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Estimation of percentage body fat in 6- to 13-year-old children by skinfold thickness, body mass index and waist circumference

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We evaluated the accuracy of skinfold thicknesses, BMI and waist circumference for the prediction of percentage body fat (PBF) in a representative sample of 372 Swiss children aged 6–13 years. PBF was measured using dual-energy X-ray absorptiometry. On the basis of a preliminary bootstrap selection of predictors, seven regression models were evaluated. All models included sex, age and pubertal stage plus one of the following predictors: (1) log-transformed triceps skinfold (logTSF); (2) logTSF and waist circumference; (3) log-transformed sum of triceps and subscapular skinfolds (logSF2); (4) log-transformed sum of triceps, biceps, subscapular and supra-iliac skinfolds (logSF4); (5) BMI; (6) waist circumference; (7) BMI and waist circumference. The adjusted determination coefficient (R^2_{adj}) and the root mean squared error (RMSE; kg) were calculated for each model. LogSF4 (R^2_{adj} 0·85; RMSE 2·35) and logSF2 (R^2_{adj} 0·82; RMSE 2·54) were similarly accurate at predicting PBF and superior to logTSF (R^2_{adj} 0·75; RMSE 3·02), logTSF combined with waist circumference (R^2_{adj} 0·78; RMSE 2·85), BMI (R^2_{adj} 0·62; RMSE 3·73), waist circumference (R^2_{adj} 0·58; RMSE 3·89), and BMI combined with waist circumference (R^2_{adj} 0·63; RMSE 3·66) ($P<0·001$ for all values of R^2_{adj}). The finding that logSF4 was only modestly superior to logSF2 and that logTSF was better than BMI and waist circumference at predicting PBF has important implications for paediatric epidemiological studies aimed at disentangling the effect of body fat on health outcomes.

Children: Body composition: Dual-energy X-ray absorptiometry: Body mass index: Waist circumference: Skinfold thickness: Regression analysis

The measurement of body composition is a central topic of current paediatric research because of its association with health and disease in infancy, childhood and adulthood[1–3]. Such an assessment is also important to investigate the effect of lifestyle interventions on fat and fat-free tissues[4].

Body fat is most commonly estimated from anthropometric measurement[5,6]. BMI is often used as a surrogate marker but does not provide an accurate assessment of body fat, and this is especially true in children and adolescents[7–9]. Waist circumference is gaining popularity as an indicator of childhood obesity but it is more related to visceral fat than to total body fat[10,11]. Skinfold thicknesses have long been used as measures of subcutaneous fat and are usually more accurate than BMI at predicting body fat[12]. Although skinfolds are not recommended for routine clinical use in children[6,7], they can be very useful in the epidemiological setting whenever a measure of body fat more accurate than BMI is needed to disentangle the effects of fat and fat-free tissues on health outcomes[13,14].

The four-compartment model has been used to cross-validate portable techniques such as anthropometry and bioelectrical impedance analysis in small samples of children under laboratory conditions[3]. However, this reference model is not suitable for use in epidemiological studies because of its complexity and cost. Although not a 'gold standard' method for the assessment of body composition, dual-energy X-ray absorptiometry (DXA) compares well with the four-component model (i.e. adjusted regression between fat mass by the two methods does not deviate from the line of identity)[15,16], is more readily available and is being increasingly used for clinical and epidemiological applications[3,17,18]. However, DXA is not portable and uses ionising radiation so that it is mainly used to validate indirect techniques that are then used to assess body composition[19].

Abbreviations: AVENA, Alimentación y Valoración del Estado Nutricional de los Adolescentes; CCC, concordance correlation coefficient; DXA, dual-energy X-ray absorptiometry; KISS, Kinder-Sportstudie; logSF2, log-transformed sum of triceps and subscapular skinfolds; logSF4, log-transformed sum of triceps, biceps, subscapular and supra-iliac skinfolds; logTSF, log-transformed triceps skinfold; PBF, percentage body fat; R^2_{adj}, adjusted coefficient of determination; RMSE, root mean squared error; SDS, standard deviation score.

