Original Article

Predicting total fat mass from skinfold thicknesses in Japanese prepubertal children: A cross-sectional and longitudinal validation

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The present study was performed to develop regression based prediction equations for fat mass from skinfold thickness in Japanese children, and to investigate the cross-sectional and longitudinal validity of these equations. A total of 127 healthy Japanese prepubertal children aged 6-12 years were randomly separated into two groups: the model development group (54 boys and 44 girls) and the cross-sectional validation group (18 boys and 11 girls). Fat mass was initially determined by using DXA (Hologic Delphi A-QDR whole-body scanner) to provide reference data. Then, fat thickness was measured at triceps and subscapular using an Eiken-type skinfold calipers. Multiple anthropometric and DXA measures were obtained one year later for 28 of the original 127 subjects (longitudinal validation group: 14 boys and 14 girls). Strong significant correlations were observed between total fat mass by DXA measurement and the skinfold thickness × height measures by caliper in the model development group of boys and girls (R^2=0.91-0.92, $p<0.01$). When these fat mass prediction equations were applied to the cross-sectional and longitudinal validation groups, the measured total fat mass was also very similar to the predicted fat mass. In addition, there were significant correlations between the measured and predicted total fat mass for boys and girls, respectively, although Bland-Altman analysis indicated a bias in cross-sectional validation group. Skinfold-derived prediction equations underestimate for obese children but are generally useful for estimating total fat mass in field research.

Key Words: DXA, fat mass, children, skinfold, prediction equation

INTRODUCTION

Skinfold thicknesses obtained from hand held skinfold calipers have been the most common field technique for estimating fat mass in children. However, there are a number of controversial points in previous studies. First, skinfold-derived prediction equations for children were based on body densities obtained from underwater weighing as the criterion measure, even though there are many difficulties using this technique with children. Another problem is that the representative skinfold equations for children were developed in the 1980's and 1990's,[1,2] even though the prevalence of obesity and the secular change of height and weight for children has changed.[3-5]

In fact, recent previous studies have indicated that the validity of skinfold methods for estimating body composition were poor in children and adolescents.[6,7] Moreover, the current representative skinfold equation of Slaughter et al.[1] when applied to the Japanese subjects resulted in substantial differences between the skinfold equation and the criterion measurements obtained by DXA (boys; n=72, DXA 22.0±7.0%, Slaughter et al 19.1±7.2%; girls; n=55, DXA 25.8±6.1%, Slaughter et al 21.3±6.8%).[8] Similar problems exist when comparing Chinese children.[9]

Therefore, the present study was performed to develop regression based prediction equations for fat mass from skinfold thicknesses in Japanese children and to investigate the cross-sectional and longitudinal validity of these equations. The major original point of this study was 'longitudinal validity' which had not been reported in previous studies when developing equations for pediatric body composition.

MATERIALS AND METHODS
Subjects
A total of 127 healthy Japanese prepubertal children, aged 6-12 years, who were not approaching Tanner stage 2 and peak height velocity (PHV), were randomly separated into two groups: the model development group (54 boys and

44 girls included 4 overweight boys, 1 obese boy, and 6 overweight girls) and the cross-sectional validation group (18 boys and 11 girls included 2 overweight boys and 3 overweight girls) (Table 1).[10] Multiple anthropometric and DXA measures were obtained one year later in 28 of the 127 original subjects (longitudinal validation group: 14 boys and 14 girls included 2 overweight boys and 1 overweight girls) (Table 1).[10] The prediction equations were developed by using data from the model development group based on skinfold thicknesses and standing height. The equations developed were then validated both on the cross-sectional and longitudinal validation groups.

All subjects were recruited through friends and acquaintances that lived in the Tokyo area. There were no criteria for inclusion to this study at the enrollment. They and their guardians received a verbal and written description of the study and gave their informed consent to participate prior to testing. All subjects did not include any athletes. None of the subjects reported any known pathologies or current medication use. The study protocol was approved by the Ethical Committee of Waseda University, and this study was conducted according to the guidelines laid down in the Declaration of Helsinki.

