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Research Article
Comparison of Several Prediction Equations Using Skinfold Thickness for Estimating Percentage Body Fat in 12-15-year-old Indonesian Children

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Abstract
Background and Objective: Gold standard measures of percentage body fat (%BF) have more obstacles in epidemiological studies. Skinfold prediction equations are among the viable methods widely used to estimate %BF. This study aimed to compare several skinfold equations estimating %BF against the %BF obtained from bioimpedance analysis (BIA) in Indonesian children aged 12-15 years. **Materials and Methods:** We invited 610 children (290 boys, 320 girls) aged 12-15 years from junior high schools in Yogyakarta Province. Weight, height and skinfold thickness at the triceps, biceps, subscapular and suprailiac skinfolds were taken according to the protocols of the International Society for the Advancement of Kinanthropometry (ISAK). The percentage of body fat was measured with BIA and estimated using several available skinfold equations. Statistical analyses using paired tests, linear regressions and Bland and Altman plots were performed. **Results:** The skinfold equations of Durnin and Rahaman and Wickramasinghe significantly overestimated %BF ($p<0.001$) in boys and girls, while the equation of Watanabe *et al.* underestimated the %BF ($p<0.001$). The equation of Slaughter *et al.* gave the lowest bias but it slightly overestimated %BF in boys (-2.02 ± 5.22% difference; $p<0.001$) and underestimated %BF in girls (0.78 ± 4.48% difference; $p<0.001$). All equations showed high correlation with %BF obtained from BIA ($r = 0.85$-0.87; $p<0.001$) sand acceptable range of limits of agreement (LOA; 2.6-5.1%), with the lowest being from Slaughter *et al.* **Conclusion:** All selected equations were highly correlated with %BF obtained from BIA and within the acceptable LOA. The skinfold equation of Slaughter et al. showed the most applicability in predicting %BF in our sample population.

Key words: Bioimpedance analysis, obesity, percentage body fat, prediction equations, skinfold thickness

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Obesity, a condition of excessive body fat, is usually assessed by body mass index (BMI), which is a proxy measure of obesity. However, as BMI does not give us information on body composition, using BMI-based definitions for obesity may result in misclassification of obesity[1,2]. As children grow, their body proportions and compositions change. The pattern of change in height, weight, BMI, body proportions and compositions may vary across gender and age groups[3]. Inconsistencies in the relationship between percentage body fat (%BF) and BMI may be observed as children grow into adolescence[4]. Skinfold thicknesses have been widely used to assess body fatness in children[5-8] despite some limitations, such as poor agreement of skinfold thickness equations in the assessment of %BF[9]. Several studies have reported that in children, skinfold thickness correlated more significantly with %BF than did BMI[2,10-13].

There is a change in the chemical composition of the fat-free mass as the child passes through puberty; thus, estimates of body fatness may reflect the changing of FFM rather than fat content[5]. It is believed that body fat increases until puberty and at puberty, boys gain proportionately more muscle and lean tissue compared to fat. In contrast, girls gain fat as a natural part of their physiological maturationt[14]. Several investigations have shown that there is a significant association between pubertal timing and obesity[15,16]. Accordingly, few skinfold prediction equations have been proposed in children according to their maturation level, e.g., the equation of Wohlfahrt-Veje *et al.*[13]. Noble prediction equations, however, also need to be developed using a multicomponent (3C or 4C) approach to body composition measurement. Studies indicate that 4C models are the best approach in paediatric populations for developing and cross-validating new body composition methods[17]. The skinfold equation of Slaughter *et al.*[5] is an example equation developed using a multicomponent model for body composition assessment and accounted for the chemical immaturity of children from pre- and post-pubescent groups. Similar to what is observed in adults, previous studies have also observed racial or ethnic differences in body fatness among children[2,18,19]. Many equations have been developed for different populations of children; however, very few have been cross-validated on other samples of children, such as those who are obese or children at different levels of maturation, e.g., the equation of Wohlfahrt-Veje *et al.*[13]. Research has shown that the application of prediction equations developed from other populations may not adequately estimate %BF in a local population, e.g., in Sri Lankan[20] and Indian children[21].