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To date, most calibration studies of anthropometry have been performed in convenience samples of children[19–22]. Only one study has been performed in a representative sample of adolescents (aged 13–18 years) from the general population and it focused on the validation of external algorithms[23]. Thus, there is a clear need of studies evaluating the accuracy of anthropometry as an index of body fat in representative samples of children.

The Kinder-Sportstudie (KISS) is a randomised controlled trial aimed to test whether a physical activity programme can improve body composition, physical activity, physical fitness and quality of life in a representative sample of 6- to 13-year-old Swiss children[24]. The baseline data of the KISS study offered the unique opportunity to cross-validate anthropometry against DXA in a representative sample of the general paediatric population. The aim of the present study was, therefore, to compare the accuracy of BMI, waist circumference and skinfold thicknesses for the assessment of percentage body fat (PBF) in the KISS children.

Methods

Study design

The study protocol of KISS (ISRCTN 15360785) is described in detail elsewhere[24]. Briefly, the KISS children were randomly selected and stratified by class, geographic area and ethnicity to be representative of Swiss children with respect to sex, sociodemographic status and BMI. The baseline data, collected in the summer of 2005, were used for the present analysis. Informed consent was obtained verbally from each child and written consent was obtained by at least one parent. The study was conducted according to the Declaration of Helsinki and was approved by the Ethical Committee of the University of Basel, the Cantonal Ethical Committee of Aargau and the Swiss Federal Institute of Technology.

Subjects

A total of 502 of 540 children agreed to participate. Complete data were available for 497 children and 372 of them (75 %) had both DXA and anthropometry measured and were evaluated for the present study. The lack of DXA measurements for 125 (25 %) of the children was due to the request of their parents that they were not exposed to ionising radiation. The option to refuse DXA measurements was explicitly recognised by the study protocol and systematically offered during the study. Anthropometry and DXA measurements were performed within 2 d as described below.

Anthropometric evaluation and pubertal assessment

Anthropometric measurements were performed by two experienced operators as described in detail elsewhere[24]. Briefly, body weight was measured to the nearest 5 g using an electronic scale (Seca, Basel, Switzerland) and standing height to the nearest 2 mm using a wall-mounted stadiometer (Seca). Waist circumference was measured to the nearest 1 mm using a flexible tape midway between the lowest rib and the iliac crest. Skinfold thickness was measured in triplicate to the nearest 1 mm using a Harpenden calliper (British Indicators, Burgess Hill, West Sussex, UK) at the triceps, biceps, subscapular and supra-iliac sites following the *Anthropometric Standardization Reference Manual*[25]. The mean of the three measurements was used for analysis. The inter-operator technical error of measurement for skinfolds, as determined by a preliminary study performed by the two study operators on thirty-six children, was 1·0 mm for triceps skinfold, 1·1 mm for biceps skinfold, 1·4 mm for subscapular skinfold and 2·9 mm for supra-iliac skinfold, with corresponding coefficients of reliability $\geq$ 0·91. These values are within the suggested limits of tolerance and are in agreement with other paediatric studies[26,27]. BMI was calculated and transformed into standard deviation scores (SDS) using the 1990 UK reference data[28]. Overweight and obesity were determined by the International Obesity Task Force classification system[29]. The triceps and subscapular skinfolds were summed to obtain the sum of two skinfolds (SF2) and the biceps, triceps, subscapular and supra-iliac skinfolds were summed to obtain the sum of four skinfolds (SF4)[12,30,31]. Pubertal stage was self-assessed using Tanner's criteria[24,32].

