Short Communication

Validity and reliability of skinfold measurement in assessing body fatness of Chinese children

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Background: Validity and reliability of skinfold equations in estimating body fat in Chinese Children has not been documented. Objective: Using Air Displacement Plethysmography (ADP) as a criterion, the validity and reliability of skinfold (SKF) measurement in predicting percent body fat (%fat) of Chinese children in Hong Kong were evaluated. Design: 230 Chinese children in Hong Kong were recruited to participate in measurements of ADP, body height and weight, waist and arm circumferences, and skinfold (SKF) from different body sites. A sub-sample of 41 participants was asked to take an additional measurement of Dual Energy X-ray Absorptiometry (DXA). %fat was measured from ADP, DXA, and estimated from Slaughter SKF equations. Results: internal consistency of SKF and ADP measurements were very high ($r \geq 0.988$). Significant difference was found between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ ($p<0.05$). The Slaughter equations slightly underestimate %fat (boys: 1.52%; girls: 1.84%). The slope of the regression line for boys and both the slope and intercept of regression line for prepubescent girls were significantly different from the line of identity. Subsequent stepwise regression found the best model for boys includes predictors of height, and ∑3SKF (triceps, calf, and suprailiac) (R^2=0.88, SE=3.70), and that for girls includes height, ∑2SKF (triceps and calf), and waist circumference (R^2=0.71, SE=3.38). The most convenient model for both genders required only triceps and age (boys: R^2=0.81, SE=4.67; girls: R^2=0.63, SE=3.77). Conclusions: Skinfold measurements provide valid and reliable %fat estimation in Chinese children. However, the application of Slaughter equations in Chinese children is questionable. Alternative skinfold models are proposed.

Key Words: childhood obesity, body composition, pediatric measurement, overweight, growth and development

INTRODUCTION

Childhood obesity is a worldwide growing epidemic. A high prevalence and increasing rates of childhood obesity have been reported globally, including from countries such as the United States,[1] England,[2] and mainland China.[3] An estimate of 22 million children under five years of age is overweight worldwide. Obesity is one of the major contributors to the global burden of chronic disease and disability, including type 2 diabetes, cardiovascular disease, hypertension and stroke, and certain types of cancer. The health consequences range from increased risk of premature death, to serious chronic conditions that reduce the overall quality of life.

The prevalence of childhood obesity in Hong Kong has increased by closed to 70% in the past 13 years.[4] However, a question has been raised about the definition of childhood obesity using the weight/height ratio which has been adopted since 1993, when 120% weight-for-height was adopted as the local criteria to define childhood obesity.[5] Scientists have commented that the weight/height ratio is only a crude index of body composition and should be considered as a screening tool of body shape rather than an accurate body fat measurement in children. Hence, for tracking childhood obesity effectively, there is an urgent need to evaluate the obesity level of children in Hong Kong using objective and practical measurement.

There are various ways of measuring human body composition. Laboratory measurement, while precise, involves sophisticated equipments and complex procedures and trained technicians. Field methods, though less accurate compared with laboratory methods, are much simpler and inexpensive, and can be carried out for large group of people in community or school settings. However, not all of them are appropriate for children. An accurate, reliable and convenient way of assessing pediatric body composition is essential for monitoring childhood obesity in Hong Kong and the world. Among various laboratory methods, the air displacement plethysmography (ADP) is a more desirable body composition method for young children because it is safe and easy to use.

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In terms of accuracy, a number of studies indicate that the validity of body fat measurement using the ADP method is comparable to those obtained by underwater weighing and the four-compartment model.[6-9]

Scientists suggest the use of the skinfold method, the measurement of subcutaneous fat, in field setting as an alternative to laboratory methods. Currently it is the most widely adopted field method for measurement of body fat in children.[10,11] Since the instruments used are portable, inexpensive and non-invasive, skinfold method can be readily applied in clinics, laboratories and schools. It also has high correlation with percent body fat.[12] At the moment, the Slaughter equations are the most widely used skinfold equations for pediatric measurement of body fatness.[13] These equations were developed from African American and Caucasian children aged 8-17 years, and had not been cross-validated in children residing in Hong Kong. Slaughter et al. found small differences in %fat prediction between different maturation groups, hence suggesting that separate equations for each maturational group were unnecessary.[13] Since these prediction equations are age and race specific, validation has to be done before applying these equations on children in Hong Kong.[14] Nevertheless, skinfold measurement of school children in Hong Kong has been collected for many years. Practitioners in Hong Kong simply adopt the sum of skinfolds to get body fatness, or erroneously applying the Slaughter equations to get an estimation of body fatness.

