British Journal of Nutrition (2002), **87**, 163–175
DOI: 10.1079/BJN2001504

Inconsistencies in bioelectrical impedance and anthropometric measurements of fat mass in a field study of prepubertal children

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(Received 6 March 2001 – Revised 23 July 2001 – Accepted 5 October 2001)

The present study examined the consistency of bioelectrical impedance analysis (BIA) and anthropometric measurements in body composition analysis in a field study of prepubertal children using a representative group of 2286 5–7-year-old children from Kiel, north-west Germany. Body composition was assessed using anthropometric measures (A; four skinfolds) and BIA. Various published algorithms (according to Lohmann (1986) and Deurenberg *et al.* (1990) for A, Kushner *et al.* (1992), Schaefer *et al.* (1994) and Wabitsch *et al.* (1996) for BIA and Goran *et al.* (1996) for a combined approach) were used to estimate body composition. Using A resulted in a sum of four skinfolds varying between age-dependent median values of 24·0 and 28·2 mm in boys and 30·5 and 33·3 mm in girls. When fat mass (FM) was calculated from A, age- and algorithm-dependent differences in median values were observed, with values varying between 8·5 and 14·6 % for boys and 11·1 and 14·9 % for girls. Using different algorithms (Lohmann (1986) *v.* Deurenberg *et al.* (1990)) only minor inconsistencies were observed. BIA-derived resistance index (height^2/resistance) varied between 18·8 and 24·4 cm^2/Ω for boys and 17·1 and 19·0 cm^2/Ω for girls. Using four different algorithms to estimate FM from BIA data resulted in high intra-individual variances in percentage FM (from 13·8 to 33·4) as well as in the prevalence of overweight (from 14·7 to 98·4 % for boys and from 42·3 to 98·5 % for girls). Data obtained using the different BIA algorithms showed some, or even marked, inconsistencies as well as systematic deviations (an overestimation of FM at low percentage FM, Schaefer *et al.* (1994) *v.* Wabitsch *et al.* (1996)). When comparing BIA with A, BIA systematically overestimated FM. The differences between the results were influenced by BMI, gender and height. Considerable inconsistencies were observed at low BMI (<10th percentile) for girls and for small children. Although the within-observer as well as between-observer CV for both techniques are acceptable, we recommend caution in relation to the algorithms used for data analysis. The use of an interchange table of percentage FM derived from different algorithms for different percentile groups of skinfold thicknesses is recommended.

Fat mass: Anthropometry: Bioelectrical impedance: Overweight: Obesity: Children

There is no uniform definition and assessment for overweight and obesity in children. The validity of BMI as an index of fatness has been examined in children (Rolland-Cachera *et al.* 1991; Dietz, 1994; Cole *et al.* 2000), but its accuracy has been questioned (Robinson, 1993). In addition, the cut off-points varied considerably. Available data allow neither a meaningful international estimate of the prevalence of obesity nor international comparisons of data (Guillaume, 1999). In view of these limitations it has been suggested that assessment of nutritional state should also include an estimate of body fat (Schaefer *et al.* 1998).

There are different methods for assessing body composition in children: densitometry, 2H dilution, total body K, dual-energy X-ray absorptiometry (DXA), anthropometry and bioelectrical impedance analysis (BIA; Lohmann, 1986). Some of these methods are expensive, technically awkward and impractical for use in a field study. Skinfold measurements as well as BIA have been recommended for the assessment of fat mass (FM) in

Abbreviations: BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass; % FM, percentage fat mass; KOPS, Kiel Obesity Prevention Study.

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large populations of children (Cordain *et al.* 1988; Houtkooper *et al.* 1989; Kushner *et al.* 1992; Schaefer *et al.* 1994; Goran *et al.* 1996; Wabitsch *et al.* 1996). Both techniques show an acceptably low CV for repeated measurements of skinfold thickness and/or whole-body resistance. The accuracy of these field methods in terms of measurements of FM depends on an appropriate prediction equation. Currently, numerous algorithms are in use in children to predict percentage FM (% FM) from anthropometry and/or BIA measurements. For those authors who are involved in field studies it is unclear which prediction formulas are appropriate.

The Kiel Obesity Prevention Study (KOPS) is a cross-sectional and longitudinal field study (Müller *et al.* 1998, 2001). The objective of this study is to reduce the prevalence and incidence of overweight and obesity in children and adolescents. Within KOPS, anthropometry and BIA are used to assess FM. Both techniques have been validated against so-called reference methods (e.g. densitometry, DXA) in small populations of children of different ages (Lohmann, 1986; Cordain *et al.* 1988; Houtkooper *et al.* 1989; Deurenberg *et al.* 1990; Kushner *et al.* 1992; Schaefer *et al.* 1994; Goran *et al.* 1996; Wabitsch *et al.* 1996). However, there is only limited experience with regard to their use in field studies. The present study compares BIA and anthropometric measurements of body fat in a group of 2286 prepubertal children from Kiel, north-west Germany.

Methods

Subjects

Within KOPS between 1996 and 1998 six different investigators assessed the nutritional status of 1146 boys and 1140 girls aged 5–7 years living in Kiel, north-west Germany. Anthropometric and BIA measurements were conducted weekly in the first month and every 14 d during the following weeks. The children were randomly sampled and examined in twenty-nine of a total of thirty-two primary schools in Kiel. The 2286 children represented 40 % of the total population of children examined by the school physicians in the same time period. Age, gender, body weight and height, as well as socio-demographic data, suggested that this subpopulation was representative of the total population of 5–7-year-old children in Kiel (Mast *et al.* 1998). The procedures involved in the investigations were explained to all parents. All parents gave their informed written consent. The study protocol was approved by the local ethical committee of the Christian-Albrechts-University of Kiel.

Anthropometry

Anthropometric measurements were performed by six trained observers, according to standard procedures (Lohmann *et al.* 1988). Weight was measured to the nearest 0·1 kg using a calibrated balance-beam scale (Model 709; Seca Vogelt Halke, Hamburg, Germany) with subjects wearing light underwear only. Height was estimated to the nearest 5 mm. Skinfold thickness was determined to the nearest 0·2 mm at the right triceps, biceps, subscapular and suprailiac sites, using a Lafayette skinfold caliper (Model 01127; Lafayette Instrument Company, Lafayette, IN 47903, USA) calibrated to exert a constant pressure of 10 g/mm^2. The between-observer CV for measurements of right triceps, biceps subscapular and suprailiac skinfolds were 5·7, 8·0, 13·2 and 8·4 % respectively (*n* 15). The corresponding within-observer CV for repeated (*n* 3) measurements in 150 children aged 5–7 years were 4·2, 6·8, 5·1 and 5·3 %. FM was determined using age- and gender-specific formulas, according to Lohmann (1986) and Deurenberg *et al.* (1990), involving the log-transformed sum of right triceps, biceps, subscapular and suprailiac skinfolds for subjects aged <12·0 years (Table 1). In order to compare values derived from different methods, we used % FM from anthropometry according to Lohmann (1986) as an example.

In a subgroup of twelve children (eight boys, four girls) aged 6·3 years with BMI of 15·1 and 15·9 kg/m^2 for boys and girls respectively we examined the relationship between measurements of body proportions (i.e. lengths of arms and legs, elbow breadth and arm, waist and hip circumference) and resistance values.

