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PEDIATRIC ORIGINAL ARTICLE

Validation of anthropometry and foot-to-foot bioelectrical resistance against a three-component model to assess total body fat in children: the IDEFICS study

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OBJECTIVE: To compare different field methods for estimating body fat mass with a reference value derived by a three-component (3C) model in pre-school and school children across Europe.
DESIGN: Multicentre validation study.
SUBJECTS: Seventy-eight preschool/school children aged 4–10 years from four different European countries.
METHODS: A standard measurement protocol was carried out in all children by trained field workers. A 3C model was used as the reference method. The field methods included height and weight measurement, circumferences measured at four sites, skinfold measured at two–six sites and foot-to-foot bioelectrical resistance (BIA) via TANITA scales.
RESULTS: With the exception of height and neck circumference, all single measurements were able to explain at least 74% of the fat-mass variance in the sample. In combination, circumference models were superior to skinfold models and height–weight models. The best predictions were given by trunk models (combining skinfold and circumference measurements) that explained 91% of the observed fat-mass variance. The optimal data-driven model for our sample includes hip circumference, triceps skinfold and total body mass minus resistance index, and explains 94% of the fat-mass variance with 2.44 kg fat mass limits of agreement. In all investigated models, prediction errors were associated with fat mass, although to a lesser degree in the investigated skinfold models, arm models and the data-driven models.
CONCLUSION: When studying total body fat in childhood populations, anthropometric measurements will give biased estimations as compared to gold standard measurements. Nevertheless, our study shows that when combining circumference and skinfold measurements, estimations of fat mass can be obtained with a limit of agreement of 1.91 kg in normal weight children and of 2.94 kg in overweight or obese children.

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Keywords: validation studies; body composition; child; body weights and measures; deuterium; electric impedance

INTRODUCTION

The worldwide rise in the prevalence of childhood obesity[1] has increased the launch of epidemiological studies investigating different aspects related to childhood obesity. However, a recent systematic review of the literature and web-based sources supported an overall leveling off of the epidemic in children and adolescents from Australia, Europe, Japan and the USA.[2] It is important to emphasize that the leveling off is not tantamount to calling off the epidemic. Additionally, it is noteworthy that previous stable phases have been followed by further increases in the prevalence of obesity. Therefore, research into the causes, prevention and treatment of obesity should remain a priority.[2]

An important challenge for all these studies is to find the most optimal field method for accurately estimating body fatness in younger age groups, especially when considering the large sample sizes often required for these kind of studies. Within the IDEFICS baseline survey, body composition was assessed in 16 220 2–9 year-old children in eight different European countries.[3,4] Laboratory methods for estimating body composition were economically and logistically not feasible in such a large-scale epidemiological study, and different field methods for assessing body composition were employed instead. Previous validation studies found inconsistent results concerning the validity of body composition measurements in children.[5–8] To assess the validity of

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the IDEFICS field measurements, a validation study was set up combining the IDEFICS study protocol with established reference methods.

This paper investigates the potential of various anthropometric field methods (height–weight, circumferences, skinfold thickness) and foot-to-foot bioelectrical resistance to predict fat mass as measured by a three-component (3C) model reference method[9] in a group of preschool and school children aged 4–10 years across Europe. Single measurements and combinations of field measurements are explored to find the optimal and the minimal set of measurements to be included in large-scale epidemiological studies that aim to estimate fat mass in children.

MATERIAL AND METHODS

Study design

The field work of the IDEFICS validation study was conducted from October 2008 to July 2009 in convenience samples of children aged 4–10 years in four different European centres at the universities of Ghent (Belgium), Glasgow (UK), Gothenburg (Sweden) and Zaragoza (Spain). In Ghent, Glasgow and Zaragoza, the study population was recruited from the general population; Gothenburg recruited children from an obesity clinic that were free of concurrent diseases. This approach was chosen to increase *post-hoc* the proportion of obese children and the range of fatness in the study sample. All measurements were done with a fixed schedule within 8 days.[10] In total, 78 children (35 male, 43 female subjects) were included in the IDEFICS validation study.