The purpose of this study was to examine the validity and reliability of skinfold measurement in predicting body density and percent body fat (%fat) in Chinese children in Hong Kong, aged 9 to 19 years old, using ADP as reference.

MATERIALS AND METHODS

Participants

A total of 230 healthy voluntary Chinese children, aged 9-19 year-old (142 boys and 88 girls) were recruited. A stratified purposeful sampling method was used to recruit a heterogeneous sample that covers a wide range of age and body composition according to their age and gender specific BMI distribution among children in Hong Kong.[15] Participants were recruited according to the following categories: BMI lower than 30th percentile for age and gender specific BMI distribution among Hong Kong children; BMI between 30th percentile and 70th percentile for age and gender specific BMI distribution among Hong Kong children; BMI higher than 70th percentile for age and gender specific BMI distribution among Hong Kong children.

The purpose, risks and benefits were explained to each participant and their parents before obtaining written informed consent. Medical history of participants was collected. The study was approved by the Ethical Committee for Conducting Research Using Human in the Chinese University of Hong Kong.

Experimental protocols and procedures

Criterion Measurement

ADP was performed using the Bod Pod (Life Measurement System, Concord, CA). Participants were required to wear a tight fitting swimsuit and swimming cap. Participants were weighed to the nearest 0.1 kg, and height was determined to the nearest centimeter. Body volume was measured using ADP which involves three steps.[7] The first step was the standard 2-point calibration process with the chamber empty to establish baseline and then with a calibration cylinder to establish range. This procedure involved a volume calibration with and without a 50 L metal cylinder.

In the second step, the participant was required to sit in the test chamber and the volume of the participant in the chamber is measured. Subjects entered the Bod Pod and sat inside the anterior chamber (450 L), which was connected to a rear-measuring chamber (300 L) via oscillating diaphragms (used to induce pressure changes in the anterior chamber), and breathed normally (relaxed tidal breathing). The procedure consisting of two measurements of body volume (50 seconds each). When body volumes differed by more than 150 ml, a third measurement was required. The final result reported by the Bod Pod instrumentation was the mean of the two (or the two closest) measurements.

In the third step, thoracic gas volume was estimated. Finally, the corrected body volume and body density and percent body fat (%fat) was calculated by the Bod Pod with well established equations.[7] The measurements of body volume, body density, and %fat were repeated twice for each participant. Reliability of internal consistency for the above ADP measurements was then determined by intra-class correlation of the two repeated trials.

Comparison of Percent Fat Criterion by ADP and DXA

To ensure ADP as an accurate criterion of body fatness measurement, %fat measured by ADP (%fat$_{ADP}$) was compared with that measured by Dual Energy X-ray Absorptiometry (DXA, Hologic QDR 4500, USA) (%fat$_{DXA}$) in a sub-sample of 41 participants. The result of repeated t-test showed that there was no difference (t = 0.15, df = 40, p>0.05) between %fat$_{ADP}$ and %fat$_{DXA}$, The computed effect size for the difference was 0.25. These are in line with previous studies that the body fatness obtained by ADP did not significantly deviate from other methods.[6,9] These suggested that ADP could be an acceptable criterion of measuring %fat in this study.

Field Measurements

Body height and weight were measured with minimal clothing and bare feet. Waist circumference was measured at the narrowest part of the torso, above the umbilicus and below the xiphoid. Harpenden caliper (UK) was used to measure participants' skinfold: including triceps, subscapular, suprailiac, abdomen, thigh, and calf, according to the standard procedures by the guidelines of American College of Sports Medicine.[16] These measurements were undertaken immediately before ADP.