Despite the extensive skinfold prediction equations proposed and validated for children from various population backgrounds and countries, very little information is available on the predictability of those prediction equations in Indonesian children. To date, no equations specifically developed for Indonesian children are available. The equations of Durnin and Rahaman[6] and Slaughter *et al.*[5] represent widely used skinfold equations applied in various studies across populations around the world, while the equations of Watanabe *et al.*[7] and Wickramasinghe[8] represent skinfold equations developed in Asian populations, which is similar to this study. The testing capability of those equations will provide worthy information for researchers and individuals attempting to assess %BF in Indonesian children. The present study compares several skinfold prediction equations in estimating %BF that are the most frequently used in Indonesian children, i.e., the equations of Durnin and Rahaman[6], Slaughter *et al.*[5], Watanabe *et al.*[7] and Wickramasinghe[8]. The purpose of the study was to find the most valid prediction equation in estimating %BF of Indonesian children aged 12-15 years compared with %BF obtained from BIA.

MATERIALS AND METHODS

Participants: The participants of this study were 610 children (290 boys, 320 girls) aged 12-15 years from two selected junior high schools in Yogyakarta Province, Indonesia in 2017. Apparently healthy boys and girls aged 12-15 were recruited into this study. Children with mental or physical disability were excluded. Ethics approval for this study was provided by the Medical and Health Research Ethics Committee of Faculty of Medicine, Public Health and Nursing Universitas Gadjah Mada. A written consent form was also obtained from the parents or guardians of each child.

Measures: Weight, height and skinfold thickness at the triceps, biceps, subscapular and suprailiac skinfolds were taken according to the protocols of the International Society for the Advancement of Kinanthropometry[22]. Body weight was measured with a Seca weight scale (Seca 803, Hamburg, Germany) to the nearest 0.1 kg while participants were wearing light clothing. Height was taken using an anthropometric set (GPM, Swiss, Ltd.) to the nearest 0.1 cm. Skinfold thicknesses were taken using a skinfold calliper

(Model 610ND, Holtain Co. Ltd., Wales, UK) at the triceps, biceps (respectively, the point on the posterior and anterior surface of the arm in the midline at the level of the mid-acromial-radial), subscapular (the undermost tip of the inferior angle of the scapula) and suprailiac (the centre of the skinfold raised immediately above the marked iliocristale) skinfolds.

Body mass index was obtained from weight (kg) divided by height (cm) squared. The WHO age and gender-specific cut-offs for BMI (Z-score) were used to determine nutritional status, i.e., underweight, normal and overweight. Percentage of body fat (%BF) was measured using a bipedal bioimpedance analysis (BIA) device to the nearest 0.1% (Tanita, BC-601, Japan) and estimated using several skinfold equations provided by Durnin and Rahaman[6], Slaughter *et al.*[5], Watanabe *et al.*[7] and Wickramasinghe[8].

Prediction equations: The prediction equations of Durnin and Rahaman[6] for estimation of %BF derived from body density (BD) were as follows:

$$BD = 1.1690-0.0788 \log \text{sum 4 skinfolds (boys)}$$

$$BD = 1.2063-0.0999 \log \text{sum 4 skinfolds (girls)}$$

$$BF (\%) = ([4.95/BD]-4.5)\times 100$$

where, the sum of 4 skinfold thicknesses is the sum of the triceps, biceps, subscapular and suprailiac skinfolds.

The prediction equations of Slaughter *et al.*[5] for the estimation of %BF were as follows:

- For boys and girls with the sum of triceps and subscapular skinfold thicknesses <35 mm:

$$BF (\%) = 1.21 \text{ (triceps and subscapular)}-0.008 \text{ (triceps and subscapular)}^2 - 1.7 \text{ (boys)}$$

$$BF (\%) = 1.33 \text{ (triceps and subscapular)}-0.013 \text{ (triceps and subscapular)}^2 - 2.5 \text{ (girls)}$$