Table 1. Algorithms used for estimating fat mass (FM) from anthropometric and bioelectrical impedance analysis data, as proposed by different authors

Anthropometry	
Lohmann (1986):	FM (kg) = weight × (5·28/D) − 4·86)
Deurenberg *et al.* (1990):	FM (%) = ((562 − 4·2 (age (years) − 2))/D − (525 − 4·7 (age (years) − 2)), where D is body density:
	boys, D (g/ml) = 1·690 − 0·0788 × (log (sum of four skinfolds))
	girls, D (g/ml) = 1·2063 − 0·0999 × (log (sum of four skinfolds))
Bioelectrical impedance analysis	
Kushner *et al.* (1992):	TBW (%) = 0·59 × RI + 0·065 × weight (kg) + 0·04
Schaefer *et al.* (1994):	FFM (Kg) = 0·15 + 0·65 × RI + 0·68 × age (years)
Wabitsch *et al.* (1996):	TBW (%) = 0·35 × RI + 0·27 × age (years) + 0·14 × weight (kg) − 0·12
Anthropometry and bioelectrical impedance analysis combined	
Goran *et al.* (1996):	FFM (kg) = (0·16 × RI) + (0·67 × weight (kg)) − (0·11 × TSF (mm)) − (0·16 × SSF (mm)) + (0·43 × gender*) + 2·41

RI, resistance index (height (cm) × height (cm))/resistance (Ω); TBW, total body water; FFM, fat-free mass (TBW/0·732); FM, weight − FFM; TSF, triceps skinfold thickness (mm); SSF, subscapular skinfold thickness (mm).
* Gender: male 1, female 2.

Table 2. Characteristics of reference studies on the algorithms for estimating fat mass from anthropometric and bioelectrical impedance analysis (BIA) data

	Anthropometry		BIA			Anthropometry and BIA combined
	Lohmann (1986)	Deurenberg *et al.* (1990)	Kushner *et al.* (1992)	Schaefer *et al.* (1994)	Wabitsch *et al.* (1996)	Goran *et al.* (1996)
Country	USA	NL	USA	Germany	Germany	USA
n	317	378	116	112	146	98
Age (years): Mean	12·4	13·8	16·7	11·8	12·7	6·6
Range	8·8–25·3	7·0–20·0	0·02–66	3·9–19·3	5·5–17·8	4·0–9·9
Weight (kg): Mean	51·4	51·2	39·4	42·8	74·1	24·1
Range	27·1–88·1	27·0–74·6	2·1–200	17·8–80·0	33·0–132·4	16·2–51·0
Reference method	Hydrodensitometry	Hydrodensitometry	^{2}H dilution	Total body K	^{2}H dilution	DXA
BIA instrument	–	–	101; RJL Systems, Detroit, MI, USA 0·8 mA, 50 kHz	Holtain Ltd,	101; RJL Systems 0·8 mA, 50 kHz	101; RJL Systems 0·8 mA, 50 kHz
r*	0·88	0·63	0·99	0·95 in girls 0·98 in boys	0·96	0·91

DXA, dual-energy X-ray absorptiometry.
*Correlation between sum of four skinfold thicknesses as well as fat-free mass (% Schaefer *et al.* (1994) and kg (Goran *et al.* 1996) or total body water (Kushner *et al.* 1992 and Wabitsch *et al.* 1996) *v.* reference data respectively.

Bioelectrical impedance analysis

Measurements of whole-body impedance in children have been described previously (Mast *et al.* 1998). Measurements were performed at a single frequency (50 kHz) with one pair of electrodes appropriately placed on the dorsal surfaces of the right hand and a second pair of electrodes placed on the right foot using Multi-Frequency-Analyzers (2000-M; Data Input GmbH, Frankfurt am Main, Germany; Müller, 1998). Three different analysers were cross-calibrated in ten children aged 5–7 years, including disconnected electrodes, and the difference in the measurements obtained using the different analysers was found to be <1 %. With the subjects lying in a supine position, measurements were performed while the hands and feet were extended at about 30° from the side of the trunk. The CV for repeated (*n* 3) estimates of resistance (Ω) and reactance (Ω) in ten children aged 5–7 years were 1·0 and 2·1 % respectively, resulting in a CV of 1·5 in % FM.

For data analysis different algorithms have been proposed for children. The prediction equations are based on resistance, height, weight, age and gender (Table 1 shows examples of algorithms). In addition, one algorithm also includes anthropometric measures in the calculation of fat-free mass (FFM) from BIA data (Goran *et al.* 1996). FM was calculated from the difference between body weight and FFM. Differences between the algorithms result from variations in age and weight in the reference population, as well as the use of different reference methods (Table 2). We assumed that the reference population studied by Schaefer *et al.* (1994) is very close to our study population (age and weight of reference population).

Statistical analyses

All analyses were performed using Excel 5.0 or SPSS for windows (SPSS Inc., Chicago, IL, USA). The data are presented as medians and interquartile ranges or as means and ranges of minimum to maximum. Basic statistics included *U* test for comparison between gender groups. Multiple regression analysis were used to assess the relationship between measurements of body proportions and resistance values. Simple linear correlation analyses were used to assess the relationship between the different methods for estimating FM. In addition to the standard procedure, a Bland & Altman (1986) plot was used to compare the differences between the two methods. A positive difference indicated an overestimation of % FM, whereas a negative difference suggested an underestimation of % FM.

Results

Table 3 shows anthropometric characteristics as well as BIA data for the KOPS population. There were significant gender differences in height, weight, skinfold thickness and impedance as well as the estimates of % FM. We found no gender differences in BMI. Using anthropometry, skinfold thicknesses were greater for girls than for boys (Table 3). For anthropometric measurements there were age-depen-

Table 3. Anthropometric and bioelectrical impedance analysis measurements in 2286 5–7-year-old boys and girls in Kiel, north-west Germany†

(Medians and interquartile ranges, with no. of subjects in parentheses)