Statistical Analysis

Means and SD was computed. Age-adjusted correlation was used to determine the relationship between measured variables. The internal consistency between repeated trials of ADP and skinfold measurement were examined

Table 1. Descriptive statistics of the physical characteristics of participants

	Boys (n=142)			Girls (n=88)			Total (n=230)		
	Mean	Range		Mean	Range		Mean	Range	
	(±SD)	Lower	Upper	(±SD)	Lower	Upper	(±SD)	Lower	Upper
Age (years)	14.37 (2.81)	9	19	14.48 (2.42)	9	18	14.41 (2.66)	9	19
Height (cm)	161.17 (13.99)	131.1	185.0	156.24 (8.67)	129.2	172.4	159.29 (12.45)	129.2	185.0
Weight (kg)	54.79 (16.91)	23.80	111.40	48.00 (8.80)	26.20	74.60	52.19 (14.71)	23.80	111.40
BMI (kg/m^2)	20.69 (4.46)	13.85	37.39	19.56 (2.69)	14.46	27.67	20.26 (3.91)	13.85	37.39
Body density (kg/L)	1.0499 (0.0248)	.984	1.090	1.0346 (0.0131)	.999	1.065	1.0440 (0.0223)	0.984	1.090
%fat$_{ADP}$ (%)	19.72 (10.62)	2.5	50.4	25.81 (6.19)	12.2	40.8	22.05 (9.63)	2.5	50.4
%fat$_{Slaughter}$ (%)	18.20 (8.58)	8.28	41.50	23.97 (4.69)	15.96	37.55	20.41 (7.85)	8.28	41.50
Arm C (cm)	23.61 (4.33)	15.9	40.5	22.54 (2.56)	17.1	29.6	23.20 (3.78)	15.9	40.5
Waist C (cm)	70.72 (12.51)	49.0	112.0	64.65 (6.11)	49.9	82.5	68.40 (10.92)	49.0	112.0
Triceps skinfold (mm)	11.91 (5.85)	4.6	28.8	16.37 (4.31)	8.9	27.1	13.62 (5.73)	4.6	28.8
Biceps skinfold (mm)	7.21 (4.09)	2.8	20.2	9.42 (3.28)	4.3	21.2	8.06 (3.94)	2.8	21.2
Subscap skinfold (mm)	13.02 (8.517)	4.4	39.0	13.91 (4.93)	5.1	34.0	13.36 (7.36)	4.4	39.0
Suprailiac skinfold (mm)	9.47 (7.05)	3.3	37.6	12.60 (5.06)	3.9	36.8	10.67 (6.54)	3.3	37.6
Thigh skinfold (mm)	15.35 (8.23)	4.8	38.6	20.90 (5.85)	8.7	38.5	17.48 (7.87)	4.8	38.6
Calf skinfold (mm)	11.49 (6.17)	4.7	27.4	14.57 (4.04)	7.9	26.1	12.67 (5.65)	4.7	27.4

Note: %fat$_{ADP}$ = percent fat measured from Air-displacement Plethysmography; %fat$_{Slaughter}$ = percent fat computed from Slaughter equations; Arm C = arm circumference; Waist C = waist circumference; SD = standard deviation.

using intra-class correlation coefficients. Age-gender specific cross-validation of the Slaughter equations was examined by paired t-test and simple regression, comparing %fat estimated from Slaughter equations and that measured by ADP. It was reported that the mean age of menarche for Chinese children was 11.7 years, to examine the influence of maturation, cross-validation analyses were conducted for the age groups 11 or under, 12-15, and 16 and above.[17] Stepwise regression analysis was used to examine the criterion-related validity of skinfold measurement in predicting criterion %fat other than the Slaughter equations. Bland-Altman plots were produced to illustrate the residual errors.[18] All analyses were conducted using SPSS 12.0, and results were considered statistically significant at $p<0.05$.

RESULTS

Descriptive Statistics

Descriptive statistics of physical characteristics of the participants are presented in Table 1. Mean percent body fat measured by ADP (%fat$_{ADP}$) was 19.7±10.62 % for boys and 25.8±6.19 % for girls. Both the mean %fat and skinfolds of different sites of girls were higher than that of boys. The mean percent body fat estimated by Slaughter skinfold equation (%fat$_{Slaughter}$) was 18.2 ± 8.58 % for boys and 24.0±4.69 % for girls.

