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Original Article

Validity of anthropometric measurements to assess body composition, including muscle mass, in 3-year-old children from the SKOT cohort

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Abstract

Nutritional status of children is commonly assessed by anthropometry both in under and overnutrition. The link between anthropometry and body fat, the body compartment most affected by overnutrition, is well known, but the link with muscle mass, the body compartment most depleted in undernutrition, associated with infections, remains unknown. In this study, we examined the relationship between common anthropometric indices and body composition measured by dual-energy X-ray absorptiometry (DEXA) in a sample of 121 healthy 3-year-old Danish children. Appendicular (arms and legs) lean mass was used to estimate muscle mass. Overall, anthropometric measures were more effective to measure absolute size of fat, lean and muscle mass than their relative sizes. Proportion of the variance explained by anthropometry was 79% for lean mass, 76% for fat mass and 74% for muscle mass. For fat mass and lean mass expressed as percentage of total body mass, this proportion was 51% and 66%, respectively; and for muscle mass as percentage of lean mass it was 34%. All the best reduced multivariate models included weight, skinfold and gender except the model estimating the proportion of muscle mass in lean body mass, which included only mid-upper arm circumference and subscapular skinfold. The power of height in the weight-to-height ratio to determine fat mass proportion was 1.71 with a 95% confidence interval (0.83–2.60) including the value of 2 used in body mass index (BMI). Limitations of anthropometry to assess body composition, and especially for muscle mass as a proportion of lean mass, should be acknowledged.

Keywords: body composition, assessment of nutritional status, DEXA, muscle mass, anthropometry, cohort study.

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Introduction

When submitted to an acute food shortage, the body preferentially mobilises fat stores to provide fuel to key organs such as brain, heart, liver and kidney, which are essential for vital body functions (Kerr *et al*. 1978; Cahill 2006). Muscle proteins can also be used to provide amino acids used as fuel or for protein synthesis, especially when there is an infection associated with an increased amino acid requirement for the immune system (Lecker *et al*. 1999). Muscle can be regarded as an amino acid provider for a whole range of clinical situations with increased protein catabolism, such as cancer or burns (Heymsfield *et al*. 1982). Reduced muscle mass is a marker of functional protein depletion. A common mechanism of selective gene activation leading to muscle breakdown has been described for these different situations (Lecker *et al*. 2004). Muscle depletion is also clinically linked to survival (Heymsfield *et al*. 1982), and longitudinal epidemiological studies carried out in Senegal and in Congo suggest the same link also exists in vulnerable populations of children (Briend *et al*. 1989; Van den Broeck *et al*. 1998). Anthropometric indices based on mid-upper arm circumference (MUAC) have been used to estimate muscle mass (Trowbridge *et al*. 1982; Chomtho *et al*. 2006), and studies have shown that MUAC is a better predictor of survival than weight-for-height (WFH) in populations with high prevalence of undernutrition (Briend *et al*. 1989, 2012; Pelletier 1994; Van den Broeck *et al*. 1996; Myatt *et al*. 2006). This suggests that the capacity of muscle tissues to provide fuel and amino acids to metabolically active organs, which is linked to the ratio of muscle to total lean body mass, is the key to resist nutritional stress and infections.

In children, the World Health Organization (WHO) recommends the use of anthropometric indices based on the comparison of weight and height with international growth standards to describe nutritional status for individual or for population assessment. To our knowledge, however, there have been only limited attempts to link these standard anthropometric indices to body composition, and in particular to muscle mass despite its functional importance in the context of undernutrition. With the increasing focus on early determinants of obesity, there is also an increasing interest in how body composition, and especially the changes in fat mass in early life, is related to later obesity and disease risk. It is therefore of interest also to assess how well body fat mass can be predicted by simple anthropometry.