Reference and field methods used

Reference method for assessing body fat. As a reference, a 3C model was used.[9,11] This approach obtains high accuracy measurements of fat mass and fat-free mass by measuring, rather than assuming, the composition of lean tissue. In the two-component model of body composition, the measurement of body density (from body mass and body volume) is used to differentiate fat mass and fat-free mass on the assumption that the fat-free mass has a constant age- and sex-specific hydration.[12] The 3C model further differentiates the fat-free mass in body water and lean dry mass, and is given by: Body mass = fat mass + body water mass + lean dry mass. Decomposing the masses into the products of volume and density, assuming densities of 0.99371 kg l^{-1} for body water (given by the density of water at 36 °C), of 0.9007 kg l^{-1} for body fat (assuming zero hydration) and of 1.5157 kg l^{-1} for lean dry mass (given by the densities of protein and mineral at an assumed fixed ratio) and exploiting the fact that the volumes of the three components add up to total body volume, the equation can be easily reformulated as:

Fat mass (kg) = 2.22 × body volume (l) − 0.764 × total body water (l) − 1.465 × body mass (kg)

The 3C model shows high agreement with the four-component model where lean dry mass is additionally separated into protein and mineral.[9]

Body volume was measured by air displacement plethysmography using Bod-Pod (Body Composition System, Life Measurement, Inc, Concord, CA, USA; Software V. 2.3) as previously described,[13,14] and corrected for thoracic gas volume and surface area artefact. Surface area artefact is automatically computed by the software and is used to account for isothermal air, close to the subject's body surface[13] and thoracic gas volume is automatically estimated using child-specific equations as previously described by Fields *et al.*[15] Total body water was measured with deuterium dilution.[16,17]

Body mass was measured with a TANITA BC 420 SMA digital weighing scale (TANITA, Tokyo, Japan). More details about these methods used in this validation study were given in Bammann *et al.*[10]

Field methods for assessing body fat. The field methods for assessing body composition comprise anthropometric and bioelectrical resistance measurements. Triceps and subscapular skinfold thicknesses were measured after prior landmarking using Holtain Tanner/Whitehouse skinfold calipers (Holtain Ltd, Crosswell, UK) according to the International standards for anthropometric assessment.[18] Additionally, biceps, suprailiac, thigh and calf skinfolds were measured in all centres, except in Glasgow, where measurements of more than two skinfolds are only available in some children.

Circumferences were measured after prior landmarking in four sites (waist, hip, neck, mid-upper arm) using a Seca 200 tape (Seca GmbH & Co KG, Hamburg, Germany) and standing height was measured using a Seca 225 stadiometer (Seca GmbH & Co) according to ISAK.[18]

Bioelectrical resistance and body mass were measured using a prototype foot-to-foot device that is based on the TANITA BC 420 SMA digital scale (TANITA Corp.). The prototype was developed by TANITA Europe (TANITA Europe GmbH, Sindelfingen, Germany) specifically for the IDEFICS surveys to be able to assess foot-to-foot bioelectrical resistance also in children whose feet were too small for the standard devices used in adults. The resistance index (RI) was calculated as squared height (cm^2) divided by resistance (Ohm). The RI was shown to be a good predictor for fat-free mass in children.[19] Based on a simple two-component model, we constructed a predictor for fat mass FMres that was calculated as body mass (kg) minus RI (cm^{2}Ohm^{-1}).

Body mass index (BMI) was calculated as weight (kg) divided by squared height (m^2). Additionally, BMI z-scores were calculated using British 1990 reference centiles.[20] For obtaining the International Obesity Task Force (IOTF) category, BMI categories given by Cole *et al.*[21,22] were interpolated for continuous age as proposed. Cubic splines were used for this interpolation.

Precision of methods. Intra- and interobserver repeatability have been assessed ($N = 342$; children 2–9 years) for all anthropometric measurements in the IDEFICS study.[23] The technical error of the mean was <1 mm in skinfold measurements and <1 cm in all circumference measurements, resulting in intra- and interobserver agreements of $>97\%$ for all measurements. The lowest agreement was found for neck circumference (intraobserver agreement: 97.3%, interobserver agreement: 97.4%) and the highest for height and weight measurements. Unfortunately, the resistance measurement was not included in this study. Accuracy at first calibration for the impedance measurement is indicated with ±2% (TANITA Europe GmbH).