	Children aged 5 years				Children aged 6 years				Children aged 7 years			
	Boys (23)		Girls (15)		Boys (765)		Girls (819)		Boys (357)		Girls (306)	
	Median	Interquartiles range	Median	Interquartiles range	Median	Interquartiles range	Median	Interquartiles range	Median	Interquartiles range	Median	Interquartiles range
Age (years)	5·02	0·2	5·5	0·2	6·1	0·4	6·1	0·4	6·7	0·2	6·6	0·2
Anthropometry												
Measurements												
Height (m)	1·20	0·1	1·17***	0·1	1·20	0·1	1·19***	0·1	1·23	0·1	1·22***	0·1
Weight (kg)	21·6	3·2	19·5**	8·2	22·3	4·5	22·0**	4·5	23·5	4·9	23·0**	4·6
BMI (kg/m^2)	14·8	1·4	14·5	2·9	15·5	2·0	15·6	2·1	15·6	2·0	15·5	1·9
Weight:hip	0·92	0·1	0·90***	0·1	0·91	0·1	0·89***	0·1	0·90	0·1	0·88***	0·1
TSF (mm)	9·0	3·2	12·0***	5·4	10·3	3·7	11·3***	4·6	9·8	4·3	11·6***	4·4
BSF (mm)	5·0	1·8	7·3***	5·5	5·6	3·4	6·3***	3·3	5·3	3·3	6·0***	3·6
SIF (mm)	5·3	2·8	7·6***	4·4	6·3	4·3	8·0***	5·4	6·0	4·4	7·6***	4·7
SSF (mm)	5·0	2·0	6·6***	3·2	5·6	2·4	6·3***	3·2	5·0	2·3	6·0***	3·0
Sum of four skinfolds (mm)	24·0	8·8	33·3***	20·7	28·2	12·1	31·7***	14·1	26·8	10·8	30·5***	14·1
Fat mass: %												
$FM_{Lohmann}$	12·0	5·9	14·9*	11·9	14·6	6·9	13·8*	8·9	13·8	6·5	13·1*	8·9
$FM_{Deurenberg}$	8·5	4·6	11·1	13·4	10·8	7·1	10·3	9·0	10·5	6·5	10·1	9·1
Kg												
$FM_{Lohmann}$	2·6	1·8	2·5*	3·0	3·2	2·0	3·0	2·5*	3·1	2·0	20·1*	3·1
$FM_{Deurenberg}$	1·7	1·4	1·9	3·0	2·4	1·9	2·2	2·3	2·4	1·9	2·2	2·4
Fat-free mass: %												
$FFM_{Lohmann}$	88·0	5·9	85·2	11·9	85·4	6·9	86·2	8·9	86·2	6·5	87·0	8·9
$FFM_{Deurenberg}$	91·5	4·6	89·0	13·4	89·2	7·1	89·7	9·0	89·5	6·5	89·9	9·1
Kg												
$FFM_{Lohmann}$	19·0	3·5	17·3	6·5	19·1	3·3	18·9	3·0	20·3	3·6	20·1	3·1
$FFM_{Deurenberg}$	20·0	3·7	17·7***	7·8	20·0	3·4	19·7***	3·1	21·0	3·8	20·9***	3·2

BIA												
Measurements												
R(Ω)	768	80·5	805***	87·3	749	101·9	788·4***	95·3	739	94·1	791	118·3
Xc(Ω)	68	6·0	73***	9·1	68·0	10·0	72·0***	12·9	67·1	11·2	72	12·0
Phase angle α	5·0	0·6	5·2	0·6	5·1	0·6	5·2	0·7	5·2	0·7	5·2	0·7
RI (cm^2/Ω)	18·8	2·9	17·1***	3·7	19·2	3·8	18·0***	2·2	20·4	3·7	19·0***	4·1
Fat mass: %												
$FM_{Schaefer}$	27·1	6·4	29·2***	15·4	25·4	8·2	27·6***	9·8	23·7	8·8	27·0***	8·5
$FM_{Kushner}$	20·3	6·9	25·2***	15·8	22·8	8·3	25·9***	9·5	22·0	9·0	26·0***	7·7
$FM_{Wabitsch}$	31·4	4·6	33·4***	10·2	30·8	5·4	32·5***	6·4	29·9	6·2	32·2***	5·6
FM_{Goran}	13·8	4·0	18·6***	6·3	15·8	4·7	19·3***	5·5	15·1	4·6	19·1***	4·9
Kg												
$FM_{Schaefer}$	5·9	1·4	5·0***	4·5	5·5	2·8	6·0***	3·3	5·4	2·9	6·1**	3·2
$FM_{Kushner}$	4·6	1·8	5·2***	4·0	4·9	2·4	5·6***	2·7	5·0	2·6	5·9***	2·5
$FM_{Wabitsch}$	6·9	1·1	5·8*	3·7	6·8	2·3	7·1*	2·6	6·9	2·3	7·3*	2·6
FM_{Goran}	2·9	1·1	3·8***	2·5	3·5	1·6	4·2***	1·9	3·5	1·5	4·4***	1·8
Fat-free mass: %												
$FFM_{Schaefer}$	72·9	6·4	70·8***	15·4	74·6	8·2	72·4	9·8	76·3	8·8	73·0***	8·5
$FFM_{Kushner}$	79·7	6·9	74·8***	15·8	77·2	8·3	74·1	9·5	78·0	9·0	74·0***	7·7
$FFM_{Wabitsch}$	68·6	4·6	66·6***	10·2	69·2	5·4	67·5	6·4	70·1	6·2	67·9***	5·6
FFM_{Goran}	86·3	4·0	81·4***	6·3	84·2	4·7	80·7	5·5	84·9	4·6	80·9***	4·9
Kg												
$FFM_{Schaefer}$	15·7	1·7	14·9***	2·4	16·7	2·6	16·0	2·1	18·0	2·5	17·0***	2·6
$FFM_{Kushner}$	17·1	2·6	15·3***	3·7	17·5	3·4	16·5	2·9	18·6	3·5	17·4***	3·5
$FFM_{Wabitsch}$	14·7	2·0	13·3*	3·3	15·6	2·3	15·0	2·4	16·6	2·7	15·9*	2·7
FFM_{Goran}	18·4	2·9	16·1***	5·9	18·8	3·1	17·7	3·0	20·1	3·5	18·9***	3·2

TSF, triceps skinfold thickness; BSF, biceps skinfold thickness; SIF, suprailiac skinfold thickness; SSF, subscapular skinfold thickness; $FM_{Lohmann}$, $FM_{Deurenberg}$; $FM_{Schaefer}$, $FM_{Kushner}$, $FM_{Wabitsch}$, FM_{Goran}, fat mass estimated based on algorithms proposed by Lohmann (1986), Deurenberg *et al.* (1990), Schaefer *et al.* (1994), Kushner *et al.* (1992), Wabitsch *et al.* (1996) and Goran *et al.* (1996) respectively (for details, see Tables 1 and 2); $FFM_{Lohmann}$, $FFM_{Deurenberg}$, $FFM_{Schaefer}$, $FFM_{Kushner}$, $FFM_{Wabitsch}$, FFM_{Goran}, fat-free mass estimated based on algorithms proposed by Lohmann (1986), Deurenberg *et al.* (1990), Schaefer *et al.* (1994), Kushner *et al.* (1992), Wabitsch *et al.* (1996) and Goran *et al.* (1996) respectively (for details, see Tables 1 and 2); R, resistance from BIA; Xc, reactance from BIA; RI, resistance index (height (cm) × height (cm))/R(Ω).

Median values were significantly different from those for boys: * $P\leq0·05$, *** $P\leq0·01$, *** $P\leq0·001$.

† For details of subjects and procedures, see p. 164.

https://doi.org/10.1079/BJN2001504 Published online by Cambridge University Press

Table 4. 10th, 50th, and 90th percentiles of anthropometric and bioelectrical impedance analysis(BIA) measurements as well as fat mass derived using both techniques for 6–7-year-old boys and girls from Kiel, north-west Germany

(Percentiles were not calculated for 5-year-old children because of the limited no. of children studied in this age-group)