Dual-energy X-ray absorptiometry (DEXA) is a non-invasive technique that allows a separate estimation of bone mineral, lean and fat mass with high reproducibility (Lohman *et al*. 2009). This method can also be used to estimate the appendicular lean mass (arms and legs), a proxy of muscle mass, most muscles being in arms and legs (Kim *et al*. 2002; Bridge *et al*. 2009). The present analysis used DEXA scans to estimate body composition (lean, muscle and fat mass) and examination of its relationship to anthropometric indices in a cohort of healthy 3-year-old Danish children. It attempted to find the multivariate models based on simple anthropometric measures describing the best body composition. The optimal power of height in the ratio of weight to height was also determined to best relate to each of the body composition indicators.

Materials and methods

Study population

The SKOT cohort is an ongoing observational cohort study of Danish children from the Copenhagen area. The aim of the cohort is to describe how complementary feeding influences growth, development and risk factors for later disease as previously described (Madsen *et al*. 2010). Three hundred thirty children were enrolled at 7–8 months of age, and examined at age 9, 18 and 36 months. Inclusion criteria were healthy singleton infants born ≥37 weeks of gestation without diseases expected to affect growth or food intake.

Participants were recruited from April 2007 to May 2008 by random selection from the National Danish Civil Registry of infants living in great Copenhagen. Mailed invitations were sent to parents of 2211 infants aged 7–8 months, of which 330 were willing to participate. Eighteen dropped out before the first examination. One was later excluded due to severe chronic

Key messages

- Anthropometry reflects imperfectly body composition in children, especially for muscle mass.
- Anthropometry is more effective to measure absolute lean, fat or muscle mass than their respective proportion in relation to body weight or to lean body mass.
- Lean mass and fat mass are mainly related to weight, height and gender. The proportion of fat and lean mass is closely related to body mass index (weight/height^2).
- Muscle mass is closely related to weight in univariate analysis.
- Muscle mass as proportion of lean body mass is best described by combining MUAC and skinfold thickness.

disorder with late manifestation. Written consent was obtained from parents or guardians. The study was approved by The Committee on Biomedical Research Ethics of the Capital Region of Denmark (H-KF-2007-0003).

As part of the 36-month visit, anthropometric measurements were carried out. After the visit, the parents were invited to bring their child to a DEXA scan for assessment of body composition.

Anthropometry

Weight was measured to the nearest 0.1 kg using a Tanita WB-100MA digital weight (Tanita Corporation, 1-14-2, Maeno-chi, Itabashi-ku, Tokyo, Japan). Height was measured to the nearest 0.1 cm using a static digital height measurer (235 Heightronic Digital Stadiometer; Quick Medical and Measurement Concepts, Snoqualmie, WA, USA).

Triceps and subscapular skinfold thickness was measured to the nearest 0.1 mm using a Harpenden skinfold calliper (Chasmors Ltd, London, UK). Waist circumference at the umbilicus level and MUAC were measured to the nearest millimetre with a non-flexible tape measure (Lasso, Child Growth Foundation, London, UK). Height, skinfold, waist circumference and MUAC measurements were performed in triplicate and averaged. *Z*-scores for WFH, weight-for-age (WFA), height-for-age (HFA) and body mass index (BMI)-for-age (BFA) were calculated using growth standards following WHO recommendations (WHO Multicentre Growth Reference Study Group 2006). Arm muscle area was defined as: $1/(4\pi) * (\text{MUAC} - \pi * \text{triceps skinfold})^2$ (Gibson 1990).

DEXA scans

The DEXA scans were performed in a Lunar Prodigy Advance using the software enCore, version 12.30 (GE Healthcare, Madison, WI, USA). Total and regional lean mass, fat mass and bone mineral were estimated (separately) by the software. Due to the young age of the children, the scans were of varying quality, with several being unfit for use. Some children had problems lying still, and sometimes parts of the parents were included in the scan when trying to calm the child.