Table 2. Regression table showing the association between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ (by gender and age-groups)

Gender	Intercept	β	r	R^2	SE
Boys					
All (n=142)	-0.527 †	1.113	0.90	0.81	4.67
Age ≤ 11 yrs (n=29)	2.764 †	1.032 ‡	0.90	0.80	4.04
Age 12-15 yrs (n=55)	1.424 †	1.058 ‡	0.90	0.80	5.10
Age ≥ 16 yrs (n=58)	-1.323 †	1.060 ‡	0.87	0.75	4.09
Girls					
All (n=88)	0.537 †	1.054 ‡	0.80	0.64	3.77
Age ≤ 11 yrs (n=14)	-8.27	1.566	0.96	0.91	2.81
Age 12-15 yrs (n=43)	5.94 †	0.825 ‡	0.67	0.45	3.77
Age ≥ 16 yrs (n=31)	-1.193 †	1.096 ‡	0.86	0.75	3.19

Note. †: Intercept of the regression line between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ was not different from zero, $p > 0.05$.
‡: Slope of the regression line between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ was not different from 1.00, $p > 0.05$.
β = regression slope; r = regression correlation; R^2 = R-square; SE = standard error.

Correlations

All SKF measurements correlated high with each other. Significant high to very high correlations (r=0.636 to 0.875) were found between $\%fat_{ADP}$ and all SKFs. In both genders, $\%fat_{ADP}$ correlated highest with triceps (r=0.875 for boys and r=0.798 for girls). It was followed by calf for boys (r=0.850) and biceps for girls (r=0.711).

Significant high to very high correlations (r=-0.644 to -0.868) were found between body density (Db) and all SKFs. In both genders, Db correlated highest with triceps (r=-0.868 for boys and r=-0.792 for girls). It was followed by calf for boys (r =-0.845) and biceps for girls (r=0.704).

Reliability

The internal consistency of skinfold measurements (r=0.996, 0.993, 0.993, 0.988, 0.993 and 0.990 for triceps, biceps, subscapular, suprailiac, thigh and calf, respectively), body volume (r=1.00), body density (r=0.991) and %fat (r=0.991) measured from ADP were all higher than 0.988.

Cross Validation of Slaughter equations

Paired *t*-test revealed significant difference between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ ($p<0.01$). The computed effect size indices for these differences were 0.32 for boys and 0.49 for girls respectively. The Slaughter equations slightly underestimate %fat of Hong Kong children compared to ADP, by 1.52% for boys (t=-3.83, $p<0.05$) and 1.84% for girls (t=-4.61, $p<0.05$).

The correlation between $\%fat_{ADP}$ and $\%fat_{Slaughter}$ were computed and scatterplots were produced. Regression analysis was performed so as to examine the criterion-related validity of Slaughter equations on estimating $\%fat_{ADP}$ criterion. Analysis was carried out by gender and by different age groups within gender. Although Slaughter et al. suggested that stages of maturation were not important, age-group specific analyses would verify such a notion. The regression table is shown in Table 2, with R-square ranging from 0.45 to 0.91, and see from 2.81% to 5.10%.

Though R-square for both boys and girls equations were high (0.81 for all boys and 0.64 for all girls), Table 2 also indicate that the slope of the regression line between $\%fat_{ADP}$ and $\%fat_{Slaughter}$ for all boys was significantly different from the line of identity (i.e. slope=1). The slope and intercept of the regression line between $\%fat_{ADP}$ and $\%fat_{Slaughter}$ for prepubescent girls (age ≤11 yrs-old) was significantly different from the line of identity (i.e. slope=1 and intercept=0). Bland-Altman analysis showed that for the Slaughter equations, 66.9% of the residuals of boys and 78.4% of that of girls fell within 5% body fat.[18]