Age group...	6 years old						7 years old					
	Boys			Girls			Boys			Girls		
n...	765			819			354			303		
Percentile...	10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th
Anthropometric measurements												
Height (m)	1·13	1·2	1·26	1·13	1·19	1·26	1·16	1·23	1·30	1·16	1·22	1·29
Weight (kg)	19·0	22·3	28·7	18·5	22·0	27·7	20·0	23·5	30·5	19·5	23·0	29·0
BMI (kg/m^2)	14·1	15·5	18·5	13·8	15·6	18·4	14·0	15·6	18·7	14·0	15·5	18·4
Weight:hip	0·83	0·91	0·97	0·82	0·89	0·96	0·83	0·90	0·96	0·80	0·88	0·95
TSF (mm)	7·3	10·3	15·3	8·0	11·3	16·3	6·8	9·8	15·0	8·0	11·6	15·6
BSF (mm)	3·3	5·6	10·3	4·0	6·3	11·0	3·0	5·3	10·2	3·6	6·0	10·6
SIF (mm)	3·8	6·3	14·0	4·3	8·0	15·3	3·6	6·0	14·2	4·3	7·6	15·0
SSF (mm)	4·0	5·6	9·9	4·0	6·3	10·7	3·4	5·0	9·0	4·0	6·0	10·7
Sum of four skinfolds (mm)	20·0	28·2	48·6	22·3	31·7	51·1	18·6	26·8	46·6	22·6	30·5	51·3
Fat mass: %												
$FM_{Lohmann}$	9·1	14·6	23·6	6·8	13·8	23·8	8·0	13·8	22·9	7·0	13·1	23·9
$FM_{Deurenberg}$	5·2	10·8	20·2	3·7	10·3	20·4	4·7	10·5	19·8	3·9	10·1	20·9
kg												
$FM_{Lohmann}$	1·9	3·2	6·3	1·3	3·0	6·3	1·7	3·1	6·9	1·4	2·9	7·0
$FM_{Deurenberg}$	1·1	2·4	5·4	0·8	2·2	5·3	1·0	2·4	5·9	0·8	2·2	6·2
Fat-free mass: %												
$FFM_{Lohmann}$	76·5	85·4	90·9	76·2	86·2	93·3	77·1	86·2	92·1	76·1	87·0	93·0
$FFM_{Deurenberg}$	79·8	89·2	94·8	79·6	89·7	96·3	80·2	89·5	95·3	79·2	89·9	96·1
kg												
$FFM_{Lohmann}$	16·3	19·1	22·8	16·3	18·9	22·1	17·6	20·3	23·9	17·3	20·1	23·5
$FFM_{Deurenberg}$	17·1	20·0	23·7	17·0	19·7	23·1	18·2	21·0	24·8	18·2	20·9	24·4

BIA												
R (Ω)	660·3	749	850	702·9	788·4	900·8	653·6	739	831·1	695·4	791·0	888·8
Xc (Ω)	58	68	79·7	61	72	85	58	67·1	78·7	61·8	72	84·9
Phase angle α	4·6	5·1	5·9	4·5	5·2	5·9	4·5	5·2	6·0	4·6	5·2	6·1
RI (cm^2/Ω)	15·6	19·2	23·2	14·9	18·0	21·3	16·9	20·4	24·8	15·7	19·0	22·8
Fat mass: %												
$FM_{Schaefer}$	17·5	25·3	35·6	19·3	27·6	37·9	16·5	23·7	34·5	19·4	27·0	37·0
$FM_{Kushner}$	14·3	22·8	31·7	17·4	25·9	34·6	13·7	22·0	30·4	17·7	26·0	33·9
$FM_{Wabitsch}$	25·5	30·8	37·6	26·8	32·5	39·2	24·7	29·9	36·6	26·8	32·2	38·8
FM_{Goran}	11·9	15·8	22·2	15·2	19·3	25·6	11·5	15·1	21·5	15·0	19·1	24·9
kg												
$FM_{Schaefer}$	3·4	5·5	10·0	3·7	6·0	10·4	3·4	5·4	10·1	3·9	6·1	11·0
$FM_{Kushner}$	3·0	4·9	8·4	3·5	5·6	9·1	3·1	5·0	8·6	3·8	5·9	9·5
$FM_{Wabitsch}$	5·1	6·8	10·5	5·2	7·1	10·8	5·2	6·9	11·0	5·4	7·3	11·4
FM_{Goran}	2·4	3·5	6·2	2·9	4·2	6·8	2·4	3·6	6·4	3·2	4·4	7·0
Fat-free mass: %												
$FM_{Schaefer}$	64·3	74·6	82·4	62·1	72·4	80·7	65·5	76·3	83·5	63·0	73·0	80·6
$FM_{Kushner}$	68·3	77·2	85·6	65·4	74·1	82·7	69·6	78·0	86·3	66·2	74·0	82·3
$FM_{Wabitsch}$	62·4	69·2	74·4	60·8	67·5	73·2	63·4	70·1	75·3	61·2	67·9	73·2
FM_{Goran}	77·8	84·2	88·1	74·4	80·7	84·8	78·6	84·9	88·5	75·2	80·9	85·0
kg												
$FFM_{Schaefer}$	14·5	16·7	19·4	14·0	16·0	18·2	15·7	18·0	20·8	14·9	17·0	19·6
$FFM_{Kushner}$	14·4	17·5	21·3	13·8	16·5	19·5	15·5	18·6	22·6	14·4	17·4	20·9
$FFM_{Wabitsch}$	13·3	15·6	18·6	12·8	15·0	17·4	14·3	16·7	19·7	13·5	15·9	18·6
FFM_{Goran}	16·2	18·8	22·8	15·2	17·7	21·2	17·3	20·1	23·8	16·0	18·9	22·5

TSF, triceps skinfold thickness; BSF, biceps skinfold thickness; SIF, suprailiac skinfold thickness; SSF, subscapular skinfold thickness; R: resistance (Ω); Xc: reactance (Ω); RI, resistance index ((height (cm) × height (cm)/resistance(Ω)); $FFM_{Lohmann}$, $FM_{Deurenberg}$, $FM_{Schaefer}$, $FM_{Kushner}$, $FM_{Wabitsch}$, FM_{Goran}, fat mass estimated based on algorithms proposed by Lohmann (1986), Deurenberg *et al.* (1990), Schaefer *et al.* (1994), Kushner *et al.* (1992), Wabitsch *et al.* (1996) and Goran *et al.* (1996) respectively (for details, see Tables 1 and 2); $FFM_{Lohmann}$, $FFM_{Deurenberg}$, $FFM_{Schaefer}$, $FFM_{Kushner}$, $FFM_{Wabitsch}$, FFM_{Goran}, fat-free mass estimated based on algorithms proposed by Lohmann (1986), Deurenberg *et al.* (1990), Schaefer *et al.* (1994), Kushner *et al.* (1992), Wabitsch *et al.* (1996) and Goran *et al.* (1996) respectively (for details, see Tables 1 and 2).

https://doi.org/10.1079/BJN2001504 Published online by Cambridge University Press

dent variations in the estimates of % FM: 12·0–14·6 for boys and 13·1–14·9 for girls according to Lohmann (1986); 8·5–10·8 for boys and 10·1–11·1 for girls according to Deurenberg *et al.* (1990). However, when values for % FM estimated according to these authors were compared, high values for r (0·99) were obtained for both genders.

For BIA the use of different equations to estimate % FM resulted in different median values for % FM, varying from 13·8 to 31·4 for boys and from 18·6 to 33·4 for girls (Table 3). When compared with the 90th percentile of anthropometrically-derived % FM (according to Deurenberg *et al.* (1990), for example, mean cut-off point for % FM ≥ 20) the prevalences of overweight varied between 14·7 and 42·3 % (calculated according to Goran *et al.* 1996) and up to 98·4 and 98·5 % (calculated according to Wabitsch *et al.* 1996) for boys and girls respectively. The influence of different algorithms was also reflected in differences in the 10th, 50th and 90th percentiles of FM and FFM on both % and kg basis (Table 4).