Published data on the precision of body composition measurements in small children is sparse. A study by Vettorazzi *et al.*[24] showed good interobserver agreement for a TANITA leg-to-leg device in infants and toddlers. A further study in children confirms this finding.[25] Precision of body volume measurement by air displacement plethysmography in adults was shown to be lower in subjects <40 l body volume.[26] Fields *et al.*[27], however, reported in their review that precision of body volume measurement by Bod-Pod is comparable in adults and children despite the smaller volume of the latter.[27]

Statistical procedures

Means and s.d.'s were calculated for all the included variables, and Bonferroni-corrected *t*-tests were performed for all variables by sex (boys versus girls) and by IOTF category (underweight or normal weight versus overweight or obese). The field measurements were plotted against 3C fat mass to check for linearity and to confirm that no transformation of variables was necessary. Unadjusted linear regression analyses were used to investigate the explained variance (calculated as the unadjusted R^2) of all single field measurements and combinations of field measurements on fat mass (kg) derived from the 3C model. The residuals of the models were exploited for calculating limits of agreement (±1.96 s.d.'s). Age, sex and fat mass (gained by 3C model) were regressed on the residuals to explore the influence of these variables on the prediction error. The fat-mass variance explained by different skinfold combinations was investigated in a subsample of the study population ($N = 63$), for which six skinfold measurements were available.

A full model was calculated by including all field measurements into the regression equation. A fitted (simplified) model was built by reducing the full model until only statistically significant ($P < 0.05$) variables were left in the model. This was done manually using several forward and backward steps to avoid possible bias introduced by automated procedures.[28] Additionally, a sparse model with $R^2 \geqslant 0.90$ was calculated to identify a minimal set of variables for estimating fat mass with a certain degree of accuracy. The model-building process was redone using ridge regression to ensure that the process was not biased by the multicollinearity present in the data. This was not the case (data not shown).

To investigate the fit of the data-driven models (full, fitted and sparse) in the IOTF categories (underweight or normal weight; overweight or obese), the residuals were again analysed by subgroup. Biases (mean of residuals) and limits of agreement (±1.96 s.d.'s) were calculated. Separate models for the investigated subgroups were fitted to the data and compared to the model fitted in the full sample. Additionally, a Bland–Altman plot was used to investigate the influence of fat mass on the residuals in the full sample.[29]

Table 1. Descriptive statistics for the study sample

	Girls (N = *43)*	*Boys* (N = *35)*	*Underweight* (N = *3) or normal weight* (N = *47)*	*Overweight* (N = *15) or obese* (N = *13)*	*All* (N = *78)*
Age (years)	6.7 (1.5)	7.3 (1.4)	6.9 (1.4)	7.0 (1.6)	7.0 (1.5)
Fat mass 3C model (kg)	6.07 (4.24)	5.54 (6.09)	**3.27 (1.63)**	**10.16 (6.06)**	5.83 (5.12)
Fat mass 3C model (%)	21.9 (9.7)	16.2 (9.0)	**14.1 (6.3)**	**28.2 (8.0)**	19.3 (9.7)
Weight (kg)	25.6 (7.6)	29.2 (12.0)	**22.9 (4.0)**	**35.0 (12.3)**	27.2 (9.9)
Height (cm)	120.0 (9.9)	126.7 (10.0)	121.4 (8.8)	125.8 (12.5)	123.0 (10.4)
Body mass index (kg m $^{-2}$)	17.5 (3.2)	17.7 (4.3)	**15.4 (0.9)**	**21.5 (3.7)**	17.6 (3.7)
Waist circumference (cm)	58.5 (9.1)	59.6 (12.4)	**53.7 (4.9)**	**68.4 (11.7)**	59.0 (10.7)
Hip circumference (cm)	66.3 (8.6)	68.0 (11.1)	**62.1 (4.5)**	**75.8 (10.5)**	67.1 (9.8)
Waist-to-hip ratio	0.88 (0.07)	0.87 (0.07)	0.86 (0.06)	0.90 (0.08)	0.88 (0.07)
Neck circumference (cm)	26.2 (1.9)	27.3 (2.4)	**25.9 (1.5)**	**28.2 (2.5)**	26.7 (2.2)
Mid-upper arm circumference (cm)	19.7 (3.3)	20.4 (4.4)	**18.1 (1.4)**	**23.3 (4.7)**	20.0 (3.9)
Triceps skinfold (mm)	13.0 (4.6)	12.3 (6.4)	**9.6 (2.0)**	**18.1 (5.4)**	12.7 (5.4)
Subscapular skinfold (mm)	9.5 (5.3)	9.0 (7.2)	**5.8 (1.3)**	**15.5 (6.7)**	9.3 (6.2)
Foot-to-foot resistance (Ohm)	656.6 (70.4)	608.4 (81.2)	**662.6 (64.2)**	**585.6 (78.9)**	634.9 (78.7)

Bold: statistically significant differences ($P < 0.05$ with Bonferroni correction). Means (s.d.'s), by sex, IOTF category and in total sample.

