Body mass index as a measure of body fatness: age- and sex-specific prediction formulas

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In 1229 subjects, 521 males and 708 females, with a wide range in body mass index (BMI; 13·9–40·9 kg/m^2), and an age range of 7–83 years, body composition was determined by densitometry and anthropometry. The relationship between densitometrically-determined body fat percentage (BF%) and BMI, taking age and sex (males = 1, females = 0) into account, was analysed. For children aged 15 years and younger, the relationship differed from that in adults, due to the height-related increase in BMI in children. In children the BF% could be predicted by the formula BF% = 1·51 × BMI − 0·70 × age − 3·6 × sex + 1·4 (R^2 0·38, SE of estimate (SEE) 4·4% BF%). In adults the prediction formula was: BF% = 1·20 × BMI + 0·23 × age − 10·8 × sex − 5·4 (R^2 0·79, SEE = 4·1% BF%). Internal and external cross-validation of the prediction formulas showed that they gave valid estimates of body fat in males and females at all ages. In obese subjects however, the prediction formulas slightly overestimated the BF%. The prediction error is comparable to the prediction error obtained with other methods of estimating BF%, such as skinfold thickness measurements or bioelectrical impedance.

Body composition: Body mass index: Obesity

Numerous methods are available to assess body composition, all with their own advantages and limitations (Lukaski, 1987). Only a few methods are suitable in epidemiological studies or clinical practice, because of their technical simplicity, their low costs, or the fact that they are not time consuming. These methods include the bioelectrical impedance technique (Lukaski *et al.* 1985, 1986; Lukaski, 1987; Segal *et al.* 1988), infra-red interactance (Conway *et al.* 1984; Elia *et al.* 1990) and anthropometry such as skinfold thickness measurements (Durnin & Womersley, 1974; Pollock *et al.* 1975; Jackson & Pollock, 1978; Slaughter *et al.* 1988; Deurenberg *et al.* 1990) or weight–height indices (Khosla & Lowe, 1967; Keys *et al.* 1972; Womersley & Durnin, 1977; Norgan & Ferro-Luzzi, 1982; Garrow & Webster, 1985).

For the assessment of body fat percentage (BF%) in epidemiological studies, a weight–height index is the most simple method. A minimum of (inexpensive) equipment is needed, i.e. only a balance and a stadiometer or microtoise, and the errors in measurement due to intra- or inter-observer variation are small. From the several weight–height indices the body mass index (BMI) or Quetelet's index, defined as body-weight/height^2 (Quetelet, 1869), seems to be the most appropriate, because its correlation with BF% is high, and its correlation with body height is low (Khosla & Lowe, 1967; Keys *et al.* 1972; Womersley & Durnin, 1977; Garrow & Webster, 1985). Due to differences in body composition between males and females, and the age-related increase in body fat mass and the decrease in fat-free mass (Forbes, 1987), the relationship between BF% and BMI will be sex- and age-dependent.

The aim of the present study was to determine the relationship between densitometrically-

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determined BF% and BMI, taking age and sex into account, and to cross-validate the developed prediction formulas.

SUBJECTS AND METHODS

Data from 1229 healthy subjects, 521 males and 708 females, were used in the present study. All subjects participated as volunteers in studies on body composition or energy metabolism of which the protocols were approved by the Ethical Committee of the Department of Human Nutrition. The subjects showed a wide age range (7–83 years) and ranged in BF% from 5 to 50. The BMI ranged from 13·9 to 40·9 kg/m^2. The total group of subjects was randomly divided into two groups: group A, and a cross-validation group B. To facilitate the preliminary crude analysis on the age dependency of the relation between BF% and BMI, the population was divided into nine age groups: group 1, 7–10 years; group 2, 11–15 years; group 3, 16–20 years; group 4, 21–25 years; group 5, 26–35 years; group 6, 36–45 years; group 7, 46–55 years; group 8, 56–65 years; group 9, $\geqslant$ 66 years.

Body-weight was measured to the nearest 0·05 kg with a digital scale (Berkel ED60-T, Rotterdam, The Netherlands). Body height was measured by means of a microtoise to the nearest 0·001 m. Body density was determined in duplicate by underwater weighing (to the nearest 0·05 kg, Sartorius 3826MP 81, Göttingen, Germany) with simultaneous determination of the lung volume by a helium dilution technique (Spiro-Junior, Jaeger GmBH, Würtzburg, Germany). In subjects aged 18 years and younger, BF% was calculated with an age-specific formula (Weststrate & Deurenberg, 1989; Deurenberg *et al.* 1990). In subjects older than 18 years, BF% was calculated from body density using Siri's (1961) equation with corrections for age and level of body fatness (Deurenberg *et al.* 1989*b*, *c*). Multiple stepwise linear regression (Kleinbaum & Kupper, 1978) was used to analyse the relationship between BF% as dependent variable and BMI, age and sex as independent variables, using the Statistical Package of Social Sciences/PC-1988-program. Prediction formulas were developed for a population of children (aged $\leqslant$ 15 years) and a population of adults (aged $\geqslant$ 16 years).