% FM derived from anthropometry calculated according to Lohmann (1986) and Deurenberg *et al.* (1990) showed a high consistency in the data (Fig. 1(a and b)). However, when % FM values derived from BIA and calculated according to the different published algorithms were compared there were some inconsistencies in the data

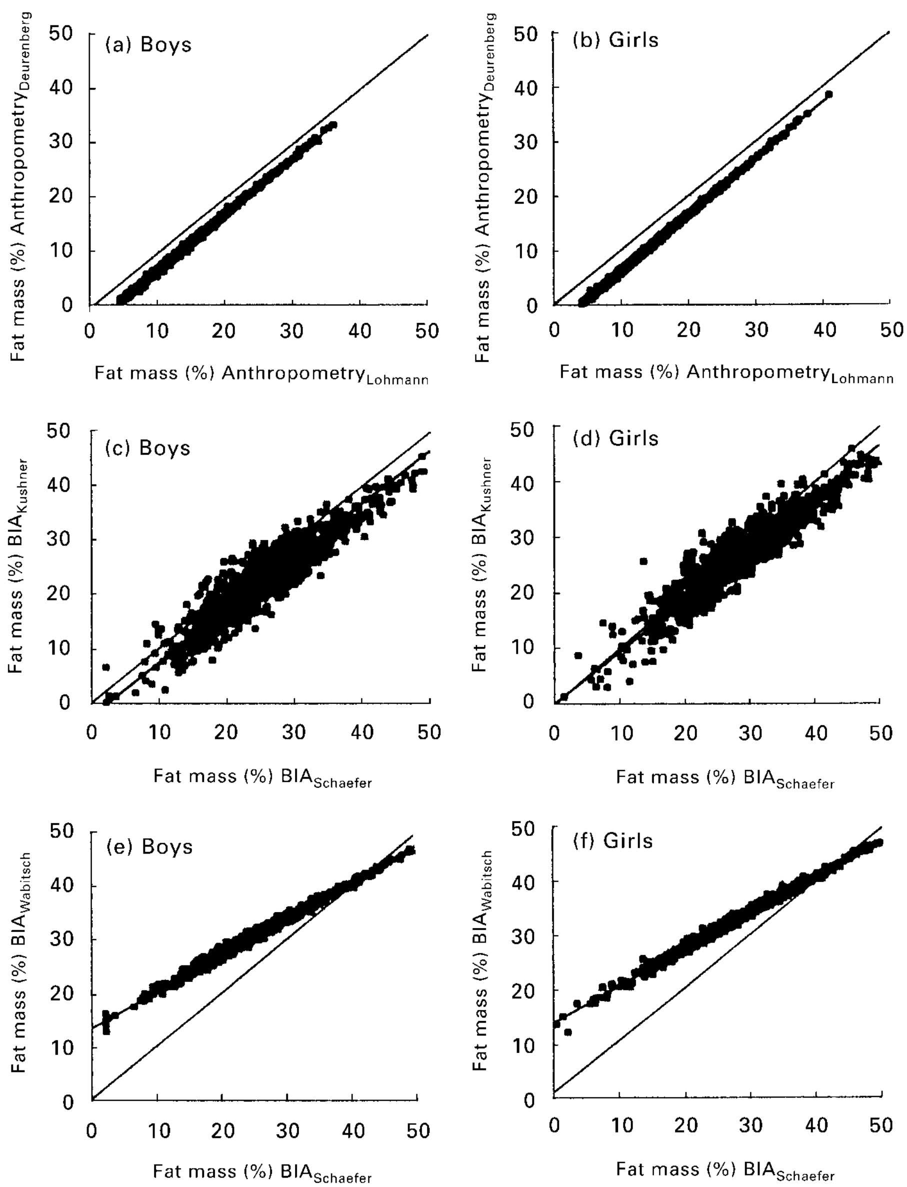

Fig. 1. Comparison of estimates of fat mass: (a, b), derived from anthropometric measurements according to Lohmann (1986) and Deurenberg *et al.* 1990; Anthropometry$_{Lohmann}$ and Anthropometry$_{Deurenberg}$ respectively); (c–f), derived from bioelectrical impedance analysis (BIA) according to Schaefer *et al.* (1994), Kushner *et al.* (1992) and Wabitsch *et al.* (1996; BIA$_{Schaefer}$, BIA$_{Kushner}$ and BIA$_{Wabitsch}$ respectively) in 2286 5–7-year-old boys (a,c,e) and girls (b,d,f) from Kiel, north-west Germany. For details of subjects and procedures, see p. 164 and Tables 1 and 2. Regression equations: (a) $y = 1{\cdot}0302x - 4{\cdot}1332$, R^2 0·9977; (b) $y = 1{\cdot}0301x - 4{\cdot}1464$, R^2 0·9987; (c) $y = 0{\cdot}9698x - 2{\cdot}2496$, R^2 0·8836; (d) $y = 0{\cdot}9261x + 0{\cdot}551$, R^2 0·8839; (e) $y = 0{\cdot}6813x + 13{\cdot}51$, R^2 0·9895; (f) $y = 0{\cdot}6724x + 13{\cdot}982$, R^2 0·99.

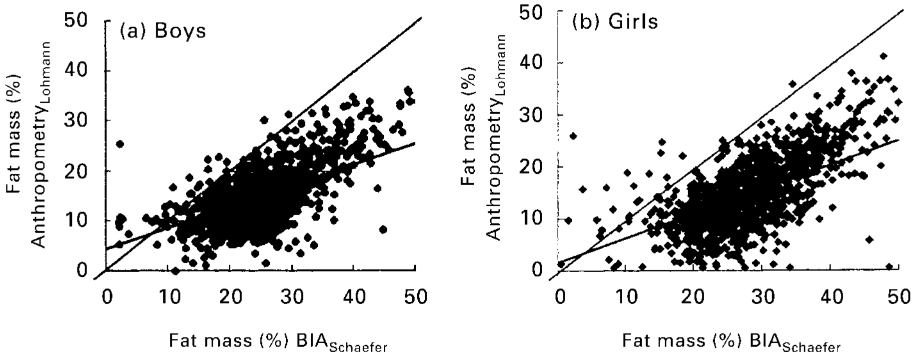

Fig. 2. Comparison of estimates of fat mass from bioelectrical impedance analysis data (data analysis according to Schaefer *et al.* (1994); BIA$_{\text{Schaefer}}$) and skinfold measurements (data analysis according to Lohmann (1986); Anthropometry$_{\text{Lohmann}}$) in 2286 5–7-year-old boys (a) and girls (b) from Kiel, north-west Germany. For details of subjects and procedures, see p. 164 and Tables 1 and 2. Regression equations: (a) $y = 0{\cdot}4219x + 4{\cdot}3424$, R^2 0·3681; (b) $y = 0{\cdot}4681x + 1{\cdot}5817$, R^2 0·3418.