Consequently, scans were divided into four categories according to the following criteria:

1. *Perfect scans.* The child is lying still. The upper body, neck and head are at a straight or almost straight line. Arms and legs are stretched and clearly separated from the body,
2. *Good scans with minor irregularities.* The child is, in general, lying still. The upper body, neck and head are at a straight or almost straight line. Arms and legs are stretched and clearly separated from the body. The child might have had some movements of the head, arms or legs, but in such a way that nothing is considered missing or scanned more than once,
3. *Scans with several irregularities.* The child is lying relatively still with the upper body, but with several or significant movements of arms or legs, resulting in difficulties in judging whether something is missing or scanned more than once, and
4. *Useless scans.* The child was lying agitated. Body parts are missing at the scan. Parents are partly in the scan in a way such that they cannot be excluded.

Several children were following the scanner arm with the head, resulting in a useless scan of the head, but a usable scan of the rest of the body. Therefore, the above categorisation was applied twice. Once for the whole scan and once for the subscan with the head omitted.

Statistics

Body composition was assessed using a number of different measures: (1) total lean mass (including the head); (2) total lean mass as percentage of total body mass; (3) muscle mass (lean mass in arm and legs); (4) muscle mass as percentage of total lean mass; (5) total fat mass; and (6) total fat mass as percentage of total body mass. Scans in category 1 or 2 were considered appropriate for analysis. For analysis of anthropometric measures and muscle mass, children with a scan categorised as 1 or 2 using the categorisation based on the whole body scan without the head were included. For analysis of all other body composition variables, children with a scan categorised as 1 or 2 using the categorisation based on the whole body scan (including the head) were included.

Anthropometric characteristics of the children with a category 1 or 2 scan were compared to children with a category 3 or 4 scan using unpaired *t*-tests, Kruskal–Wallis test and chi-square test as appropriate. Normally distributed variables were presented as mean ± SD. Continuous variables, not following a normal distribution, were presented as median and interquartile range. Categorical variables were presented as frequency and percentage of total.

Correlations between anthropometric measures and measures of body composition were estimated using the Spearman correlation coefficient.

For each of the body composition indicators, the performances of five multivariate models, using different combinations of anthropometric measures, were assessed. The five models used to estimate different measures of body composition included the following variables:

- Model 1: gender, log weight, log height;
- Model 2: gender, MUAC, log height;
- Model 3: gender, MUAC, log weight;
- Model 4: gender, MUAC, triceps skinfold, subscapularis skinfold, waist circumference, log weight, log height; and
- Model 5: reduced model after stepwise backward model elimination from model 4.

Variables were removed one by one if insignificant at a 0.05 level, but with gender always included in the model.

All models were estimated using least squares regression. Height and weight were logarithm transformed to obtain linearity in the association to lean, muscle and fat status. The models were compared using adjusted R-squared (adj. R^2), Akaike's information criterion (AIC) and bootstrapped root-mean-square error (RMSE). Adj. R^2 was used to compare the variability in the data set accounted for by the statistical model. AIC was used to compare the information lost when a given model was used to describe the true underlying mechanism. Bootstrapped RMSE was used to compare the predictive performance.

To determine the optimal power of height in the ratio of weight to height for assessing body composition, a multiple linear regression was carried out. Logarithm-transformed height and weight as well as gender were included as predictors in the model. Estimated coefficients for the logarithm-transformed height and weight (denoted b and c, respectively) were used to calculate the optimal power for height, -c/b (Prudhon *et al*. 1996), while standard errors and correlation gave the 95% – confidence interval using the delta method (Weisberg 2005).

All analyses were done using SAS version 9.2 (SAS Institute Inc, Cary, NC, USA) and the open-source statistical programming environment R version 2.11.0 (http://www.r-project.org). Missing data were considered missing at random. The overall significance level used was 0.05.