Dual-energy X-ray absorptiometry

The three-compartment DXA model separates body mass into lean tissue mass, fat mass and bone mineral content[33]. DXA was performed by the same operator using an Hologic QDR-4500 densitometer (Hologic, Waltham, MA, USA) coupled with paediatric software. Head measurements were excluded from the calculation of body composition. The DXA scanner was calibrated daily against a standard phantom provided by the manufacturer. PBF was calculated as (fat mass/body weight) $\times$ 100.

Statistical analysis

Normally distributed variables are given as mean values and standard deviations, and minimum and maximum values. Variables that were not normally distributed (skinfolds) were log-transformed using natural logarithms to achieve or better approach the normal distribution (Shapiro–Wilk test) and are given as geometric mean and minimum and maximum values. Between-group comparisons of continuous variables were performed using unpaired Student's *t* tests on untransformed values for normally distributed variables and on log-transformed values for not normally distributed variables[34]. Between-group comparisons of categorical variables were performed using Fisher's exact test. We selected eight potential predictors of PBF for evaluation: sex (male *v.* female), age (continuous), pubertal stage (Tanner stage 1 *v.* stages 2–5), BMI (continuous), waist circumference (continuous), log-transformed triceps skinfold (logTSF; continuous), log-transformed sum of triceps and subscapular skinfolds (logSF2; continuous) and log-transformed sum of triceps, biceps, subscapular and supra-iliac skinfolds (logSF4; continuous). Potential predictors were chosen on the basis of the following considerations: (1) sex, age and pubertal stage are major determinants of body composition[18]; (2) triceps skinfold is easily accessible and does not require that the subject takes off her/his clothes (provided that the acromion and the olecranon can be properly localised), which is an important condition in the epidemiological setting, especially for girls; (3) logSF2 is

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expected to be more accurate than a single skinfold (logTSF) and is less burdensome than logSF4, which requires the measurement of four skinfolds[12,31]. The contribution of each predictor was evaluated by measuring its bootstrap inclusion fraction at multiple backward stepwise linear regression on 1000 random samples of 372 subjects (P value to enter=0·05; P value to remove=0·10)[35,36]. On the basis of the bootstrap analyses, we evaluated seven combinations of predictors. Age, sex and pubertal stage were included in all models, plus: (1) logTSF; (2) logTSF and waist circumference; (3) logSF2; (4) logSF4; (5) BMI; (6) waist circumference; (7) BMI and waist circumference. Standard diagnostic tests and plots were used to check model assumptions and fit[37]. The 95 % CI of regression coefficients and measures of model fit – adjusted determination coefficient (R^2_{adj}) and root mean square error of the estimate (RMSE) – were calculated on 1000 bootstrap samples of 372 subjects with bias correction. In other words, the bootstrap analysis provides an internal cross-calibration on 1000 samples.

Multivariable fractional polynomials were used to test whether the fit could be improved by non-linear transformations[35]. Because there was no gain in fit for any model, all continuous predictors were modelled as linear. Bland & Altman's method was used to calculate the fixed and proportional bias of the seven models[38]. Lin's concordance correlation coefficient (CCC) was used as a further measure of agreement because of the presence of proportional bias[39,40]. We also tested for the existence of a trend between the absolute inter-method difference and the quintiles of the average using the Jonckheere–Terpstra test for ordered alternatives (both ascending and descending). All statistical tests were two-tailed and statistical significance was set to a P value $<$ 0·05. Statistical analysis was performed using STATA 11.0 (StataCorp, College Station, TX, USA).

Results

Of the 497 KISS children for whom age, weight and height were available, 372 (75 %) underwent anthropometry and DXA and were considered for the present study. The age of the children without DXA measurements was significantly lower than that of the children who had them available (8·6 (SD 2·2) v. 9·5 (SD 2·1) years; $P<0·001$) but the distribution of sex ($P = 0·520$) and the SDS of weight ($P = 0·238$), height ($P = 0·206$) and BMI ($P = 0·346$) was not different between the two groups (data not shown).