(Fig. 1(c–f)). When compared with data calculated from the algorithm of Schaefer *et al.* (1994), the Kushner *et al.* (1992) algorithm underestimated % FM (Fig. 1(c and d)). By contrast, the algorithm proposed by Wabitsch *et al.* (1996) overestimated % FM when compared with the data derived from the algorithm of Schaefer *et al.* (1994) at low and normal % FM, but showed some underestimation at high % FM (Fig. 1(e and f)). % FM derived from BIA calculated according to Schaefer *et al.* (1994) correlated with % FM derived from anthropometry according to Lohmann (1986) (Fig. 2 (a and b)), as well as with % FM as derived from the equation of Goran *et al.* (1996) (Fig. 3 (a and b)). A Bland & Altman (1986) plot showed that % FM according to Schaefer *et al.* (1994) overestimated % FM according to Lohmann (1986) at normal and high % FM. By contrast % FM according to Schaefer *et al.* (1994) underestimated % FM according to Lohmann (1986) at low % FM (Fig. 4(a and b)). Calculating the data according to Goran *et al.* (1996) showed some overestimation at high % FM and underestimation at low % FM (Fig. 5(a and b)).

There was no correlation between skinfold measurements and resistance score (sum of four skinfolds *v.* resistance index; r 0·13 for both genders) as well as % FFM from anthropometry derived according to Lohmann (1986) and resistance score (% FFM from anthropometry derived according to Lohmann (1986) *v.* resistance index; r 0·1 for both genders). By contrast there was a significant relationship between the resistance score and kg FFM derived from anthropometric data (r 0·7 for boys and r 0·5 for girls).

The differences between % FM derived from anthropometry and BIA are influenced by BMI and height as well as gender. Comparing the differences in % FM at different BMI the closest association was found in boys and girls within the >10th and <90th BMI percentile (Table 5). In this group the correlation was higher for girls than for boys. The lowest correlation was for children who were below the 10th BMI percentile. The correlation was also lower in children who were above the 90th BMI percentile than in children with a normal BMI. The correlation between the two measures (anthropometry and BIA) of % FM was higher in boys than in girls (see data for >90th BMI percentile as well as <10th BMI percentile, Table 5). Height also affected the association between % FM derived from either the anthropometric or BIA data; the closest correlation was seen for boys who are >90th percentile for height. Within the 10th and 90th height percentiles the correlation was higher for boys than for girls. The lowest correlation was clearly in small children (height <10th percentile, Table 5).

Body proportions may also have an impact on algorithms.

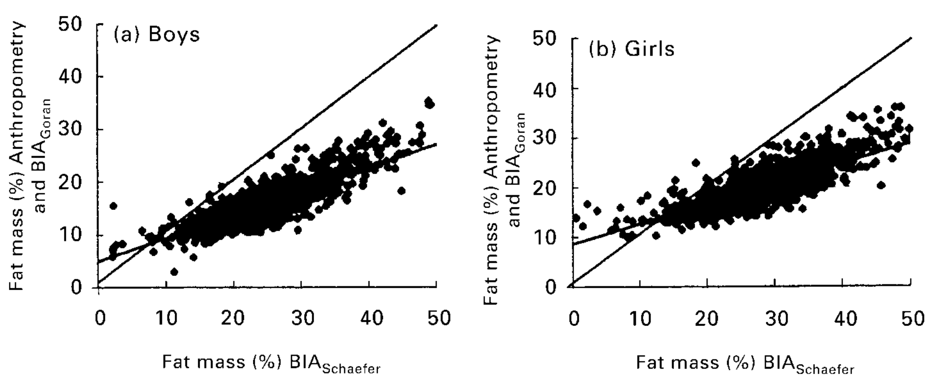

Fig. 3. Comparison of estimates of fat mass from bioelectrical impedance analysis data (data analysis according to Schaefer *et al.* (1994); BIA$_{\text{Schaefer}}$) and skinfold measurements and bioelectrical impedance analysis data (data analysis according to Goran *et al.* (1996); Anthropometry and BIA$_{\text{Goran}}$) in 2286 5–7-year-old boys (a) and girls (b) from Kiel, north-west Germany. For details subjects and procedures see p. 164 and Tables 1 and 2. Regression equations: (a) $y = 0{\cdot}4413x + 4{\cdot}9579$, R^2 0·7218; (b) $y = 0{\cdot}4024x + 8{\cdot}6231$; R^2 0·6512.

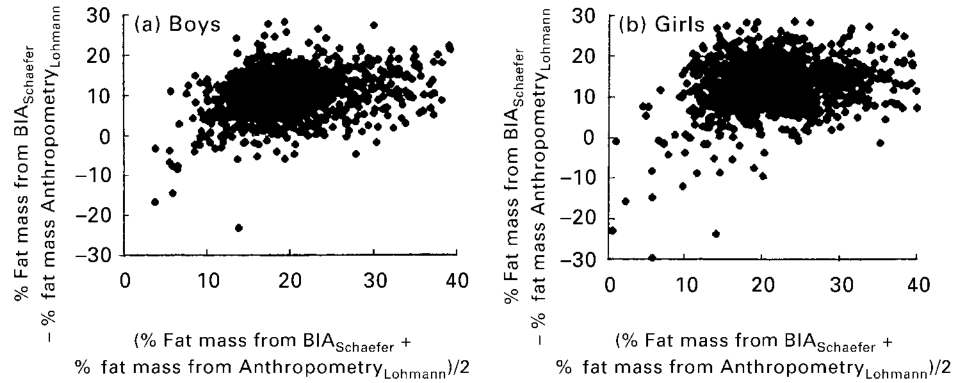

Fig. 4. Comparison of estimates of fat mass from bioelectrical impedance analysis data (data analysis according to Schaefer *et al.* (1994); $BIA_{Schaefer}$) and skinfold measurements (data analysis according to Lohmann (1986); $Anthropometry_{Lohmann}$) in 2286 5–7-year-old boys (a) and girls (b) from Kiel, north-west Germany in a Bland & Altman (1986) plot. For details of subjects and procedures, see p. 164 and Tables 1 and 2.

However, we did not find an association between resistance values and anthropometric data and lower and upper extremity length, limb circumferences and elbow breadth in a well-matched and anthropometrically characterized subgroup of twelve children (data not shown).

Discussion

BMI can be easily obtained and is generally accepted as an index of overweight and obesity in adults. However, in children and adolescents interpretation of BMI data is only possible when the age-dependent distribution is known, because BMI shows developmental variation (Hebebrand *et al.* 1994; Reilly *et al.* 1996). Several authors recommend assessment of body composition and the use of more accurate estimates of body fat as an index of overweight and obesity in children (Robinson, 1993; Schaefer *et al.* 1998). In field studies only simple methods can be used for body composition analysis. However, the consistency of these methods in children has not been proven in a field study.