- For boys and girls with the sum of triceps and subscapular skinfold thicknesses >35 mm:

$$BF (\%) = 0.546 \text{ (triceps and subscapular)}+9.7 \text{ (boys)}$$

$$BF (\%) = 0.783 \text{ (triceps and subscapular)}+1.6 \text{ (girls)}$$

The prediction equations of Watanabe *et al.*[7] for the estimation of %BF were as follows:

$$BF (\%) = 1.0875-0.0010 \text{ (triceps+subscapular) (boys)}$$

$$BF (\%) = 1.0716-0.0007 \text{ (triceps+subscapular) (girls)}$$

The prediction equation of Wickramasinghe[8] for estimation of %BF was as follows:

$$BF (\%) = (-0.28\times \text{age})+(0.49\times \text{triceps}) + (0.34\times \text{subscapular}) - (7.97\times \text{gender})+26.8$$

where, gender = 1 for boys and gender = 0 for girls.

Statistical analysis: Analyses of Student's t-tests and chi-squared tests were performed to find the mean difference between gender and within categories. Paired correlations and differences were used to evaluate the relationship and difference between %BF obtained from BIA and the prediction equations. Limits of agreement between %BF obtained from BIA and the selected prediction equations were evaluated using paired-tests, regressions and Bland and Altman analysis. The limits of agreement (LOA) were defined as the mean±1.96 SD for the upper and lower limits. All statistical analyses were performed using SPSS (version 25.0, SPSS Inc., 2017, Chicago, IL) and $p<0.05$ was considered statistically significant.

RESULTS

The characteristics of the participants are presented in Table 1. There were no significant differences between boys and girls in the average age and body weight but boys were

Table 1: Characteristics of the participants

	Mean±SD		
	Boys	Girls	p-value
N	290	310	
Age (y, mean)	13.8±0.9	13.7±0.9	0.15[a]
12 year	17 (5.9%)	32 (10.0%)	
13 year	108 (37.2%)	112 (35.0%)	0.15[b]
14 year	99 (34.1%)	118 (36.9%)	
15 year	66 (22.8%)	58 (18.1%)	
Weight (kg)	46.11±13.74	44.82±11.14	0.20[a]
Height (cm)	153.89±9.13	149.67±6.55	<0.001[a]
BMI (kg/m^2)	19.16±4.04	19.87±4.22	0.03[a]
BMI categories (n (%))			
Underweight	24 (8.3%)	19 (5.9%)	
Normal	207 (71.4%)	237 (74.1%)	0.08[b]
Overweight	34 (11.7%)	47 (14.7%)	
Obese	25 (8.6%)	17 (5.3%)	

N: Number of total participants, SD: Standard deviation, [a]Significant difference between boys and girls using t-test analysis, [b]Significant difference within ages and BMI category using chi-squared analysis approximately 4 cm taller than girls (p<0.001). Girls showed a higher mean BMI than boys (p<0.05); however, there was no significant difference in the prevalence of BMI category (p = 0.077). As many as 8 and 6% of boys and girls, respectively, were underweight, while approximately 20% of children were obese (including overweight) regardless of gender.

The differences and the limits of agreement between %BF obtained from BIA and various selected skinfold equations are described in Table 2 and 3, respectively. The means of %BF were 15.16±10.08% and 23.99±8.53% in boys and girls, respectively. All skinfold equations tended to overestimate %BF in boys, except the equation of Watanabe *et al.*[7], while the equations of Watanabe *et al.*[7] and Slaughter *et al.*[5] underestimated %BF in girls (Table 2).

The lowest %BF difference in boys was approximately 2% obtained from the equations of Slaughter *et al.*[5] and Watanabe *et al.*[7] but the former overpredicted while the latter underpredicted %BF. Both the equations of Durnin and Rahaman[6] and Wickramasinghe[8] overpredicted (approximately 6-7%) %BF in boys. For girls, the equation of Slaughter *et al.*[5] also showed the least difference with the BIA, i.e., only approximately 0.8% (±4.48%), while the equation of Wickramasinghe[8] showed the highest difference with the BIA, as it overpredicted, i.e., approximately 10% (±5.78%), in girls.

Although, all prediction equations significantly correlated with %BF BIA, all of them also showed statistically significant bias with the BIA. The limit of agreement indicated that the equation of Slaughter *et al.*[5] showed the best performance, i.e., the smallest mean difference and limits (95% CI) (Table 3).