Exploration of Alternative Equations

Stepwise regression analyses were computed to determine the best combination of predictors for estimating $\%fat_{ADP}$ other than the Slaughter equations. $\%fat_{ADP}$ was entered as the dependent variable, whereas body height, weight, BMI, age, arm circumference, waist circumference, individual skinfold sites, and different combinations of skinfold sites (∑SKF) were entered as independent variables. To avoid multi-collineality, each skinfold site was entered only once either as an individual variable or included as a composite element of the skinfold combination. Different regression models, including both linear and polynomial models, were explored. Results are summarized in Table 3. Triceps skinfold was included in all the models, showing that it was the most significant predictors for estimating $\%fat_{ADP}$. For boys, the model consists of height, sum of triceps, calf and suprailiac skinfolds (∑3SKF) and square of ∑3SKF has the highest R square (R^2=0.88) and lowest see (SE=3.70%). While for girls, the model consists of the sum of triceps and calf skinfolds (∑2SKF), height and waist circumference (R^2=0.71, SE=3.38%).
These two models, while accurate, require four body composition measurements, which made them less convenient in practice. The most convenient model in practice is the model of triceps and age for both genders because of its comparable accuracy (R^2=0.81, SE=4.67% for boys and R^2=0.64, SE=3.77% for girls) and conven
ience. It consists of one skinfold measurement (triceps) only. The above three models were selected for further analysis. Repeated *t* analysis revealed that there was no significant difference between $\%fat_{ADP}$ and %fat estimated by all three models. Simple regressions were generated between

Table 3. Summary of the regression models for estimating %fat_{ADP} criterion

Model	Gender	Intercept	β	r	R^2	SE
Best Models						
$(\sum 3SKF)^2 + \sum 3SKF$ + Height	Boys	22.091	-0.003	0.94	0.88	3.7
			0.76			
			-0.147			
$\sum 2SKF$ + Height + Waist C	Girls	17.539	0.303	0.84	0.71	3.38
			0.516			
			-0.175			
Convenience Models						
Triceps + Age	Boys	14.405	1.479	0.9	0.81	4.67
			-0.856			
Triceps + Age	Girls	13.936	1.17	0.8	0.64	3.77
			-0.502			

Note. ∑2SKF = sum of triceps and calf skinfolds; ∑3SKF = sum of triceps, calf and suprailiac skinfolds; Waist C = waist circumference; β = regression slope; r = regression correlation; R^2 = R-square; SE = standard error.

the estimated %fat and %fat_{ADP} criterion. It was determined by the slopes and intercepts of the regression lines between %fat estimation and %fat_{ADP}. For all models, their slopes and intercepts of the regression lines were not different from the line of identity, showing that the estimated %fat from these models and %fat_{ADP} were statistically equivalent. The Bland-Altman plot found that 87.5% (boys) and 85.2% (girls) for the theoretical models, and 76.8% (boys) and 78.4% (girls) for the convenient model of the residuals fell within 5%, comparing with 66.9% and 78.4% for the Slaughter equations.

DISCUSSION

Our results revealed that skinfold measurement is a reasonable estimate of percent body fat and body density in Chinese children aged 9 to 19 years old. However, validity of the Slaughter skinfold equations in estimating %fat of Chinese children is questionable. The high correlation between %fat, Db and skinfold shows that skinfold measurement is a reasonable variable predicting body composition in children. Comparing with the prediction of body composition with individuals' weight-height relationship, such as BMI and weight-for-height, measurement of skinfold thickness is a measurement of adiposity, which may yield better validity, as researchers found that high adult body fatness is better predicted by adolescent skinfold thickness than by adolescent BMI.[19] However, these two methods are of different purposes. The BMI should be utilized as a screening tool for parents and in the school setting because of its ease of use. The skinfold method should be treated as an alternative to laboratory measurement in the clinical setting where laboratory test equipment such as Bod Pod and DXA machine is not available.

In our study, the internal consistency of skinfold measurement were similar to that of previous studies,[20,21] supporting that skinfold as a highly reliable measurement.

The accuracy of the Slaughter equations varies in different previous validation studies. A summary of these studies is shown in Table 4. Though some of the studies found that the accuracy of the Slaughter equations were acceptable,[22,23] most of them suggested that there is a need of refinement in order to obtain a more accurate %fat estimation.[14,24,25] Janz and colleagues found that the see of Slaughter equations ranged from 3.5 to 4.6%,[24] and the prediction was significantly different (p<0.05) from the criterion measurement. Hui and colleagues found that the Slaughter equations shared small variances with the criterion with large standard error of estimates (see) for both boys (R^2=0.25, SE=8.02%) and girls (R^2=0.21, SE=6.71%).[14] Reilly and colleagues found that the existing published skinfold equations,[26] including the Slaughter equations, were associated with large random errors or significant systematic errors.