Results

From the 311 children in the SKOT cohort, 263 participated in the third visit with a mean age of 3.0 (SD = 0.1) years, and 189 of these completed a DEXA scan with a mean age of 3.1 (SD = 0.1) years. The average time difference between the third visit and the DEXA scan was 22 (SD = 19) days. Among the whole body scans 49, 52, 66 and 22 were categorised as category 1, 2, 3 and 4 scans, respectively, resulting in 101 usable scans. Disregarding the head, 82, 39, 48 and 20 scans were placed in category 1, 2, 3 and 4, resulting in a total of 121 usable scans.

Table 1 shows descriptive statistics for the 189 children with a DEXA scan. No differences were found between children with a category 1 or 2 scan and the children with a category 3 or 4 scan for any of the variables (all *P*-values > 0.06). Furthermore, no differences were found with respect to the anthropometric measures between children scanned and those who were not (results not shown). All the following results were solely based on scans in category 1 or 2. Results of similar magnitudes were found when repeating the analyses for category 1 scans only.

Children on average had a higher WFA (0.21, $P < 0.0001$), WFH (0.31, $P < 0.0001$) and BFA (0.30, $P < 0.0001$) than the WHO standard. HFA followed the WHO standard (–0.02, $P > 0.1$).

Table 1. Characteristics of the children with a DEXA scan

	N	Category 1 + 2 scans	N	Category 3 + 4 scans	Test for difference (P-value)‡
Age at scan (years)*	121	3.10 (3.03;3.18)	68	3.06 (3.02;3.12)	0.061
Age at examination (years)	121	3.02 (2.97;3.12)	68	2.99 (2.96;3.08)	0.20
Gender, female (%)	121	60/121 (50%)	68	39/68 (57%)	0.30
Height (cm)	121	95.77 ± 3.32	68	95.72 ± 3.73	0.87
Weight (kg)	121	14.6 ± 1.5	68	14.7 ± 1.6	0.55
BMI (kg m^{-2})	121	15.78 (15.11;16.59)	68	15.92 (15.41;16.86)	0.32
Height-for-age z-score	121	–0.04 ± 0.85	68	0.01 ± 0.93	0.55
Weight-for-age z-score	121	0.18 ± 0.77	68	0.29 ± 0.80	0.37
Weight-for-height z-score	121	0.28 ± 0.84	68	0.40 ± 0.79	0.50
BMI-for-age z-score	121	0.18 (–0.30;0.83)	68	0.37 (–0.07;1.03)	0.29
MUAC (cm)	121	16.6 ± 1.0	68	16.7 ± 1.0	0.51
Arm muscle area (mm^2)	120	1496 ± 191	68	1 494 ± 180	0.94
Waist circumference (cm)	121	50.2 (48.6;52.0)	68	50.0 (48.5;52.3)	0.61
Skinfold, triceps (mm)	120	9.3 (8.0;10.2)	68	9.3 (8.4;11.0)	0.20
Skinfold, subscapular (mm)	119	6.3 (5.6;7.0)	68	6.2 (5.5;7.5)	0.68
Sum of skinfolds (mm)	118	15.5 (13.8;17.2)	68	16.0 (13.9;18.3)	0.43
Total lean mass (g)†	101	11 593 ± 1040	88	12 028 ± 2559	0.12
Total lean mass, % of total body mass†	101	80.36 ± 4.65	88	81.23 ± 15.79	0.60
Muscle mass (g)	121	3844 ± 469	68	4035 ± 1784	0.27
Muscle mass, % of total lean mass†	101	32.71 ± 1.58	88	33.99 ± 8.64	0.15
Total fat mass (g)†	101	2513 ± 749	88	2728 ± 966	0.087
Total fat mass, % of total body mass†	101	17.22 ± 4.14	88	18.27 ± 5.24	0.15

BMI, body mass index; DEXA, dual-energy X-ray absorptiometry; MUAC, mid-upper arm circumference. *Normal distributed variables are presented as mean ± SD. Non-normal distributed variables are presented as median (interquartile range). Categorical variables are presented as frequencies (%). †Categorisation for this variable is based on the whole body scan including head. ‡P-values correspond to unpaired t-test (normal distributed variables), Kruskal–Wallis test (non-normal distributed variables) or chi-square test (categorical variables).