All statistical analyses were done with SAS 9.2 (SAS Institute, Cary, NC, USA).

Statement of ethics

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. Approval by the appropriate Ethical Committees was obtained by each of the four centres doing the field work. The children provided oral informed consent, and their parents provided written informed consent. This consent comprised all examinations, the collection of urine samples, and subsequent analysis and storage of personal data and collected samples.

RESULTS

Table 1 displays the descriptive statistics of the study sample. Twenty-nine percent were less than 6 years old, 55% were girls and 36% were overweight or obese. We found no statistically significant differences between the boys and girls of our sample. With the exception of age, height and waist-to-hip ratio (WHR), all other variables differed by IOTF category. Mean fat mass (determined by 3C model) was 3.27 kg in the underweight/normal weight children and 10.16 kg in the overweight/obese children.

The explained variance of fat mass by single field measurements ranged between 32.4% for height and 88% for hip circumference (see Table 2). In combination, height and weight accounted for 89% and the four circumferences for 88.3% of the variance of fat mass. Employing any kind of formulae always resulted in a loss of explained variance as compared to including the involved variables untransformed into the model (for example, BMI: 80% as compared to 89% for weight and height, WHR: 4% as compared to 88% for the four circumferences). This loss, however, was very moderate when summing up skinfolds (cf. Table 3). Circumference models were in general superior to height–weight models. For all models, fat mass was significantly associated with the prediction error. Sex, but not age, was significantly associated with this error in the height–weight models and the circumference models.

Data-driven models were able to explain >90% of the fat-mass variance. This holds for the model containing the full set of variables (full model: 94.6%, limits of agreement: ±2.33 kg) as well as for the models that were built by a manual selection procedure (fitted model: 94.1%, limits of agreement: ±2.44 kg). The fitted model contains hip circumference, triceps SF and FMres, and is given by:

body fat (kg) = 0.26912 hip circumference (cm) + 0.16961 triceps SF (mm) + 0.34585 FMres − 15.226.

A sparser model containing only hip circumference and FMres explains still 93.6% of the variance of fat mass (limits of agreement: ±2.54 kg). For all data-driven models, sex and age are not associated with the residuals. However, fat mass is significantly associated with the prediction error in the fitted and in the sparse model, although to a lesser degree than in most of the other investigated models. The Bland–Altman plot for the fitted model (versus 3C reference model) shows no clear association of prediction error with fat mass (Figure 1).

The investigation of the subgroup with additional skinfold measurements ($N = 63$) showed that the proportion of explained variance of fat mass by skinfolds increased with increasing number of sites measured (86.5% for two sites to 90.2% for six sites) (see Table 3). Single skinfolds that contributed most to the explanation of fat-mass variance were biceps SF and triceps SF. This holds for both sexes. Further informative skinfolds were subscapular SF and calf SF in boys, and thigh SF in girls (data not shown). Combining subscapular or suprailliac SF with hip circumference improved the proportion of explained variance by another 3% (in the total sample: hip circumference: 88%, subscapular SF: 90.7%; data not shown). The inclusion of triceps and biceps SF increased the proportion of the explained variance of the mid-upper arm circumference measurement considerably to 90.2% (additional inclusion of calf SF and thigh SF: 91.3%). Models with combinations of circumference and skinfold measurements (trunk models, extremity models) performed slightly better than skinfold models alone with the exception of the model containing six single skinfolds.

Fat mass was significantly associated with prediction error in the single SF measurements and the trunk models, but not in the skinfold models and the extremity models. Age was significantly associated with the prediction error in all models, but the trunk models and sex were significantly associated with the prediction error of all but some of the skinfold models.

The performance of the fitted model by sex and IOTF category is displayed in Table 4. The bias, which is zero in the total group, did differ moderately by IOTF category (underweight/normal weight: 0.06 kg, overweight/obese: −0.10 kg) and by sex (girls: 0.18 kg, boys −0.22 kg). As a last step, the model-building process was redone and stratified by sex and IOTF category. Variables that contributed most consistently over categories to the estimation of fat mass were hip circumference and FMres that were included in three of four models, and triceps SF and weight that were included in two of four models (data not shown).