Anthropometric and skinfold thickness measurements
Body mass was measured on a digital balance to the nearest 0.1 kg wearing only leggings and underwear, and height was measured on a stadiometer to the nearest 0.1 cm. Body mass index (kg/m^2) was calculated as body weight in kg/(height in m)^2. Skinfold thickness was measured to the nearest 0.5 mm using an Eiken skinfold caliper (MK-60, Yagami, Japan) at the triceps and subscapular sites by authors TM and MO who specialized in body composition.[11]

Dual energy X-ray absorptiometry (DXA)
Total fat mass was measured using DXA (Delphi A-QDR, Hologic Inc, Bedford, MA, USA; Version 12.4:3 Pediatric Whole body). Head and neck areas were excluded from the calculation of the total body fat mass value. The estimated coefficient of validation (CV) for DXA measurements from test-retest analysis was determined to be <1%.

Statistical analysis
All results are presented as means and standard deviations (SD). Simple linear regression analyses were calculated between the DXA-measured fat mass and the skinfold thickness×height measures and were performed separately for boys and girls. The parameters of the prediction equations for fat mass were determined as skinfold thickness (ie triceps + subscapular) in centimeters (cm)×standing height in meters (m). Standing height was used to express the length factor of the fat mass, since fat thickness is only a predictor of fat area.

The difference between the measured and the predicted fat masses were examined using paired t-tests. Agreement of fat masses between the measured and predicted values were further examined by plotting the differences in predicted values against the means with limits of agreement (mean difference ± 2 SD of the differences: the 95% limits of agreement, which gives an indication of the precision of the method), as suggested by Bland and Altman (1986).[12] Lin's concordance correlation coefficient (CCC) was used as a further measure of agreement.[13] McBride (2005) suggests the following descriptive scale for CCC values: CCC <0.90 is poor strength of agreement, 0.90-0.95 is moderate, 0.95-0.99 is substantial and >0.99 is almost perfect.[14] Statistical analyses were performed using SPSS for Windows (version 17.0J; SPSS Inc, Chicago, IL), and MedCalc for Windows (version 11.3.6; MedCalc Software, Broekstraat 52, 9030 Mariakerke, Belgium). Differences were regarded as significant when the probabilities were <0.05.

RESULTS
The physical characteristics and fat thicknesses measured by caliper were shown in Table 1. As mean height and weight values were comparable to the nationwide statistics for the physical development of Japanese children,[15] this indicated that the mass and distribution of fat for subjects in the present study should be representative of Japanese prepubertal children.

Strong significant correlations were observed between total fat mass by DXA measurement and the sum of fat thickness by caliper×height in the model development group of boys and girls (Figure 1 and Table 2). When these fat mass prediction equations were applied to the

Table 1. Physical characteristics of the development, cross-sectional validation and longitudinal validation groups

	Development		Cross-sectional validation		Longitudinal validation	
	Boys (n = 54)	Girls (n = 44)	Boys (n = 18)	Girls (n = 11)	Boys (n = 14)	Girls (n = 14)
Age (year)	10 ± 2	9 ± 2	9 ± 2	9 ± 2	11 ± 2	10 ± 2
Standing height (m)	1.38 ± 0.11	1.37 ± 0.13	1.37 ± 0.13	1.35 ± 0.12	1.42 ± 0.11	1.36 ± 0.11
z score	0.05 ± 0.92	-0.02 ± 1.02	0.07 ± 0.86	0.25 ± 1.07	-0.15 ± 0.89	-0.25 ± 0.76
Body mass (kg)	32.8 ± 9.0	31.9 ± 9.6	31.7 ± 10.3	30.8 ± 8.6	35.5 ± 13.3	30.7 ± 6.8
z score	-0.08 ± 0.92	-0.15 ± 1.00	-0.26 ± 0.82	0.01 ± 1.20	-0.23 ± 1.04	-0.33 ± 0.78
BMI (kg/m^2)	17.0 ± 2.5	16.7 ± 2.5	16.4 ± 2.6	16.6 ± 3.2	17.2 ± 3.7	16.5 ± 2.2
%fat (%)	22.3 ± 7.4	25.4 ± 5.4	21.2 ± 6.0	27.8 ± 8.4	21.8 ± 7.4	25.9 ± 7.3
Skinfold thickness (cm)						
Triceps	1.3 ± 0.6	1.3 ± 0.5	1.2 ± 0.4	1.5 ± 0.5	1.3 ± 0.6	1.3 ± 0.4
Sabscapular	0.9 ± 0.6	1.0 ± 0.5	0.8 ± 0.4	1.2 ± 0.7	0.9 ± 0.7	1.1 ± 0.6