Total lean mass and muscle mass were most closely related to the weight of the child followed by height (Table 2). The correlation to WFA and HFA z-score was almost as high. Total fat mass was highly correlated with MUAC, sum of skinfolds, WFH and waist circumference. When these measures were expressed as percentage of total body mass or percentage of lean body mass, results were different. Apart from height and HFA, all anthropometric indices were significantly negatively correlated with lean mass expressed in percentage of total body mass. Muscle mass as a percentage of total lean mass was highly correlated with weight, MUAC and arm muscle area. Body fat as a percentage of total body mass was highly correlated with sum of skinfolds, the individual skinfolds and MUAC (Table 2).

Tables 3 and 4 summarise the performance of the five models as assessed using three different methods: adj. R^2, AIC and bootstrapped RMSE. Overall, the same conclusions could be drawn from each of the three methods. The full model (containing all of the anthropometric measurements) and the reduced model did the best for all measures of body composition. However, for total lean mass and muscle mass, the model containing log weight and log height could be considered best alternative model for assessing body composition, with the model containing MUAC and log weight achieving almost the same results. Also, for total fat mass, the model containing log weight and log height was the best alternative to the full and the reduced model (Table 3).

For total lean mass as a percentage of total body mass, the model containing log weight and log height gave the best alternative to the full and the reduced models. For muscle mass as a percentage of total lean mass, all of the three alternatives to the full and the reduced model performed equally well, while the

Table 2. Correlations between anthropometric measures and body composition indicators

	Total lean mass†	Total lean mass, % of total body mass†	Muscle mass	Muscle mass, % of total lean mass†	Total fat mass†	Total fat mass, % of total body mass†
MUAC	0.458***	–0.539***	0.558***	0.489***	0.735***	0.571***
Arm muscle area	0.588***	–0.279*	0.655***	0.479***	0.419***	0.228*
Weight	0.786***	–0.376***	0.813***	0.507***	0.636***	0.381**
Weight-for-age	0.709***	–0.446***	0.755***	0.483***	0.712***	0.486***
Height	0.724***	0.031	0.675***	0.266*	0.181	–0.036
Height-for-age	0.679***	–0.012	0.642***	0.254*	0.236*	0.046
Weight-for-height	0.437***	–0.532***	0.535***	0.437***	0.708***	0.539***
Triceps skinfold	0.053	–0.487***	0.080	0.163	0.651***	0.631***
Subscapular skinfold	0.015	–0.500***	0.047	0.072	0.590***	0.597***
Sum of skinfolds	0.022	–0.571***	0.053	0.134	0.712***	0.711***
Waist circumference	0.467***	–0.508***	0.522***	0.335**	0.709***	0.534***

MUAC, mid-upper arm circumference. *$P < 0.05$, **$P < 0.001$, ***$P < 0.0001$ (testing the hypothesis that the correlation could be 0). †Categorisation for this variable is based on the whole body scan including head.

Table 3. Model characteristics for each of 5 models for the absolute measures of body composition

	Total lean mass*			Muscle mass			Total fat mass		
	Adj. R^2	AIC	RMSE	Adj. R^2	AIC	RMSE	Adj. R^2	AIC	RMSE
Log weight, log height	0.77	1233.63	513.10	0.71	1311.07	259.60	0.71	1262.11	213.68
MUAC, log height	0.69	1262.33	596.38	0.63	1338.32	291.20	0.62	1293.37	243.39
MUAC, log weight	0.74	1247.65	549.64	0.69	1318.70	268.84	0.67	1276.07	226.61
MUAC, triceps skinfold, subscapular skinfold, waist circumference, log weight, log height	0.79	1227.36	508.86	0.74	1299.36	252.39	0.76	1243.98	203.89
Reduced model†	0.79	1223.92	488.90	0.74	1298.98	248.49	0.75	1243.98	200.48

MUAC, mid-upper arm circumference. *The presented characteristics are adjusted R^2, Akaike's information criterion (AIC) and bootstrapped root-mean-square error (RMSE). †Gender was included in all reduced models whether significant or not.

model containing MUAC and log height was the best alternative model for total fat mass as a percentage of total body mass (Table 4).