The essential finding of the present study is that in a field study on 5–7-year-old children anthropometric and BIA measurements provide inconsistent data and result in very different estimates of % FM within the same population. These discrepancies are in part due to the algorithms used to calculate body composition from skinfold thickness and/or resistance. The published algorithms for estimating FM are related to the reference populations studied as well as the method used for validation (Table 2). There are considerable differences in relation to the reference populations as well as the reference methods (Table 2). Strictly speaking an algorithm is only valid for the reference population group from which it is derived. Thus, differences between the study population and the reference population affect the consistency of the results. With regard to the KOPS data, the reference population studied by Schaefer *et al.* (1994) is very similar to our study population. Both Schaefer *et al.* (1994) and Wabitsch *et al.* (1996) assessed German children, but Wabitsch *et al.* (1996) studied obese children. Although estimates of % FM obtained by BIA as well as by skinfold measurements have been shown to be highly correlated with data obtained by more sophisticated reference methods (Table 2), the different procedures involved in the calculations result in marked differences in % FM in our study population (Tables 3 and 4). Intra-individual comparison of the data obtained by the two techniques shows high correlation

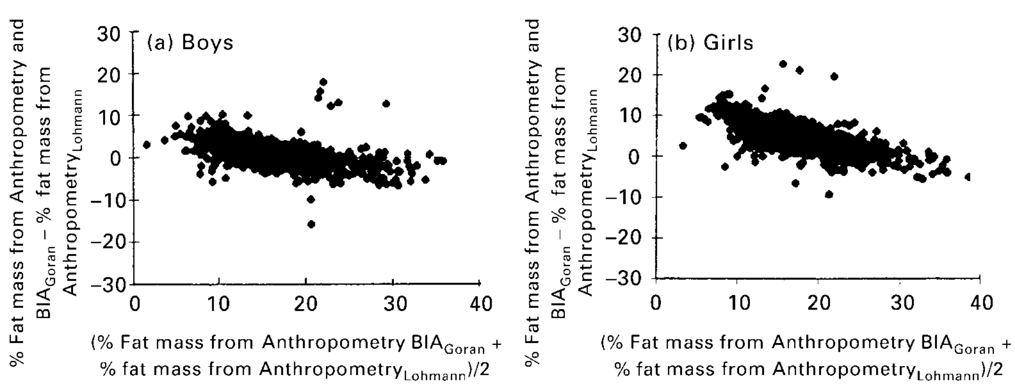

Fig. 5. Comparison of estimates of percentage fat mass from anthropometry and bioelectrical impedance analysis data (data analysis according to Goran *et al.* (1996); Anthropometry and BIA_{Goran}) and skinfold measurements (data analysis according to Lohmann (1986); $Anthropometry_{Lohmann}$) in 2286 5–7-year-old boys (a) and girls (b) from Kiel, north-west Germany in a Bland & Altman (1986) plot. For details of subjects and procedures, see Tables 1 and 2.

Table 5. Correlation between measurements derived by anthropometry *v.* bioelectrical impedance analysis (BIA) as calculated using different equations for 6-year-old children from Kiel, north-west Germany in different groups of BMI and height

	BMI						Height					
Percentile…	≤10th		>10th and <90th		≥90th		≤10th		>10th and <90th		≥90th	
	Boys (*n* 74)	Girls (*n* 82)	Boys (*n* 613)	Girls (*n* 652)	Boys (*n* 78)	Girls (*n* 85)	Boys (*n* 97)	Girls (*n* 117)	Boys (*n* 569)	Girls (*n* 620)	Boys (*n* 99)	Girls (*n* 82)
TSF (mm) *v.* RI (cm^2/Ω)	0·15	0·06	0·12	0·09	0·13	0·14	0·05	0·18	0·17	0·20	0·26	0·23
Σ 4 SF (mm) *v.* RI (cm^2/Ω)	0	0·08	0·04	0·07	0·12	0·12	0·16	0·20	0·20	0·19	0·30	0·27
% $FFM_{Lohmann}$ *v.* RI (cm^2/Ω)	0	0·08	0	0·07	0·15	0·14	0·12	0·20	0·17	0·18	0·34	0·28
kg $FFM_{Lohmann}$ *v.* RI (cm^2/Ω)	0·87	0·36	0·72	0·72	0·39	0·41	0·45	0·39	0·57	0·60	0·60	0·56
% $FM_{Lohmann}$ *v.* % $FM_{Kushner}$	0·20	0·02	0·31	0·43	0·29	0·13	0·41	0·25	0·52	0·54	0·63	0·50
% $FM_{Lohmann}$ *v.* % $FM_{Schaefer}$	0·27	0·06	0·42	0·53	0·39	0·22	0·49	0·35	0·53	0·63	0·71	0·63
% $FM_{Lohmann}$ *v.* % $FM_{Wabitsch}$	0·25	0·04	0·39	0·50	0·52	0·19	0·47	0·32	0·50	0·61	0·69	0·60

TSF, triceps skinfold thickness; Σ 4 SF, sum of triceps, biceps, suprailiac and subscapular skinfold thickness; RI, resistance index ((height (cm) × height (cm))/resistance(Ω)); % $FFM_{Lohmann}$, kg $FFM_{Lohmann}$ percentage and kg fat-free mass from anthropometry according to Lohmann (1986) % $FM_{Lohmann}$, percentage fat mass from anthropometry according to Lohmann (1986);; % $FM_{Kushner}$, percentage fat mass from BIA according to Kushner *et al.* (1992); % $FM_{Schaefer}$, percentage fat mass from BIA according to Schaefer *et al.* (1994); % $FM_{Wabitsch}$, percentage fat mass from BIA according to Wabitsch *et al.* (1996).

(Fig. 1(a–f)), but also some systematic over- or under-estimations of % FM in children (Figs. 2–5). For example, one boy aged 6·2 years with 7·5 % FM derived from BIA according to Schaefer *et al.* (1994) had a corresponding value of 18·7 when derived according to Wabitsch *et al.* (1996). This finding points to a more general problem when comparing % FM data from different studies using the same method but different algorithms. To compare the results of many different studies we recommend the use of an interchange table. Table 6 shows the corresponding % FM derived from different methods and different algorithms for different percentiles of the sum of four skinfold thicknesses.

Our results agree with those of previous investigations involving smaller samples of children. Reilly *et al.* (1996) investigated ninety-eight healthy children to test the ability of four published equations to accurately estimate FFM from BIA in a group of prepubertal children in the UK. The authors found an overestimation, but also an under-estimation, of FFM using different algorithms. Ellis (1996) investigated ninety-nine healthy children. The objective of the study was to determine the consistency of body fat measurements using four techniques for measuring body composition: BIA; bioelectrical impedance spectroscopy; total body electrical conductivity; DXA. A Bland & Altman (1986) plot indicated differences in body fat values between methods, ranging from −0·30 (SD 6·7) kg to 4·2 (SD 2·7) kg. Differences in percentage fat ranged from 0·8 (SD 3·5) to −9·9 (SD 5·2). These data suggest that classification of an individual as normal, overweight or obese was dependent on the method (Ellis, 1996). This finding is in line with our data showing that estimates of % FM in children are dependent on the method and the algorithm.