The Slaughter equations have been established for 20 years, yet no in-depth validation work has been done for Chinese children in Hong Kong. In this study, 230 participants aged from 9-11 years old were covered. It was one of the largest scale validation studies of the Slaughter equation among Chinese children. The sample size, age and %fat of the sample covered in this study may be more representative than other previous studies.[14,22]

One possible reason accounts for the difference between the Slaughter equations and the criterion may be the effect of ethnicity. Scientists found that, for the same BMI, the %fat of the Chinese was 3-5% higher compared to Caucasians,[27] thus the prevalence of obesity for Asian is likely underestimated. This discrepancy may be ex plained by differences in trunk-to-leg-length ratio and differences in slenderness,[27] and the fact that for a given total body fat, majority (98%) of Chinese participants has a greater proportion of visceral adipose tissue.[28] Hence, as suggested by Heyward,[29] a valid skinfold equations should be ethnic-specific, and the Slaughter Equations are recommended for estimating %fat of African American and Caucasian children and adolescents only. The equations should be validated, and modified if necessary, prior to applying in a sample of a different ethnic group. Alternative equations or refinement of the Slaughter equations is thus suggested in order to have more accurate estima-

Table 4. List of validation studies with the Slaughter equations on healthy school children

Study	Ethnicity	Gender	Age	N	Criterion	SE	Comment
Original study [13]	Caucasian, African-American	Boys & girls	8-17	242	4-C Model	0.038	
Janz et al. [23]	Caucasian	Boys & girls	8-17	122 (67B, 55G)	UWW	3.5-4.6%	Hold promise, but refinement needed
Reilly et al. [25]	Caucasian	Boys & girls	5-11	98 (64B, 34G)	UWW	-	Poor agreement (wide limits of agreement from Bland-Altman plots)
Goran et al. [24]	Caucasian, Native American	Boys & girls	4-10	50	DXA	0.046	Systematic error exists
Louie et al. [21]	Chinese	Boys & girls	6-12	44	UWW	0.0369	Acceptable, but underestimated 2.3% fat
Hui et al. [14]	Chinese	Boys & girls	8-13	141 (66B, 75G)	UWW	Boys: 8.02% Girls: 6.71%	
Steinberger et al. [22]	Caucasian, African-American	Boys & girls	11-17	130 (72B, 58G)	DXA	Boys: 4.17% Girls: 3.88%	Moderately effective (r = .69 - .79)
This study	Chinese	Boys & girls	9-19	230 (142B,88G)	ADP	Boys: 4.67% Girls: 3.77%	

Note. UWW = Underwater weighing; DXA = Dual-energy x-ray absorptiometry; ADP = Air-displacement plethysmography; SE = standard error.

tion on %fat of children in Hong Kong.

The high R-square and low see of these three models are comparable to that of the original Slaughter equation, showing that the models are good predictors of %fat for Hong Kong children. The Bland-Altman plots of these three models, however, show less deviation than that of the Slaughter equation. The alternative models agree more than the Slaughter equations in predicting body composition of Chinese children in Hong Kong. It is found that triceps skinfold is the best predictor of $\%fat_{ADP}$. This is in line with the study done by Sardinha and colleagues.[30] They reported that triceps skinfold thickness gave the best results for obesity screening in adolescents, comparing with BMI and arm circumference. A local study done by Hui and colleagues also found that it is acceptable to adopt triceps as the only predicting variable for boys.[14]

Scientists suggested that there was an interaction between the SKF equation and subject maturation level.[24,26] The inclusion of age as a variable in the equation may produce better %fat estimation. The skinfold model 3 of our study was in line with this finding, with age is included as a variable to predict %fat. Model 3 is also regarded as the convenient model, as only one skinfold measurement (i.e: triceps), and the subject's age, is needed for the %fat estimation. It is more convenient than the Slaughter equations, since measurement of calf skinfold can be omitted while accuracy is unaffected.

Due to lengthy procedures and difficulty in performing the tests required for the multi-component model, including underwater weighing (UWW), hydrometry, DXA and ADP, it would be difficult to carry out all the tests in order to obtain body density, total body water and bone mineral mass, especially for children. However, if equipments and resources are available, the most accurate way to carry out body composition research is to adopt the multi-component model, which is regarded as the gold standard of measuring %fat, as the criterion.