The data presented as mean ± SD. %fat: measured by DXA.
z score: standing height and weight were calculated into z score using the nationwide statistics for the physical development of Japanese children.[15]
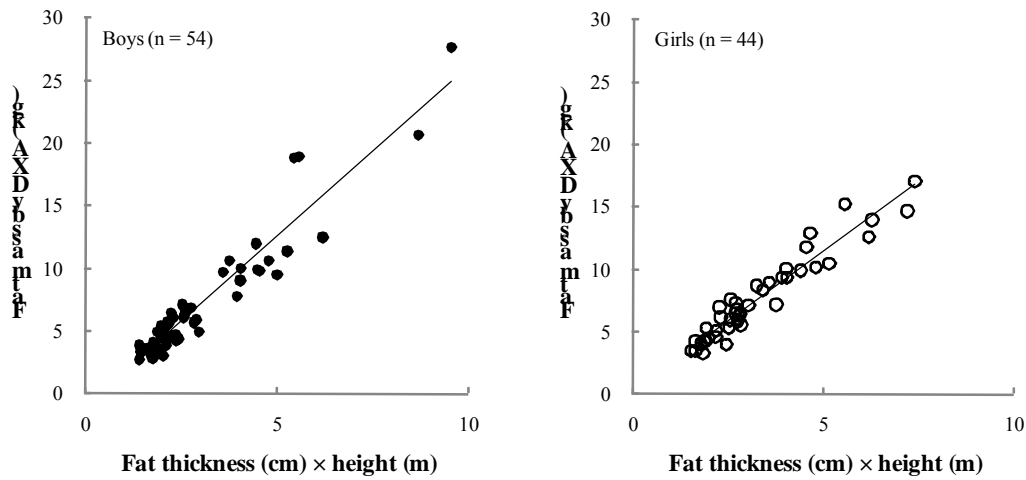
Figure 1. Relationship between DXA measured fat mass and the skinfold thickness × height measures by caliper. ●: Boys (n = 54), ○: Girls (n = 44).

Table 2. Skinfold equations for estimating total body fat mass in boys and girls

						R^2	SEE
				Equations			
Boys (n = 54)	FM_{DXA} (kg) =	2.7209 ×	(Skinfold × Ht)	−	1.0913	0.91	1.54
Girls (n = 44)	FM_{DXA} (kg) =	2.2190 ×	(Skinfold × Ht)	+	0.3191	0.92	0.99

FM_{DXA}: Predicted DXA fat mass.
Skinfold = Triceps + Subscapular fat thickness by caliper in cm, Ht; Height in m.
SEE: standard error of the estimate.