DISCUSSION

We investigated the potential of various anthropometric field methods to predict total body fat mass in a group of children aged 4–10 years in Europe, using the 3C model as a reference. With the

Table 2. Capability of field methods to predict fat mass (kg; 3C model)

	Unadjusted R^2	*Limits of agreement ± in kg*	*Influence on prediction error standardized parameter estimate*		
			Age	*Sex*	*Fat mass (3C)*
Single measurements					
Weight	0.831	4.13	−0.61***	1.70***	0.22***
Height	0.324	8.25	−1.30***	1.11***	0.79***
Waist circumference	0.762	4.89	0.10	0.95	0.22***
Hip circumference	0.880	3.53	−0.38**	1.01**	0.15***
MUAC	0.748	5.04	0.38*	1.51**	0.21***
Neck circumference	0.484	7.21	−0.67***	1.58**	0.57***
Triceps skinfold (SF)	0.835	4.08	0.50**	0.17	0.12**
Subscapular SF	0.821	4.25	0.54***	0.48	0.12**
FMres	0.789	4.61	0.23	−0.61	0.19***
Height–weight models					
Height, weight	0.889	3.35	0.08	1.51***	0.10**
BMI	0.800	4.49	0.46**	1.04*	0.15**
BMI *z*-score	0.569	6.59	0.75***	0.85	0.35***
Circumference models					
WHR	0.042	9.82	0.21*	0.05	0.94***
Waist, hip	0.879	3.50	−0.32*	1.02**	0.15***
Waist, hip, MUAC	0.881	3.47	−0.25	1.10**	0.14***
Waist, hip, MUAC, neck circumference	0.883	3.44	−0.20	1.00**	0.13***
Data-driven models					
Full model	0.946	2.33	0.00	0.51	0.05
Fitted model: Hip circ, triceps SF, FMres	0.941	2.44	−0.02	0.36	0.06*
Sparse model: Hip circ, FMres	0.936	2.54	−0.15	0.40	0.08*

Abbreviations: BMI: body mass index; 3C, three component; circ: circumference; FMres: weight (kg) minus RI (cm^{2}Ohm^{-1}); MUAC: mid-upper arm circumference; SF: skinfold; WHR: waist-to-hip ratio. Full models with all variables. Fitted models with maximum adjusted R^2. Sparse models with minimal numbers of variables and $R^2 \geqslant 0.90$. *$P<0.05$, **$P<0.01$, ***$P<0.001$. Linear OLS regression ($N=78$).

exception of height and neck circumference, all single measurements were able to explain at least 74% of the fat-mass variance in the sample. In combination, circumference models were superior to skinfold models and height–weight models, however the best predictions were given by combinations of skinfold and circumference measurements of the trunk. These models were able to explain 90.7% of the observed fat-mass variance. The optimal datadriven model for our sample includes hip circumference, triceps skinfold and total body mass minus RI, and explains 94.1% of the fat-mass variance; a sparse model containing only hip circumference and total body mass minus RI performs only slightly worse (93.6% explained fat-mass variance). However, even these models with over 90% explained variance, lead to fairly high limits of agreement of 2.44 kg fat mass and above. Except in the data-driven models, prediction errors were highly associated with age (skinfold models, arm models), sex (circumference models, trunk models) or both age and sex (height–weight models). In all investigated models, prediction errors were associated with fat mass, although to a lesser degree in the skinfold models, the arm models and the data-driven models.

Differences in study protocol design and methods (including different age ranges) made it difficult to compare our data with results derived from other studies. These limitations should be considered when interpreting the comparisons with other studies reported below. Moreover, very few validations against multi-component models have been undertaken in children and there are no directly comparable studies. For weight and height measurements, like the frequently used BMI z-score, contradictory findings concerning the validity to determine body fat among children have been found in literature. In our study, the combination of weight and height was a good predictor of body fat, however, BMI and especially BMI z-score performed worse.

Although some studies in the literature have considered the usefulness of waist circumference and WHR for estimating body fat among children, no studies have examined the validity of hip circumference. Our study showed a large explanatory power and predictive value of hip circumference measurements in comparison with the other field methods when using the 3C model as a reference. Besides, the explanatory power for waist circumference in our study was a bit lower and waist circumference was not included in the multivariate models predicting fat mass. It might be possible that hip circumference is important to predict total body fat, whereas waist circumference may be important as predictor of body fat distribution in children.[30–33] Concerning the validity of WHR, our results confirm previous findings showing its unsuitability for determining total fat mass in children.[31]

A large body of literature concerning the validity of skinfold thicknesses in children is restricted to the use of body fat equations with often poor results regarding their validity.[7,9,34] In a study of Bray *et al.*[5] untransformed skinfold measurements showed very similar R^2 for total body fat to those obtained in our study, and likewise the predictive value improved with a rising number of included measurement sites.