In this study, the minimum age of participants was nine, and it is identical to the only previous study published so far in which the 4-C model was used in children to compare with ADP.[9] Nevertheless, until further validation is made, the equations suggested in this study were only valid for Hong Kong children aged 9-19 years old. In order to further determine the applicability of the skinfold models proposed in this study, cross validation of the proposed models using different criteria measures, such as DXA, UWW, hydrometry or a combination of these methods (i.e. multicomponent model), should be determined.

Possible future studies can be worked on existing skinfold data of this population that has been collected in recent years. They can be converted to %fat by adopting skinfold models introduced in this study for more accurate estimation of the prevalence of childhood obesity in Hong Kong, as previous figures of childhood obesity in Hong Kong were generated using crude indices such as BMI or weight-for-height as the criteria. By understanding the figure with %fat, not only will trends be observed, but scientists and practitioners will also be able to know the actual body composition of the children. The effectiveness of health promotion strategies in Hong Kong can then be evaluated more validly.

In summary, this study showed that skinfold measurement is a reasonable estimate of percent body fat and body density in Chinese children aged 9 to 19 years old. The reliability of skinfold measurement was very high. We compared the %fat estimated from Slaughter equations with that measured by ADP in Chinese school children. Significant difference was found between the two estimations, and the slope of the regression line of Slaughter equation for boys was significantly different from the line of identity. Both the slope and intercept of prepubescent girls were significantly different from the line of identity. We concluded that the Slaughter equations are not applicable for Chinese children in Hong Kong. We also developed three alternative skinfold prediction models for estimating percent body fat of Chinese children in Hong Kong, which combining anthropometric measurements and the children's age. The accuracy of these models is comparable to the Slaughter equations, and the estimated %fat by these alternative models was less deviated from $\%fat_{ADP}$ than that estimated by the Slaughter equations.

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AUTHOR DISCLOSURES
The authors, both Daniel C.S. Yeung and Stanley S.C. Hui, declare that there is no conflict of interest related to this study.

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Short Communication

Validity and reliability of skinfold measurement in assessing body fatness of Chinese children

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以皮褶厚度測量來評估中國兒童體脂肪的信度和效度

背景：以皮褶厚度測量來估計中國兒童體脂肪比例之信度和效度的報告仍然闕如。目的：以空氣置換體積描記法(ADP)為標準，評量以皮褶厚度量度預估香港的中國兒童體脂肪率(%fat)的信度和效度。設計：以有目的的分層抽樣方法招募了香港 230 位由不同身體質量指數及年齡組成的中國兒童，參與 ADP 測量及身高、體重、腰與臂圍、和身體不同部位的皮褶厚度量度。其中 41 位參與者亦接受雙能量 X 射線掃瞄(DXA)量度脂肪。由 ADP、DXA 測量及 Slaughter 皮褶量度公式所得的體脂肪率，做一比較。結果：皮褶量度和 ADP 的信度均非常高($r \geq 0.988$)。以 ADP 量度的體脂肪率和以 Slaughter 公式推算所得出的結果有顯著差異($p<0.05$)。Slaughter 公式些許低估體脂肪率(男童：1.52%及女童：1.84%)。男童迴歸分析線的斜度及青春期前女童迴歸分析線的斜度與截線點，均顯著地有別於恆等線。接著以逐步迴歸分析發現，預測男童的最佳模型包含身高和三項皮褶厚度總和(三頭肌、小腿、肩胛骨下) (R^2=0.88, SE=3.70)；女童最佳模型則包含身高、兩項皮褶總和(三頭肌、小腿)及腰圍(R^2=0.71, SE=3.38)。亦發現最方便的模型，只需要代入三頭肌皮褶厚度及年齡來計算(男童：R^2=0.81, SE=4.67；女童：R^2=0.63, SE=3.77)。結論：皮褶厚度測量對中國兒童體脂肪率提供有效及可信的估計。可是以 Slaughter 公式推算是值得懷疑的，本研究建議了新的皮褶厚度推算公式。

關鍵字：兒童肥胖、體組成、幼兒測量、過重、生長與發育