Table 3. Measured and predicted total body fat mass for the cross-sectional and longitudinal validation groups

	Boys					Girls				
	Measured	Predicted	Mean difference	p	CCC	Measured	Predicted	Mean difference	p	CCC
Cross-sectional	6.4 ± 4.0	6.3 ± 3.4	-0.1 ± 0.8	0.71	0.98	8.1 ± 3.7	8.5 ± 3.4	0.4 ± 0.7	0.08	0.97
Longitudinal	7.7 ± 6.2	7.6 ± 5.7	-0.1 ± 1.7	0.75	0.96	7.5 ± 3.5	7.5 ± 3.1	0.1 ± 1.0	0.81	0.96
Change	1.1 ± 1.6	1.6 ± 2.2	0.5 ± 1.2	0.15	0.78	0.9 ± 5.0	0.6 ± 4.7	-0.4 ± 1.0	0.36	0.95

The data presented as mean ± SD. FM: fat mass. 'Cross-sectional': Boys (n = 18), Girls (n = 11). 'Longitudinal' and 'Change': Boys (n = 14), Girls (n = 14). 'Change': the difference of values between first and second measurement.
Mean difference: calculated as (predicted - measured fat mass). *P* value for paired t-tests : Measured vs. predicted fat mass.
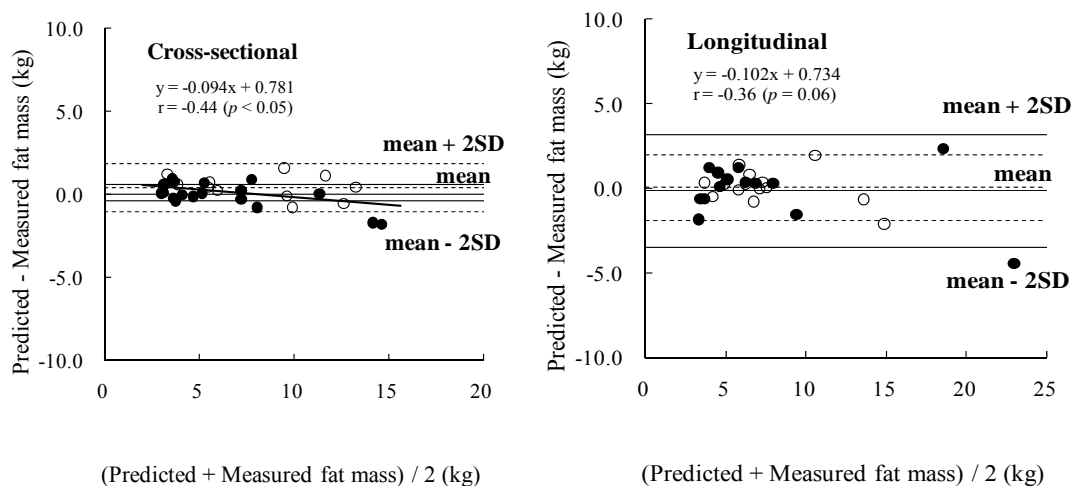CCC: Lin's concordance correlation coefficient.

Figure 2. Bland–Altman analysis. "Cross-sectional": Boys (n = 18), Girls (n = 11); "Longitudinal": Boys (n = 14), Girls (n = 14). ●: Boys, ○: girls. Mean ± 2SD: Solid line for boys, dot line for girls.

cross-sectional and longitudinal validation groups, the measured total fat mass was also similar to the predicted fat mass (Table 3). Furthermore, there were not significant differences between changes in the measured fat mass by DXA and the predicted fat mass by skinfold equations for boys and girls. CCC shows relatively high agreement between measured and predicted fat masses except for change in measured and predicted fat mass for boys. Bland-Altman analysis indicated a bias in cross-sectional validation group ($p<0.05$) (Figure 2).

DISCUSSION

From the background of increasing pediatric obesity, body composition research for pediatric use is critical. Based on this situation, we have carefully developed and verified prediction equations for total body fat mass in both boys and girls using skinfold thicknesses by skinfold calipers. An original aspect of this study is that DXA was chosen as the criterion measure since DXA provides a much simpler and more reliable technique for obtaining fat mass of children in the current study, unlike underwater weighing that is largely affected by human body water and an accurate measurement of residual lung volume. In addition, we performed not only cross-sectional validation but also longitudinal validation of the skinfold developed prediction equations. This longitudinal validation is absolutely imperative for growing children, although it had not been reported in previous studies that developed equations for pediatric body composition. Therefore, the skinfold-prediction equations using calipers in the present study seem to be more useful in estimating body composition specifically for children as a field method.