Table 1 reports the anthropometric measurements of the 372 children. Of the children, 260 (70 %) were prepubertal (117 girls and 143 boys) and 112 (30 %) children were pubertal or postpubertal (seventy-seven girls and thirty-five boys). While there was no difference in age, weight, height and BMI between males and females, total body fat and PBF, as well as single skinfolds and their sums, were significantly higher in girls. Of the children 322 (87 %) had a normal weight, forty-one (11 %) were overweight and nine (2 %) were obese according to the International Obesity Task Force classification[29].

Table 2 gives the bootstrap inclusion fraction, i.e. the number of times out of 1000 that the candidate predictors were selected for inclusion in the models. In model 1, sex, age and logTSF were selected 100 % of the time while waist was selected 93 %, BMI 57 % and pubertal stage 25 % of the time. In model 2, sex, age and logSF2 were selected 100 % of the time while waist was selected 41 %, pubertal stage 25 % and BMI 21 % of the time. Last, in model 3, sex, age and logSF4 were selected 100 % of the time while BMI was selected 49 %, pubertal stage 40 % and waist 17 % of the time. In other words, waist circumference improved the prediction of PBF in the model including logTSF, while

Table 1. Measurements of the 372 children
(Mean values, standard deviations and ranges)

	Females (n 194)				Males (n 178)				
	Mean	SD	Min	Max	Mean	SD	Min	Max	P*
Age (years)	9·5	2·1	6·0	12·2	9·6	2·1	6·3	13·0	0·635
Weight (kg)	33·0	9·8	16·5	70·3	32·9	9·6	17·6	67·3	0·909
Weight (SDS)	0·20	1·00	−2·35	3·36	0·27	0·95	−2·34	2·49	0·499
Height (m)	1·37	0·13	1·07	1·67	1·37	0·13	1·12	1·64	0·666
Height (SDS)	0·24	0·96	−2·36	3·37	0·26	0·90	−1·81	2·83	0·831
BMI (kg/m²)	17·3	2·6	11·9	28·4	17·1	2·5	13·3	27·5	0·467
BMI (SDS)	0·06	1·10	−3·07	2·94	0·16	1·04	−2·13	2·73	0·357
Waist circumference (cm)	60·1	7·6	46·5	83·0	60·5	7·8	47·0	95·0	0·693
Triceps skinfold (mm)†	12·2	–	5·7	23·7	10·3	–	5·1	31·1	<0·001
Biceps skinfold (mm)†	6·6	–	2·9	21·0	5·4	–	2·7	20·2	<0·001
Subscapular skinfold (mm)†	6·9	–	3·3	25·7	5·8	–	3·3	20·7	<0·001
Supra-iliac skinfold (mm)†	6·8	–	2·6	22·3	5·2	–	2·6	29·0	<0·001
SF2 (mm)†	19·2	–	9·4	49·4	16·2	–	9·3	44·8	<0·001
SF4 (mm)†	33·0	–	16·0	91·6	27·1	–	15·3	83·7	<0·001
Body fat (kg)	8·8	3·9	3·4	21·7	7·3	3·8	2·6	23·6	<0·001
Body fat (%)	25·9	5·6	14·4	43·8	21·3	5·5	11·0	38·3	<0·001

Min, minimum value; Max, maximum value; SDS, standard deviation score; SF2, sum of triceps and subscapular skinfolds; SF4, sum of triceps, biceps, subscapular and supra-iliac skinfolds.
* Student's t test.
† Geometric mean (between-group comparison performed on log-transformed value).

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Table 2. Bootstrap selection of predictors of percentage body fat (n 372)*

	Model 1	Model 2	Model 3
Sex	1000	1000	1000
Age	1000	1000	1000
Pubertal stage	246	249	395
LogTSF	1000	–	–
LogSF4	–	–	1000
LogSF2	–	1000	–
BMI	568	209	491
Waist	933	414	168

LogTSF, log-transformed triceps skinfold; logSF4, log-transformed sum of triceps, biceps, subscapular and supra-iliac skinfolds; logSF2, log-transformed sum of triceps and subscapular skinfolds.