Body fat measured with BIA was plotted against the selected skinfold equations (Fig. 1). The magnitude of the regression lines was almost similar (r^2 = 0.63-0.79). However, there was a tendency to overestimate %BF in individuals with a lower %BF and to underestimate %BF in individuals with a higher %BF in all of the prediction equations. In the figure, it is apparent that the equation of Slaughter *et al.*[5] had the best fit with the reference line (the least diverged). This meant that the equation had the lowest mean discrepancy of estimated %BF, whereas the equation of Wickramasinghe[8] indicated further spread from the reference line.

Figure 2 illustrates the Bland and Altman plots of %BF obtained from BIA and the mean differences of the selected skinfold equations with upper and lower 95% CI. The equation of Slaughter *et al.*[5] showed the lowest prevalence of individuals beyond the lower and upper limits of agreement (LOA), i.e., approximately 2.5%. The equation of Durnin and Rahaman[6] had approximately 2.8% individuals beyond the lower and upper LOA. With regard to %BF, approximately 4.4% and 5.3% of individuals were either over- or underpredicted,

Table 2: Difference between the %BFs obtained from BIA and various skinfold equations

	Paired correlation			Paired difference		
	Mean±SD	r±SEE	p-value	MD±SD	t	p-value
Boys (n = 290)						
%BF from BIA	15.16±10.08					
%BF from skinfold (A)	21.22±7.07	0.87±5.00	<0.001	-6.06±5.27	-19.68	<0.001
%BF from skinfold (B)	17.18±7.03	0.87±4.91	<0.001	-2.02±5.22	-6.60	<0.001
%BF from skinfold (C)	13.14±4.24	0.87±5.00	<0.001	2.02±6.73	5.10	<0.001
%BF from skinfold (D)	22.77±4.01	0.87±5.07	<0.001	-7.61±6.92	-18.75	<0.001
Girls (n = 320)						
%BF from BIA	23.99±8.53					
%BF from skinfold (A)	25.62±6.94	0.88±3.99	<0.001	-1.70±4.24	-7.19	<0.001
%BF from skinfold (B)	23.15±6.83	0.87±4.27	<0.001	0.78±4.48	3.52	<0.001
%BF from skinfold (C)	19.00±2.95	0.87±4.26	<0.001	3.93±6.28	11.62	<0.001
%BF from skinfold (D)	33.99±3.81	0.85±4.46	<0.001	-10.07±5.78	-31.66	<0.001

(A): %BF predicted from the skinfold equation of Durnin and Rahaman[6], (B): %BF predicted using the formula of Slaughter *et al.*[5], (C): %BF predicted using the formula of Watanabe *et al.*[7], (D): %BF predicted using the formula of Wickramasinghe[8], MD: Mean difference: %BF BIA-%BF skinfold equation

Table 3: Limits of agreement between the %BF obtained from BIA and various prediction equations

	Boys		Girls	
	MD±limit	Lower, Upper	MD±limit	Lower, Upper
BIA and skinfold (A)	-6.06±10.33	-16.39, 4.27	-1.70±8.31	-10.01, 6.61
BIA and skinfold (B)	-2.02±10.23	-12.25, 8.21	0.78±8.78	-8.00, 9.56
BIA and skinfold (C)	2.02±13.19	-11.17, 15.21	3.93±12.31	-8.38, 16.24
BIA and skinfold (D)	-7.61±13.56	-21.17, 5.95	-10.07±11.33	-21.40, 1.26

(A) %BF predicted from the skinfold equation of Durnin and Rahaman[6], (B) %BF predicted using the formula of Slaughter *et al.*[5], (C) %BF predicted using the formula of Watanabe *et al.*[7], (D) %BF predicted using the formula of Wickramasinghe[8], MD: Mean difference: %BF BIA-%BF skinfold equation