Moreover, the characteristic of the skinfold-prediction equations in the present study included 'skinfold thicknesses' and 'standing height' as parameter of equations. The previous studies use only the sum of skinfold thicknesses[1] or skinfold thickness with age[2] as parameter of equations. In fact, the predicted accuracy when using the fat thickness×height [boys, R^2=0.91 and SEE (standard error of the estimate)=1.54 kg; girls, R^2=0.92 and SEE=0.99 kg) were higher than when using only the sum of skinfold thicknesses obtained from the triceps and subscapular sites without the length factor (boys, R^2=0.85 and SEE=1.93 kg; girls, R^2=0.88 and SEE=1.32 kg), and when using the fat thickness with age (boys, R^2=0.87 and SEE=1.83 kg; girls, R^2=0.90 and SEE=1.14 kg). Since it is relatively easy to measure body height, standing height was the important factor to express the length factor of the fat mass for the developing children.

On the other hand, one major problem with skinfold method is that the error of estimation increases as body fat increases.[16] In fact, the results of the present study indicated that skinfold-derived prediction equations using calipers underestimated for overweight and obese children (Figure 2). As a solution to this problem, we developed prediction equations for evaluating total and regional fat mass in children using B-mode ultrasound.[17] Even though the ultrasound technique is much more expensive than the hand held skinfold caliper, ultrasound can be used in a field setting with much greater accuracy, reliability, and validity when compared to a criterion method for determining total and regional fat masses in a variety of body types and for different ages. When using the skinfold method by calipers, it is necessary to recognize this bias and use both calipers and ultrasound.

There are a number of limitations in the current study that need to be addressed. First, since the equations were created and validated using fat measurements from a Hologic Delphi A-QDR, these equations cannot be applied to other models or manufacturers of DXA machines as the fat mass assessed by different DXA machines varies.[18] Moreover, since these equations were developed using healthy Japanese children, it might not apply to other nationalities, or malnourished and obese children, which warrant future investigation.

In summary, we have developed prediction equations for evaluating total fat mass in children using skinfold calipers, which are useful for determining group means. Future research will focus on developing prediction equations for skeletal muscle mass in children using skinfold calipers.

AUTHOR DISCLOSURES
There is no conflict interest on the part of any of the authors.

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以皮脂厚度預測日本青春期前兒童的體脂肪質量：橫斷及縱貫式效度

此研究利用日本兒童的皮脂厚度資料以回歸法發展可預測體脂肪量的公式，且檢定這些公式的橫斷及縱貫效度。總共有 127 名健康的日本青春期前的兒童，年齡介於 6-12 歲，被隨機分派到兩組：模式發展組(54 名男孩和 44 名女孩)及橫斷效度組(18 名男孩和 11 名女孩)。脂肪質量先以 DXA(Hologic Delphi A-QDR 全身掃描儀)測量以提供參考數據。再以 Eiken-type 皮脂厚度儀測量三頭肌及肩胛骨下皮脂厚度。一年之後取得 127 名研究對象中 28 位的多重體位及 DXA 測量資料(縱貫效度組：14 名男孩和 14 名女孩)。以 DXA 測得的脂肪量及以皮脂厚度儀測量的皮脂厚度 x 身高得到的體脂肪量，在模式發展組的男女孩都有顯著的強相關性(R^2=0.91-0.92，p<0.01)。當這些脂肪質量預測公式被應用在橫斷及縱貫效度組，測量的與預測的體脂肪量非常相近。此外，男孩或女孩分別的體脂肪測量值與預測值，都具有顯著相關性，儘管 Bland-Altman 分析顯示有一個誤差在橫斷效度組。以皮脂厚度衍生的預測公式在肥胖兒童可能低估脂肪量，但是用在田野研究中估計總體脂肪量，普遍來說是可行的。

關鍵字：双能 X 光骨質密度儀、體脂肪量、兒童、皮褶、預測公式