The explained variance of body mass minus RI derived by foot-to-foot BIA measurements in our study was low. Although foot-to-foot resistance showed the highest predictive value among the overweight children, results from previous studies do not recommend the use of the foot-to-foot BIA in individual children who are overweight or obese.[35] Moreover, Wells *et al.*[9] showed poor agreement between fatness determined by total BIA analysis and 4C model data. However, it may be of use for obtaining group mean values.[35] Nevertheless, in our study it was one of the three measurements that were included in the data-driven models and this was also persistent in subgroup analyses.

Table 3. Capability of skinfold measures to predict fat mass (kg; 3C model)

	Unadjusted R^2	*Limits of agreement ± in kg*	*Influence on prediction error standardized parameter estimate*		
			Age	*Sex*	*Fat mass (3C)*
Single measurements					
Triceps SF	0.845	4.23	0.55**	0.42	0.10*
Subscapular SF	0.829	4.45	0.68**	0.70	0.10*
Biceps SF	0.869	3.89	0.53**	1.30**	0.08
Suprailliac SF	0.789	4.93	0.67**	1.01	0.14*
Thigh SF	0.711	5.77	0.54*	− 1.21	0.24***
Calf SF	0.797	4.84	0.53*	− 0.36	0.15**
Skinfold models					
Triceps SF, subscapular SF	0.865	3.95	0.62**	0.56	0.07
Sum of two SF	0.863	3.97	0.64**	0.59	0.07
Triceps SF, subscapular SF, biceps SF, supailliac SF	0.881	3.70	0.58**	0.98*	0.06
Sum of four SF	0.864	3.96	0.65***	0.88	0.07
Triceps SF, subscapular SF, biceps SF, supailliac SF, thigh SF, calf SF	0.902	3.36	0.60***	1.01*	0.04
Sum of six SF	0.868	3.90	0.64***	0.16	0.07
Trunk models					
Hip, subscap. SF	0.907	3.27	0.05	1.06*	0.09*
Hip, subscapular SF, suprailliac SF	0.910	3.21	0.01	0.99*	0.09*
Extremities models					
MUAC, triceps SF	0.880	3.71	0.40*	1.00*	0.08
MUAC, triceps SF, biceps SF	0.902	3.36	0.43**	1.40***	0.05
MUAC, triceps SF, biceps SF, thigh SF, calf SF	0.913	3.17	0.45**	1.24**	0.04

Abbreviations: 3C, three component; circ, circumference; FMres, weight (kg) minus RI ($cm^2 Ohm^{-1}$); MUAC, mid-upper arm circumference; SF, skinfold. *$P<0.05$, **$P<0.01$, ***$P<0.001$. Linear OLS regression (Individuals with full set of SF measurements ($N=63$)).

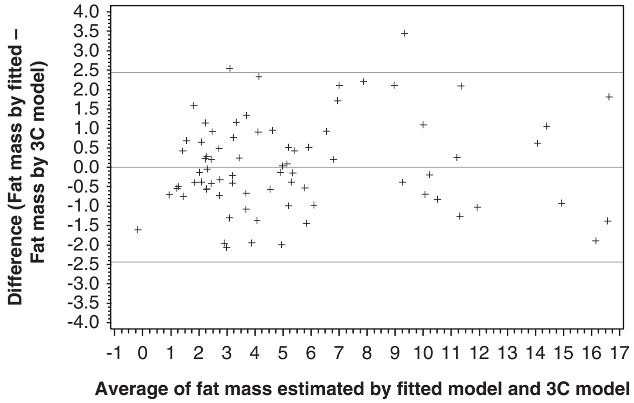

Figure 1. Bland–Altman plot (only children <30 kg fat mass; $N=77$) illustrating the agreement of fat mass estimation between the fitted model and 3C model. The scatter plot shows agreement between both techniques in individuals; the solid lines are the mean bias and the limits of agreements (± 2 s.d.'s of the bias).