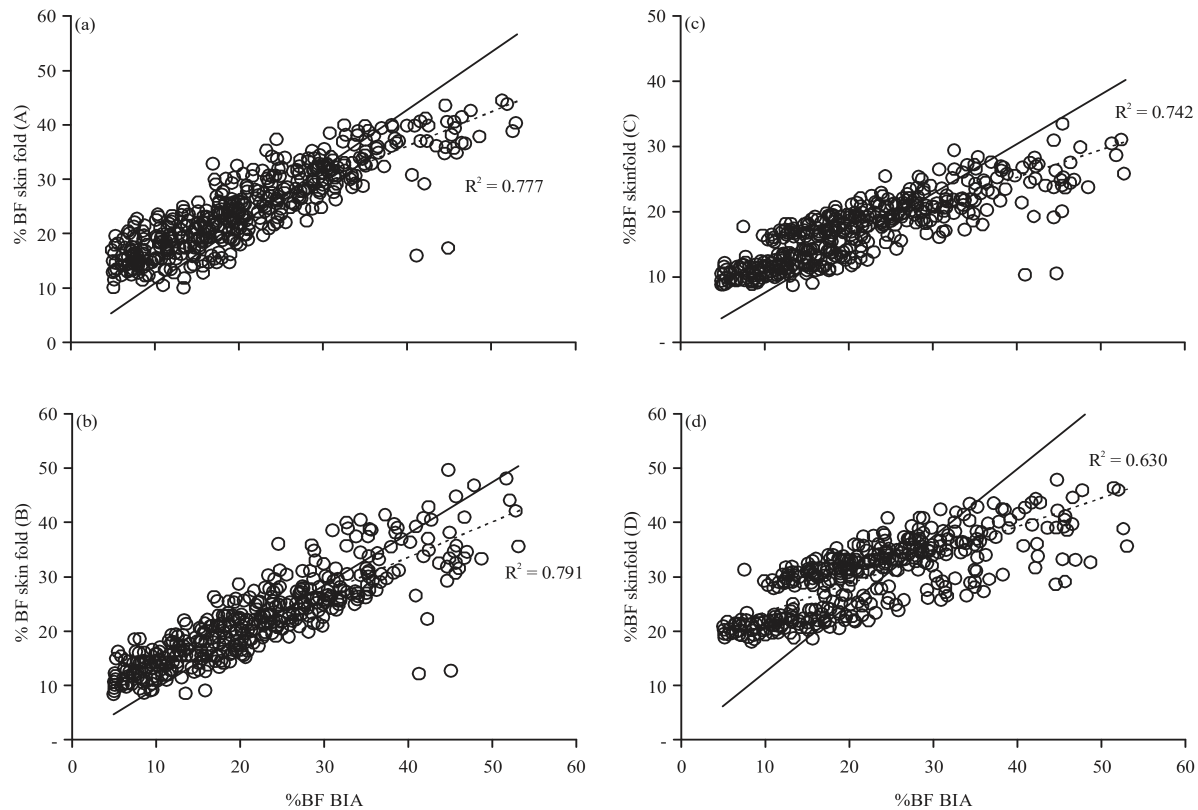

Fig. 1(a-d): Scatter plots with regression lines of %BF obtained from BIA against those estimated from the skinfold equations of (a) Durnin and Rahaman[6], (b) Slaughter *et al.*[5] (c) Watanabe *et al.*[7] and (d) Wickramasinghe[8]

respectively, compared with those obtained from BIA beyond the lower and upper LOA using the equations of Watanabe *et al.*[7] and Wickramasinghe[8], respectively. Moreover, the two equations had a tendency to underestimate %BF in individuals with higher %BF.

DISCUSSION

The present study evaluated the applicability of the available skinfold equations of Durnin and Rahaman[6], Slaughter *et al.*[5], Watanabe *et al.*[7] and Wickramasinghe[8] in predicting %BF among Indonesian children aged 12-15 years and compared with %BF obtained from BIA. All the selected equations were highly correlated with %BF obtained from BIA and within the acceptable LOA. Among others, the skinfold equation of Slaughter *et al.*[5] showed the most applicability in predicting %BF in our sample population.