* Values represent the bootstrap inclusion fraction, i.e. the number of times out of 1000 that the candidate predictors were selected as predictors at bootstrapped backward stepwise linear regression.

neither BMI nor waist circumference improved the prediction of PBF in the models including logSF4 or logSF2.

Table 3 gives the seven prediction models selected for further evaluation on the basis of the previous analysis. As determined by R^2_{adj} and RMSE, models 3 and 4 were similarly accurate and better than models 1, 2, 5, 6 and 7.

Table 4 reports the fixed and proportional bias and the CCC for the seven prediction models. The fixed bias, i.e. the mean inter-method difference, was 0 % in all cases but the limits of agreement were narrower for models 3 and 4 than for the remaining models. Likewise, a negative proportional bias, i.e. a negative correlation between the inter-method difference and the average of the methods, was present in all cases but was lowest for models 3 and 4. Because the presence of a proportional bias makes the fixed bias an unreliable measure of agreement, we used CCC to evaluate agreement. CCC shows that models 3 and 4 are better than the other models at predicting PBF. The absolute inter-method difference for the respective models is shown in Fig. 1. The absolute inter-method difference showed an increasing trend for increasing quintile of the average of methods only for models 6 and 7.

Discussion

KISS allowed us to perform a novel cross-calibration study of anthropometry for the prediction of PBF in a representative sample of the general paediatric population. To date, only the Alimentación y Valoración del Estado Nutricional de los Adolescentes (AVENA) study has performed a validation of anthropometry in a general population of children[23]. However, the AVENA children were older (aged 13–18 years) than the KISS children and the main aim of the AVENA study was to validate external algorithms[23]. In the present study, we showed that logSF2 is nearly as accurate as logSF4 and that both are better than BMI and waist circumference at estimating PBF in 6- to 13-year-old Swiss children. Although logTSF is less accurate than log2SF, it is still a better predictor of PBF than BMI, waist circumference and their combination. This has important implications for paediatric epidemiological research aiming to disentangle the effects of fat and fat-free tissues on health outcomes.

Table 3. Comparison of seven regression models for the prediction of percentage body fat (n 372)

(Regression coefficients or measures of model fit and 95 % bootstrapped confidence intervals†)

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI	R^2_{adj}	95 % CI
Male sex	−2·08*	−2·72, −1·43	−2·64*	−3·25, −2·02	−1·83*	−2·38, −1·27	−1·64*	−2·13, −1·14	−4·20*	−4·95, −3·45	−4·69*	−5·47, −3·91	−4·36*	−5·09, −3·63
Age (years)	−0·44*	−0·61, −0·28	−0·80*	−0·98, −0·62	−0·59*	−0·73, −0·45	−0·64*	−0·77, −0·51	−0·65*	−0·85, −0·45	−1·18*	−1·42, −0·95	−0·90*	−1·14, −0·66
LogTSF (mm)	15·01*	13·95, 16·08	11·85*	10·66, 13·05	–	–	–	–	–	–	–	–	–	–
Waist (cm)	–	–	0·23*	0·17, 0·29	–	–	–	–	–	–	0·64*	0·58, 0·70	0·24*	0·10, 0·38
LogSF2 (mm)	–	–	–	–	16·13*	15·25, 17·01	–	–	–	–	–	–	–	–
LogSF4 (mm)	–	–	–	–	–	–	14·77*	14·07, 15·47	–	–	–	–	–	–
BMI (kg/m²)	–	–	–	–	–	–	–	–	1·75*	1·56, 1·93	–	–	1·19*	0·79, 1·58
Intercept	−7·46*	−9·94, −4·97	−9·92*	−12·22, −7·61	−16·22*	−18·54, −13·90	−19·68*	−21·92, −17·45	1·87	−1·16, 4·90	−1·51	−4·55, 1·54	−0·67	−3·66, 2·32
R^2_{adj}	0·75	0·71, 0·79	0·78	0·74, 0·81	0·82	0·79, 0·85	0·85	0·82, 0·88	0·62	0·56, 0·67	0·58	0·53, 0·64	0·63	0·58, 0·68
RMSE (kg)	3·02	2·78, 3·26	2·85	2·63, 3·06	2·54	2·34, 2·73	2·35	2·14, 2·55	3·73	3·45, 4·00	3·89	3·65, 4·13	3·66	3·42, 3·91