In Tables 5 and 6, the reduced models from Tables 3 and 4 are presented. We found that besides gender, a measure of the triceps skinfold together with weight and height gave the best model for total lean mass, while subscapular skinfold, waist circumference and weight gave the best model for muscle mass. For total fat mass, the remaining anthropometric measures were both measures of skinfold, weight and height (Table 5). Similar results were found for the relative measures. As for total lean mass, a measure of the triceps skinfold together with weight and height gave the best model for total lean mass as a percentage of total body mass. For total fat mass as a percentage of total body mass, the remaining anthropometric measures were again both measures of skinfold, weight and height. MUAC and subscapularis were the only two remaining anthropometric measures in the model for muscle mass as a percentage of total lean mass (Table 6).

As a next step, we determined the optimal power of height in the ratio of weight to height to assess muscle and fat mass. The optimal power of height for assessing the different body composition indicators is shown in Table 7. Weight and height models could be used to describe fat mass, absolute lean mass and lean

Table 4. Model characteristics for each of 5 models for the relative measures of body composition

	Total lean mass, % of total body mass*			Muscle mass, % of total lean mass			Total fat mass, % of total body mass		
	Adj. R^2	AIC	RMSE	Adj. R^2	AIC	RMSE	Adj. R^2	AIC	RMSE
Log weight, log height	0.46	247.81	3.53	0.25	67.77	1.43	0.52	210.14	2.95
MUAC, log height	0.40	258.08	3.71	0.25	68.20	1.43	0.56	202.86	2.83
MUAC, log weight	0.38	261.21	3.77	0.27	65.46	1.42	0.52	210.19	2.94
MUAC, triceps skinfold, subscapular skinfold, waist circumference, log weight, log height	0.51	241.55	3.50	0.34	58.89	1.41	0.66	179.53	2.56
Reduced model†	0.51	238.80	3.37	0.30	61.59	1.39	0.66	178.75	2.53

*The presented characteristics are adjusted R^2, Akaike's information criterion (AIC) and bootstrapped root-mean-square error (RMSE). †Gender was included in all reduced models whether significant or not.

Table 5. Reduced models from Table 3 with absolute measures found by stepwise backward model elimination from the full models

Total lean mass (g)				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	–39 772	7776.39	<0.0001	0
Gender (female)	–456.21	99.48	<0.0001	–0.22
Triceps skinfold (mm)	–108.86	31.69	0.0009	–0.19
Log weight (kg)	7 407.00	784.27	<0.0001	0.67
Log height (cm)	7 301.70	1979.82	0.0004	0.24
Muscle mass (g)				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	–6959.66	656.37	<0.0001	0
Gender (female)	–40.44	50.32	0.4232	–0.04
Subscapular skinfold (mm)	–74.02	19.83	0.0003	–0.21
Waist circumference (cm)	–34.08	15.20	0.0269	–0.19
Log weight (kg)	4881.25	398.91	<0.0001	1.02
Total fat mass (g)				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	7224.94	6258.00	0.2512	0
Gender (female)	350.92	80.60	<0.0001	0.24
Triceps skinfold (mm)	112.16	26.75	<0.0001	0.27
Subscapular skinfold (mm)	92.39	36.94	0.0141	0.17
Log weight (kg)	5431.91	643.17	<0.0001	0.69
Log height (cm)	–4682.45	1605.23	0.0044	–0.22

Pr, probability; SE, standard error.

mass as percentage of body mass, whereas no significant relation of height to muscle mass as a percentage of total lean mass was found (confidence interval includes 0).