Concerning the nature of the equations, present study cross-validated several skinfold equations developed from various races/ethnicities; several were gender-specific and discerned age or maturation level. Durnin and Rahaman[6] proposed an equation predicting %BF from body density measured with underwater weighing (UWW) and the subsequent %BF by Siri[6]. No specific race/ethnicity was reported in the equations but they differentiated between boys and girls as well as adult men and women of a European population. The equation of Watanabe *et al.*[7] was a gender-specific formula developed from Japanese children aged 12-15 years using body density determined by underwater weighing (UWW) as a criterion method. Wickramasinghe *et al.*[8] used Sri Lankan children aged 5-15 years using the deuterium isotope dilution method to propose a non-specific age and gender equation. The equation of Slaughter *et al.*[5] was the only equation among the selected ones that applied the multi-compartment approach of body composition assessment. The equation was developed in black and white populations using %BF obtained from several criterion methods, i.e., body density from UWW, total body water (TBW) assessed with deuterium isotope dilution and bone mineral density using photon absorptiometry.

All skinfold equations cross-validated in our samples were within the acceptable range of mean difference limits (94.7-97.5%) and highly correlated (r = 0.85-0.87) with %BF obtained from BIA as the reference. Nonetheless, several

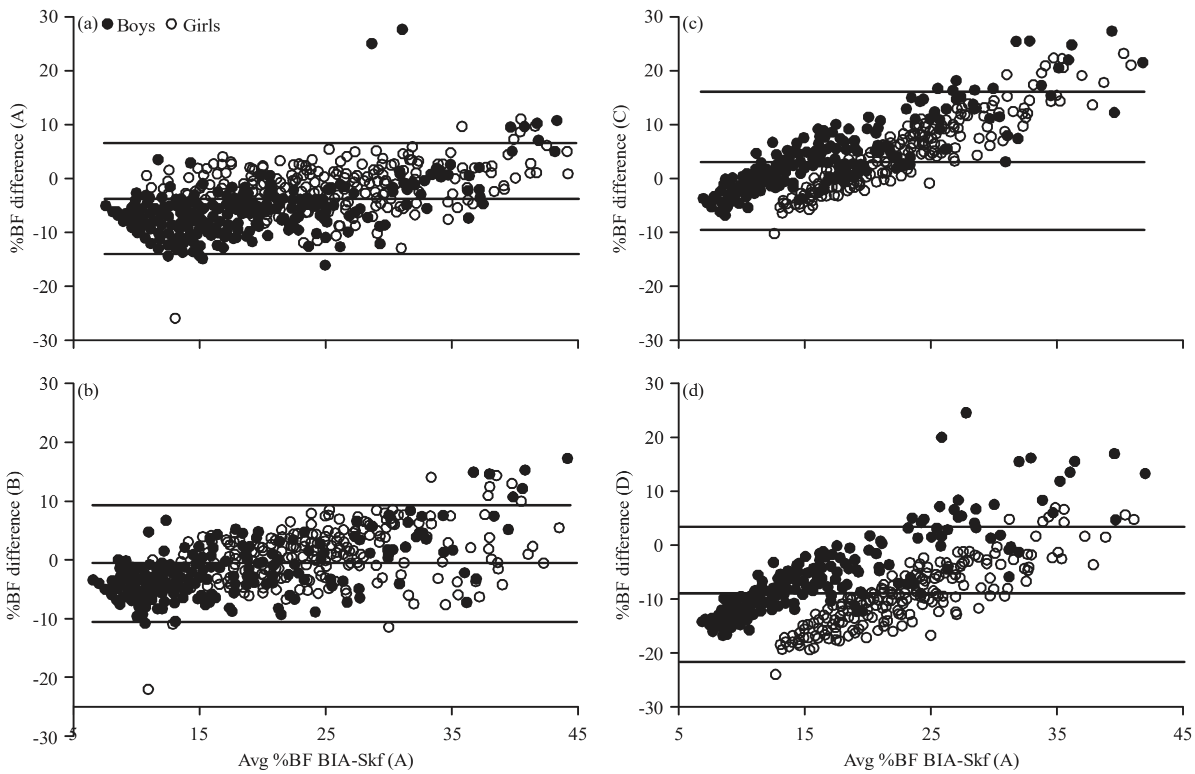

Fig. 2(a-d): The Bland and Altman plots of difference between %BF obtained from BIA and skinfold equations of (a) Durnin and Rahaman[6], (b) Slaughter *et al.*[5], (c) Watanabe *et al.*[7] and (d) Wickramasinghe[8], U: 95% CI upper limit, M: mean difference, L: 95% CI lower limit; mean difference: %BF BIA-%BF skinfold equation; Avg: Average of %BF from BIA and skinfold equation