R^2_{adj}, adjusted determination coefficient; logTSF, log-transformed triceps skinfold; logSF2, log-transformed sum of triceps and subscapular skinfolds; logSF4, log-transformed sum of triceps, biceps, subscapular and supra-iliac skinfolds; RMSE, root mean squared error.

* $P<0·001$.

† 95 % CI were calculated using bootstrap in 1000 random samples.

Table 4. Bias and concordance of the seven models for the prediction of percentage body fat (n 372)

	Fixed bias*					Proportional bias		Concordance†		
	Mean	SD	LLA	ULA	P‡	r	P§	CCC	LCC	UCC
Model 1	0·00	3·01	5·90	−5·90	1·000	−0·28	<0·001	0·86	0·83	0·88
Model 2	0·00	2·83	5·55	−5·55	1·000	−0·26	<0·001	0·88	0·85	0·90
Model 3	0·00	2·53	4·95	−4·95	1·000	−0·23	<0·001	0·90	0·89	0·92
Model 4	0·00	2·34	4·58	−4·58	1·000	−0·21	<0·001	0·92	0·90	0·93
Model 5	0·00	3·71	7·27	−7·27	1·000	−0·36	<0·001	0·76	0·73	0·80
Model 6	0·00	3·87	7·59	−7·59	1·000	−0·39	<0·001	0·74	0·70	0·78
Model 7	0·00	3·64	7·14	−7·14	1·000	−0·36	<0·001	0·78	0·74	0·81

LLA, Bland & Altman's lower limit of agreement; ULA, Bland & Altman's upper limit of agreement; r, Pearson's correlation coefficient; CCC, Lin's concordance correlation coefficient; LCC, 95 % lower limit of agreement of CCC; UCC, 95 % upper limit of agreement of CCC.
* Calculated as (predicted − measured).
† $P<0·001$ for all values of the CCC.
‡ Tests the null hypothesis that the mean bias equals 0.
§ Tests the null hypothesis of no association between the bias and the average.

In recent years, it has been increasingly recognised that BMI and waist circumference are not accurate measures of body fat, especially in children[9,10]. The present results are in general agreement with other studies performed in non-representative samples of children showing that skinfolds are better than BMI at predicting PBF[6,19–22,41]. The present results are also in general agreement with the AVENA study, which shows that selected skinfolds offer reasonably accurate estimates of PBF at the population level in a representative sample of 13- to 18-year-old Spanish adolescents[23]. The most accurate prediction of PBF in the AVENA study from the sum of triceps and subscapular skinfolds was obtained using the Slaughter equation in males. However, in the KISS study, this equation was less accurate than in the AVENA study. The Slaughter equation applied to KISS boys showed in fact a mean fixed bias of −5·7 (SD 2·8) % ($P<0·001$) *v.* one of 1·6 (SD 0·6)% in the AVENA study and, more importantly, a substantial proportional bias (r 0·87; $P<0·001$) which was absent in the AVENA study (r 0·01; $P>0·05$). Despite these differences, which are likely to reflect differences in the study populations, the KISS and AVENA studies together suggest that skinfolds may be used for predicting PBF in children and adolescents.