Discussion

To our knowledge, this study is the first to examine the relationship between anthropometric indicators

Table 6. Reduced models from Table 4 with relative measures found by stepwise backward model elimination from the full models

Total lean mass, % of total body mass				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	−57.13	53.71	0.2901	0
Gender (female)	−3.06	0.69	<0.0001	−0.33
Triceps skinfold (mm)	−0.73	0.22	0.0013	−0.28
Log weight (kg)	−28.50	5.42	<0.0001	−0.58
Log height (cm)	49.29	13.67	0.0005	0.37
Muscle mass, % of total lean mass				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	17.26	2.36	<0.0001	0
Gender (female)	0.32	0.29	0.2622	0.10
MUAC (cm)	1.05	0.16	<0.0001	0.66
Subscapular skinfold (mm)	−0.37	0.12	0.0032	−0.32
Total fat mass, % of total body mass				
Variable	Estimate	SE	Pr > |t|	Standardised estimate
Intercept	91.63	41.09	0.0281	0
Gender (female)	2.40	0.53	<0.0001	0.29
Triceps skinfold (mm)	0.74	0.18	<0.0001	0.32
Subscapular skinfold (mm)	0.63	0.24	0.0105	0.21
Log weight (kg)	19.21	4.22	<0.0001	0.44
Log height (cm)	−30.73	10.54	0.0044	−0.26

MUAC, mid-upper arm circumference; Pr, probability; SE, standard error.

Table 7. The optimal power of height in the ratio of weight to height for assessing body composition

	Optimal power of height	95% confidence interval
Total lean mass	−1.60	(−1.91, −1.29)
Total lean mass, % of total body mass	1.74	(0.80, 2.68)
Muscle mass	−0.92	(−1.35, −0.49)
Muscle mass, % of total lean mass	0.39	(−0.79, 1.56)
Total fat mass	1.14	(0.61, 1.68)
Total fat mass, % of total body mass.	1.71	(0.83, 2.60)

and body composition, including muscle mass, in a representative sample of children under 4 years old. In a previous study, Brambilla *et al*. examined this relationship, but their analysis was based on an *ad hoc* non-representative sample including some overweight and some undernourished children (Brambilla *et al*. 2000). The age (3 years old) of the children in the present analysis is especially relevant both in relation to undernutrition in low-income countries where acute malnutrition may occur in this age group and in countries with high prevalence of obesity, where there is much emphasis on the early development of obesity.

Like others (Poortmans *et al*. 2005; Bridge *et al*. 2009), we used DEXA to assess body composition in the children. Compared with other methods like urinary creatinine or total body potassium, DEXA shows good precision. Mid-thigh muscle and fat mass assessed by DEXA and magnetic resonance imaging has been shown to be highly correlated, but with DEXA slightly underestimating both muscle and fat mass and discordance increasing with the level of the muscle and fat mass (Bridge et al. 2009). Compared with the four-compartment model (protein, body fat estimated by hydrodensitometry, total body water estimated by deuterium dilution and bone mineral values estimated by DEXA), DEXA has been shown to underestimate body fat in leaner individuals (Plank 2005). Also differences in measurements using different machines or softwares have been reported, with a potential influence on especially longitudinal and multicentre studies. DEXA is, however, importantly non-invasive with an extremely low radiation dose (Plank 2005) and only takes 5 min for a whole body scan of a child and is therefore appropriate for examining healthy children. Very few studies present DEXA scans in children below 4 years of age. Scanning young children is a challenge because it is very difficult to have them lying still for 5 min. This is also the explanation why a relatively large proportion of the scans in this study could not be used.

