Medical Ethical Committees of the participating institutes. Written informed consent was obtained for all subjects by their parents and/or caregivers. Any findings, opinions, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of FrieslandCampina. FrieslandCampina was not involved in the recruitment of participants or the final results.

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