The measurement of skinfolds is not recommended for routine evaluation of obese children[6,7]. This is because skinfolds do not add to the prediction of body fat in subjects with a BMI above the 95th percentile for age and, more importantly, to the prognostic value of BMI[7,41–43]. This is partially attributable to the higher error of measurement of skinfolds at high levels of adiposity. In this respect, the lack of an association between the absolute inter-method difference and the quintiles of the average for skinfolds has to be interpreted in light of the fact that just 2 % of our children were obese, so that the well-known lower reproducibility of skinfold measurements at higher values of adiposity had a minimal effect on the accuracy of the estimate of PBF in our population[27].

On the other hand, epidemiologists are increasingly interested in evaluating the effects of fat and fat-free tissues on health outcomes using adiposity indexes rather than BMI[44]. The present study shows that log-transformed skinfolds are much better than BMI, waist circumference and their combination at estimating PBF in a general population of 6- to 13-year-old children, supporting their use as surrogate measures of body fat in epidemiological studies. The skinfolds measured in the present study were chosen because they are the most commonly employed[18,30,31]. The modest increase of R^2_{adj} and the modest reduction of RMSE obtained by predicting PBF from logSF4 (RMSE 2·35; 95 % CI 2·14, 2·55 kg) as compared with logSF2 (RMSE 2·54; 95 % CI 2·34, 2·73 kg) is not enough to justify the measurement of four skinfolds in an epidemiological context where time is a significant constraint. Yet, for selected epidemiological applications, one may accept the lower R^2_{adj} and the higher RMSE of logTSF (RMSE 3·02; 95 % CI 2·78, 3·26 kg) as compared with log2SF by considering that the triceps skinfold is simpler and less embarrassing to measure and offers a prediction of PBF that it still better than by the use of BMI and waist circumference.

Although the present analysis of the KISS data provides novel information for the non-invasive assessment of body fat in paediatric epidemiological studies, it is not without limitations. First, 25 % of our children did not undergo DXA measurements. These children were younger than those with DXA, but they had the same SDS of weight, height and BMI. Thus, we are confident that the generalisability of our findings to the entire KISS population is not compromised. Second, our conclusions apply only to 6- to 13-year-old Swiss children. It is of interest, however, that the mean SDS of BMI is very close to the 50th percentile and its minimum and maximum values are within three SDS of the reference data, reflecting the distribution of anthropometry expected in the UK and possibly other Western populations. Third, DXA measurements are sensitive to soft tissue hydration. In particular, PBF estimates made by DXA tend to be higher when the hydration of the fat-free mass is low[45]. However, the magnitude of this error under normal conditions, as in the present study, is small and does not affect the validity of DXA[46]. Fourth, a well-known limitation of DXA is that body composition estimates made by densitometers of different manufacturers are not comparable[47], which makes the external cross-validation of DXA-based prediction models potentially more difficult than with other methods.

In conclusion, the log-transformed sums of two and four skinfolds were found to be similarly accurate indices of PBF