Our study is derived from a very homogenous population, and other studies will be needed to develop models applicable to children of different age categories and of different ethnic origins. Our study included children of the same age. As muscle mass in relation to body weight increases with age (World Health Organization 1985; Poortmans *et al.* 2005), its link with nutritional indices adjusted for age (or for height as a proxy of age) such as WFA or WFH could have been weaker, had our sample included a broader age group of children. In this regard, the Brambilla study included children of different ages, and its results suggested that WFA and WFH were poorly linked with appendicular muscle mass in relation to central lean mass (Brambilla *et al.* 2000). Our study included mainly children of European origin. As leg length, a determinant of appendicular lean mass that also influences WFH (Myatt *et al.* 2009), varies between different populations; our results may not be applicable to non-European populations.

Overall, our study suggests that anthropometric measures are more effective in measuring the absolute size of fat, lean and muscle mass than their relative size expressed in percentage of total body mass or of lean body mass (for muscle mass). This is already clear in the univariate analysis where all the correlation coefficients for the estimation of body fat and muscle mass are higher for all anthropometric indices (apart from skinfolds) when assessing these body compartments in absolute terms rather than in proportion of body weight or lean body mass. This is also confirmed by multivariate models.

In univariate analysis, lean body mass as a percentage of total body mass was negatively correlated with all indices with the exception of height and HFA. This presumably reflects that lean body mass and fat mass represent almost all body mass and are inversely related when expressed as percentage of total body mass, as mineral bone content constitutes a relatively small percentage of the total body mass for children of this age.

Our study also found that anthropometric indices are more valuable to assess the importance of fat mass in relation to total body mass than for assessing the importance of lean mass as a proportion of total body mass or muscle mass in proportion of lean body mass. Our results are consistent with the findings of a previous study using MUAC-based indicators to estimate body composition (Chomtho *et al.* 2006), but these results extend this finding to indices using weight and height that does not seem superior to MUAC to assess relative body composition.

For assessment of lean body mass and of fat mass, both in absolute value and in proportion of body weight, all the reduced multivariate models included weight, height, skinfold and gender. For absolute muscle mass, the best reduced model included weight, and, with a negative coefficient, waist circumference and subscapular skinfold. In contrast, the best reduced model estimating the proportion of muscle mass in lean body mass included only MUAC and subscapular skinfold.

Models based on weight and height ratios suggest quite different powers of height for different measures of body composition. The estimation of lean body mass and fat as a percentage of total body mass, gave a power of height of 1.74 and 1.71, respectively, not significantly different from the exponent 2 used for calculating BMI. Interestingly, a study in malnourished children treated in therapeutic feeding centres found that the best exponent of height to predict survival was 1.74 (Prudhon *et al.* 1996).

It is not clear whether the value of 2 would remain within the confidence interval of the power of height to estimate the proportion of fat in the body with a higher sample size and a narrower confidence interval for this coefficient. However, a power of 2 for height relates it to a surface area, and this makes this power plausible, considering that most body fat in these children were at the periphery of the body, at its surface.

In contrast, the power of height to estimate muscle mass as a percentage of total lean mass had a wide confidence interval, which included zero. This suggests that weight unadjusted for height might be just as good as a combination of weight and height to describe this indicator of body composition in a group of children of the same age.

For total lean mass as a percentage of total body mass and muscle mass as a percentage of total lean mass, the proportion of the variance explained by anthropometry remained below 55% in all models. For muscle mass as a proportion of total lean mass, the best models explained only 34% of the variance. This suggests that anthropometric indices imperfectly reflect these measures of body composition, although the link between anthropometry and body composition may be stronger in malnourished children (Chomtho *et al*. 2006). The limits of estimating body composition from anthropometric measures should be taken into consideration when examining functional implications and prognostic value of different anthropometric indices.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

SMJ analysed and interpreted the data and wrote the initial draft of the manuscript. AB provided the initial idea and assisted in interpreting the results. KFM and CM conceived and designed the study and assisted in interpreting the results. LBC and KTE participated in the data collection and assisted in the interpretation of results. All the co-authors participated in the manuscript preparation and critically reviewed all sections of the text for important intellectual content.

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