To date, pediatric studies in which body composition methods have been validated against 3C and 4C models are scarce and usually very small, with typically <20 subjects per age and sex group.[36] However, there are notable exceptions to this.[37,38] The IDEFICS validation study with its large battery of investigated field methods, gives detailed insight into sex- and age-specific validity of body composition assessment in children.

The field work of the validation study was conducted in four centres from different regions in Europe. This clearly introduces heterogeneity to the data, both from potential measurement error and potential country-by-country differences. This multicentre approach might be seen as a drawback of the study. However, a common study protocol, the same devices and measurement procedures were used in this multicentre validation study. All centres participated in the IDEFICS central trainings where all field measurements were learned. Moreover, skinfold measurements were trained in additional sessions. Intra- and interobserver reliability in the IDEFICS surveys was assessed in a separate study and was high, indicating a good success of the training procedures.[23]

When choosing instruments for large-scale epidemiological surveys, different aspects have a role besides validity of measurements, like economic costs, training effort, burden on the participants, availability of reference values and so on. Economic costs are comparably low for all of our used field methods. The most expensive device is the TANITA prototype scale that is also of moderate costs. The training effort and the time for performing the measurements in the field are not to be underestimated in anthropometric measurements and it is highest in mid-upper arm circumference, waist circumference and all skinfold measurements, because landmarking is used in these methods (cf. ISAK). Moreover, children move a lot during measurements, especially when done on their back (subscapular SF) or on their sides (suprailliac SF, landmarking for waist circumference), calling for observers trained for doing measurements in children. The duration of the measurement and the burden on the participating child is low. However, some measurements like thigh SF or those requiring bareness can pose a problem during field work because of their sensitive nature, especially in children of a certain age or with specific cultural background. In any case, alternative procedures should be trained. Keeping this in mind, we would recommend employing circumference measurements (hip and waist) over pure height–weight measurements. If trained observers are available or observers can be trained thoroughly, we recommend to additionally assess skinfold measurements (biceps SF and triceps SF). For data analyses,

Table 4. Fit of data-driven model[a] by sex and IOTF category

	Unadjusted R^2	*Bias (kg)*	*Limits of agreement ± in kg*	*Unadjusted R^2*	*Bias (kg)*	*Limits of agreement ± in kg*
Sex		Girls (*N* = 43)			Boys (*N* = 35)	
Model (Hip circ, triceps SF, FMres) fitted in total group		0.18	2.13		− 0.22	2.73
Model (Hip circ, triceps SF, FMres) fitted in subgroup	0.943	0.00	1.98	0.954	0.00	2.56
Full model fitted in subgroup	0.959	0.00	1.68	0.969	0.00	2.11
IOTF category		*Underweight (N = 3) or normal weight (N = 47)*			*Overweight (N = 15) or obese (N = 13)*	
Model (Hip circ, triceps SF, FMres) fitted in total group		0.06	1.91		− 0.10	2.94
Model (Hip circ, triceps SF, FMres) fitted in subgroup	0.696	0.00	1.76	0.938	0.00	2.96
Full model fitted in subgroup	0.825	0.00	1.34	0.948	0.00	2.70

Abbreviations: Circ, circumference; FMres, weight (kg) minus RI (cm^{2}Ohm^{-1}); SF, skinfold. Full models with all variables. [a]Model is given by body fat (kg) = 0.26912 hip circ (cm) + 0.16961 triceps SF (mm) + 0.34585 FMres − 15.226.

we would not recommend combining measurements in children to WHR, BMI or sum of skinfolds without good reason, for example, if used as an outcome.

A recent review from Himes[39] states that for identifying overweight or obesity in children and adolescents, apart from the BMI, no other measure of body fat is sufficiently practicable or provides appreciable added information. Consequently, he does recommend the BMI for most clinical, school or community settings for routine practice.[39] We cannot present a suitable alternative in this paper. The variability of error in any of our investigated models is clearly too high for precise estimations of total body fat in individuals. However, this holds even more for the suitability of the BMI, whose limits of agreement are about 40% higher than in all our data-driven models.

Despite the general flaws of anthropometric measurements regarding determination of fat mass in children, they are widely used in clinical practice. Our results suggest, however, that other anthropometric indicators might be better suited for this purpose. A crucial point for the acceptance of alternative measurements related to body fat is the availability of reference values. Some first studies provide reference data on a national level for BIA[40–42] and for other anthropometric measurements.[43–45] Large-scale multicentre studies would be needed to create a solid basis for international valid reference data for body fat in childhood populations.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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