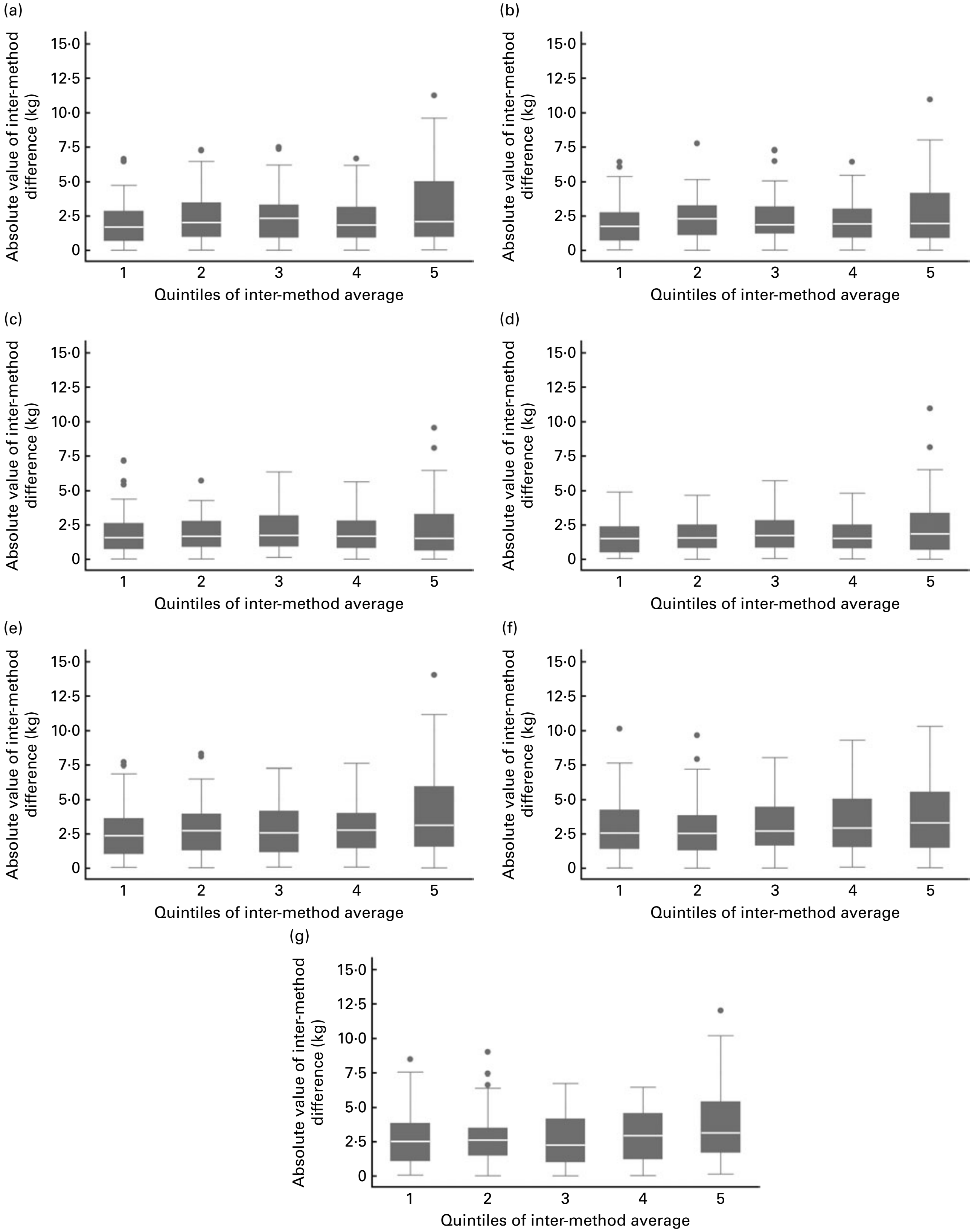

Fig. 1. Relationship between the absolute inter-method difference (calculated as predicted − measured) and the quintiles of the average of the methods for the seven different models: (a) model 1 (P=0·1984); (b) model 2 (P=0·4930); (c) model 3 (P=0·4936); (d) model 4 (P=0·0684); (e) model 5 (P=0·0373); (f) model 6 (P=0·0159); (g) model 7 (P=0·0062). The absolute inter-method difference showed an increasing trend for increasing quintile of the average of methods only for models 6 and 7. Box plots give the median value (═), 25th and 75th percentiles (lower and upper limits of the box) and lower and upper adjacent values (whiskers). ●, Outliers. The P values for trend were obtained from a Jonckheere–Terpstra test for ordered alternatives (both ascending and descending).

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in a representative sample of 6- to 13-year-old Swiss children. Due to its simplicity and low cost, the sum of two skinfolds may be used to evaluate the association of PBF with health outcomes in epidemiological studies. Nevertheless, the KISS algorithms should be cross-validated in external samples before being employed in research.

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