In a previous study we investigated 316 boys and 294 girls aged 5–7 years in Kiel (Mast *et al.* 1998). Calculating percentage fat from skinfold measurements according to Lohmann (1986) resulted in a lower estimate of % FM (15·5 for boys and 13·6 for girls) than data calculated from BIA measurements (17·9 for boys and 18·6 for girls; Mast *et al.* 1998). The ‘Chemical immaturity’ and body proportions of children could explain the observed inconsistency in the estimates of % FM. Using BIA data FM is indirectly assessed from: (1) total body water; (2) calculated FFM based on the assumption of a constant composition of FFM; (3) the difference between body weight and FFM. However, FFM does not have a constant composition in children, but shows systematic variations during development (Fomon *et al.* 1982; Lohmann, 1986). Malina & Bouchard (1991) have estimated the composition of FFM during growth, and found a water content of 76·6 % for boys and 77·6 % for girls for children aged 5–7 years. These values exceed FFM hydration of about 73 % observed in adults. It has been suggested also that there is a high inter-individual variability in FFM composition of children of a similar age (Malina & Bouchard, 1991). Comparing % FM calculated from BIA data based on the assumption that the water content of FFM of 76·6 % (boys) or 77·6 % (girls) instead of 73·2 % results in higher % FM (i.e. for boys and girls respectively the median of % FM calculated from BIA according to Kushner *et al.* (1992)

Table 6. Values for percentage fat mass (% FM; as derived from different algorithms) and the population-specific percentiles of the sum of four skinfold thicknesses Σ 4 SF for 5–7-year-old children from Kiel, north-west Germany

Percentile of Σ 4 SF*	Gender	*n*	% $FM_{Lohmann}$ Mean	% $FM_{Lohmann}$ Min–Max	% $FM_{Deurenberg}$ Mean	% $FM_{Deurenberg}$ Min–Max	% $FM_{Schaefer}$ Mean	% $FM_{Schaefer}$ Min–Max	% $FM_{Kushner}$ Mean	% $FM_{Kushner}$ Min–Max	% $FM_{Wabitsch}$ Mean	% $FM_{Wabitsch}$ Min–Max	% FM_{Goran} Mean	% FM_{Goran} Min–Max
≤10th	Boys	113	6·5	0·1–8·5	3·1	0·6–5·7	20·6	2·2–44·8	18·7	1·4–40·0	27·7	14·1–43·8	11·4	3·1–18·2
	Girls	110	4·2	0·5–6·7	1·5	0·2–3·4	23·1	0·5–75·4	23·1	5·8–90·1	29·5	2·4–68·9	15·1	4·5–36·0
10th–90th	Boys	918	14·6	8·5–23·1	10·9	4·2–20·0	24·8	2·1–81·0	22·1	0·2–90·4	30·4	8·8–71·6	15·7	5·9–35·6
	Girls	915	14·2	6·7–23·9	10·4	2·6–20·9	27·2	1·5–76·8	25·4	1·3–90·8	32·2	1·7–69·5	19·4	7·3–31·8
≥90th	Boys	115	27·5	23·2–36·3	24·3	19·8–33·2	37·9	2·3–53·8	32·5	13·7–49·7	38·5	4·0–49·4	25·0	12·7–35·3
	Girls	115	27·9	24·0–41·1	24·6	20·3–38·4	38·6	2·2–54·5	34·4	13·2–48·5	39·6	12·1–50·2	27·6	16·7–36·0
≥95th	Boys	58	30·3	26·9–36·3	27·1	23·6–33·2	41·2	25·6–53·8	35·0	16·2–49·7	40·4	4·0–49·4	27·3	12·7–35·3
	Girls	58	30·7	26·6–41·1	27·5	23·4–38·4	41·9	29·8–54·5	37·0	25·5–48·5	41·8	33·7–50·2	29·8	23·9–36·0

% $FM_{Lohmann}$, % $FM_{Deurenberg}$, % $FM_{Schaefer}$, % $FM_{Kushner}$, % $FM_{Wabitsch}$, % FM_{Goran}, percentage fat mass estimated based on algorithms proposed by Lohmann (1986), Deurenberg *et al.* (1990), Schaefer *et al.* (1994), Kushner *et al.* (1992), Wabitsch *et al.* (1996) and Goran *et al.* (1996) respectively (for details, see Tables 1 and 2).
* Sum of triceps, biceps, suprailiac and subscapular skinfold thickness.

was 25·9 and 30·1 instead of 22·4 and 26·0, while the median of % FM from BIA according to Wabitsch *et al.* (1996) was 33·6 and 36·2 instead of 30·5 and 32·4.

In addition to hydration of FFM, the geometric proportions of children may also differ (i.e. a greater proportion of body mass and body water is accounted for by the trunk relative to the extremities). This factor may have an impact, since the trunk only makes a minor contribution to total body impedance (National Institutes of Health, 1996). Using standard equations the body proportions of children would tend to result in an overestimation of % FM. However, investigating several variables (i.e. lengths of arms and legs, elbow breadth and arm, waist and hip circumferences) of twelve children we did not find that different body proportions had an impact on the variance in impedance data (data not shown).

The differences between the methods of assessing % FM are influenced by BMI as well as height. Comparing the differences in % FM at different BMI the best correlation was found in boys and girls at normal BMI (i.e. within >10th and <90th BMI percentile group). In contrast, there was a poor correlation in children below the 10th BMI percentile (Table 5). Height also influences the relationship between % FM from anthropometry and BIA data: the closest correlation was seen for boys with a height above the 90th percentile. By contrast the lowest correlation was found in short children (Table 5).

When establishing the validity of a method or an algorithm for estimating % FM a reference method (i.e. a 'gold standard') is necessary. In general, we do not feel that we presently have a true 'gold standard' for the measurements of body composition in children. All methods used to date give method- and algorithm-specific estimates of percentage FFM and % FM. They are based on a considerable number of assumptions. In adults densitometry or DXA have been most commonly used as reference methods. In Kiel DXA measurements in children are not permitted for ethical reasons (because of radiation exposure). In addition, densitometry as well as DXA cannot be applied in a school setting. Thus, as in many other field studies we have to use standard techniques (anthropometry and BIA) and published algorithms. Using BIA we found that the different algorithms are inappropriate in the assessment of FM in prepubertal children (e.g. Tables 3 and 4). Standard techniques as well as algorithms have to be used with caution. We feel that anthropometric as well as BIA measurements are accurate and reproducible, but at present the body composition data can only be used as method- and algorithm-specific values. Kraemer *et al.* (1990) have suggested five criteria for choosing a measure of adiposity. These criteria include: (a) accessibility, including characteristics such as cost, convenience, ease of use and acceptability to patients; (b) individuality, referring to independence from a population reference standard; (c) reliability, minimizing measurements error; (d) measurement validity; (e) clinical validity or the ability to predict morbidity and mortality. The present results show that BIA and skinfold measurements perform most of the criteria (a, c, d) but cannot achieve independence from a population reference standard. In the case of a population of children its clinical validity as well as its ability to predict morbidity and mortality are unproven. Although the measurement error can be minimized, the measurement and validity of the data remain unclear.

Conclusion

There are inconsistencies between and within anthropometric- and BIA-derived assessments of body composition in children. If anthropometry and/or BIA are used to assess FM in a field study in children we recommend caution with regard to the use of equations derived from the literature. When the results derived from different prediction formulas are compared, there are systematic over- or underestimations of % FM in children. Combining BIA and anthropometric data cannot totally exclude this error. We conclude that development of a specific algorithm derived within the study population and validated against a so-called 'gold-standard' (i.e. densitometry) is preferable. If this approach is not possible, we suggest that the methods should be considered for what they directly provide (i.e. skinfold thickness and/or impedance scores). If BIA is used in field studies to obtain data from children, interpretation should make reference to an interchange table (Table 6) comparing % FM derived using different algorithms with different percentile groups for the sum of four skinfold thicknesses.

Acknowledgements

This work was supported by grants from Deutsche Forschungsgemeinschaft Mu 714-5-1 und 5-2, Bonn; Verein zur Förderung der Rehabilitationsforschung in Schleswig-Holstein e.V., Lübeck; Deutsche Gesellschaft für Gesundes Leben mbH, Bickenbach; Institut Danone für Ernährung e.V., München; Wirtschaftliche Vereinigung Zucker, Bonn; Hansa Tiefkühlmenue GmbH & Co., Hilter.

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