equations seemed to overestimate or underestimate %BF in the boys and girls of our samples. Although both the equations of Watanabe *et al.*[7] and Wickramasinghe[8] were developed from Asian populations similar to our sample population, they produced a relatively high bias of estimated %BF. The equation of Wickramasinghe[8] was found to produce the most significant bias, which overestimated %BF by approximately 8 and 10 units in boys and girls, respectively, than the reference, while the equation of Watanabe *et al.*[7] seemed to underestimate %BF in both boys and girls by approximately 2 and 4 units, respectively.

As race/ethnicity is associated with body fat in children, prediction equations should be race/ethnicity-specific. However, even with skinfold equations developed using population with racial compositions similar to that in our sample, the results were not supported. It is probable that other factors may account for this difference, e.g., living environment[8]. It has been reported that there was a significant difference in %BF among Sri Lankan children living in their country of origin and Australia, while no difference was found between those living in Australia and children of Caucasian origin in Australia[8].

On the other hand, the equation of Slaughter *et al.*[5], although developed from a Caucasian population, provided the most applicability in our samples. It should be considered that study design might improve the acceptability of the equations proposed. The equation of Slaughter *et al.*[5] was developed using the multi-compartment (4C) method of body composition assessment. It is believed that multicompartment models, specifically the 4C model, can account for the potential effects of age, gender and race/ethnicity differences in FFM density and composition when used as the criterion method, despite residual differences. Hence, specific BIA and/or anthropometric equations for visibly distinct age, gender and ethnic groups of children and adolescents are essential to apply a 4C model as the criterion method[17]. Research has indicated that prediction equations developed using the multi-compartment model are more valid than using a single criterion method[22,23]. This equation also considers gender and level of maturation in the development of the equations, while, level of maturation is believed to be associated with body composition in children, which also has different patterns between genders[5,15,24]. Present study continuously supported the applicability of the Slaughter *et al.*[5] prediction equation among children, as reported by Freedman *et al.*[25,26] and Hussain *et al.*[24] and validated against %BF from DEXA measures.

Caution has to be exerted when applying results of the current study to general populations of Indonesian children. First, this study used %BF obtained from BIA measurement as the reference, which is not a gold standard criterion for body composition assessment. Future studies should consider the use of possible gold standard techniques, such as DEXA or deuterium isotope dilution or a combination of both techniques. Nonetheless, application of the BIA technique was the most viable method in the absence of sophisticated instruments for gold standard criteria. Studies have reported that the BIA technique is useful and accurate for the assessment of body composition in children[8,27,28]. A previous study supported the use of %BF measured with BIA to cross-validate %BF predicted from skinfold thickness in Indian children[21]. However, a study reported that using selected two portable BIA instruments led to underestimated FM and %BF in children. Thus, the body composition results obtained using the inbuilt equations of BIA should be interpreted with caution[29].

Second, due to the vast number of ethnicities in Indonesia, results of the present study may not be generalizable to all Indonesian children. However, our samples are all of the Javanese population, which is considered the most populous ethnic group and Asian children (the most populous race in Indonesia) and hence could represent a wide range of children. Current study strongly suggests proposing prediction equations developed from Indonesian children that consider gender, age and ethnicity while using the criterion method of body composition for reference.

CONCLUSION

Our results show that the available skinfold equations of Durnin and Rahaman, Slaughter *et al.*, Watanabe *et al.* and Wickramasinghe were highly correlated with %BF obtained from BIA and within the acceptable limits of agreement in predicting %BF among Indonesian children aged 12-15 years. However, the equation of Slaughter et al. showed the most applicability in predicting %BF in our sample population. Several cautions should be considered when attempting to apply the results of the current study.

SIGNIFICANCE STATEMENT

This study discovered the most appropriate skinfold prediction equation for the estimation of %BF in Indonesian children aged 12-15 years, which can be beneficial for the valid assessment of body composition when a more advanced method is not available. This study will guide the researcher to the critical areas of child body composition that many researchers were not able to explore. Thus, a new theory on the assessment of body composition in Indonesian children may be arrived at.

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