Some physical characteristics of the subjects in the validation and cross-validation group are given in Table 2 (p. 107). ANOVA was used to test for differences between groups. Differences between measured and predicted parameters were tested for significance by the paired two-sided Student's t test. All results are expressed as means with their standard errors.

RESULTS

Table 1 shows for males and females in each age group the correlation coefficient between BMI and body height and BF%. In the two lower age groups, that is until the age of 16 years, BMI and body height were positively ($P < 0·001$) correlated, whereas in the older age groups the correlation between BMI and height was not significant or even negative. For the total adult male and adult female groups the correlation of BMI with body height was −0·30 and −0·19 respectively ($P < 0·01$). BF% was also negatively correlated with body height (correlation coefficient −0·43 and −0·23 in males and females respectively, $P <$ 0·001). After correction for the effect of BF% the partial correlation of BMI with body height in both males and females was 0·02, which is not significantly different from zero. In children BF% and body height were not correlated.

The correlation of BMI with BF% was generally higher in the adult groups. In the total group of children the correlation between BMI and BF% was 0·43 and 0·53 ($P < 0·001$), whereas in the adult male and female groups the correlations were 0·75 and 0·76 respectively ($P < 0·001$). Therefore subsequent analyses were performed in two age

Table 1. *Correlation coefficient of body mass index and body height and body fat % in different age groups*

Age (years)...	7–10	11–15	16–20	21–25	26–35	36–45	46–55	56–65	≥ 66
Males (*n*)	56	177	50	101	25	45	23	15	29
Body height	0·55*	0·50*	0·09	−0·28*	−0·47*	−0·18	0·09	−0·35	−0·01
Body fat %	0·59*	0·44*	0·39*	0·47*	0·92*	0·74*	0·80*	0·72*	0·37
Females (*n*)	83	164	120	203	24	50	21	22	21
Body height	0·44*	0·38*	−0·07	0·06	0·08	−0·15	0·33	−0·20	−0·22
Body fat %	0·63*	0·65*	0·55*	0·51*	0·89*	0·81*	0·75*	0·50*	0·51

* $P < 0{\cdot}01$.

Table 2. *Physical characteristics of the two populations (groups A and B) of children and adults*

(Means with their standard errors)

	Children				Adults			
	Group A		Group B		Group A		Group B	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Male/female	121/132		112/115		140/216		148/245	
Body-wt (kg)	41·3	0·7	41·6	0·8	69·4	0·7	70·2	0·6
Body height (m)	1·517	0·009	1·518	0·009	1·740	0·005	1·736	0·005
Body mass index (kg/m²)	17·6	0·1	17·7	0·1	22·9	0·2	23·2	0·2
Body density (kg/l)	1·047	0·001	1·048	0·001	1·042	0·001	1·039	0·001
Body fat (%)	18·4	0·4	18·0	0·4	24·7	0·5	25·7	0·4

Table 3. *Regression of body fat percentage (BF%) as dependent variable, and body mass index (BMI), age and sex as independent variables in the populations of children (age ≤ 15 years)*

(Means with their standard errors)

	Regression coefficients								SEE		
	BMI		Sex*		Age		Intercept				
Group *n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	BF%	CV%	R^2
A 253	+1·32	0·14	—		—		−4·9	2·6	4·8	26	0·25
	+1·33	0·13	−3·8	0·6	—		−3·2	2·4	4·4	24	0·36
	+1·72	0·15	−3·5	0·5	−0·77	0·15	−1·1	2·3	4·2	23	0·42
B 227	+1·12	0·15	—		—		−1·9	2·7	5·0	28	0·20
	+1·03	0·14	−3·9	0·6	—		+1·6	2·5	4·7	26	0·32
	+1·32	0·16	−3·7	0·6	−0·62	0·17	+3·8	2·6	4·6	25	0·35
A+B 480	+1·22	0·10	—		—		−3·3	1·9	4·9	27	0·22
	+1·18	0·09	−3·8	0·4	—		−0·7	1·7	4·6	25	0·34
	+1·51	0·11	−3·6	0·4	−0·70	0·12	+1·4	1·7	4·4	24	0·38

SEE, standard error of estimate, CV%, coefficient of variation; R^2, explained variance.
* Sex: males = 1, females = 0.

Table 4. *Observed body fat percentage (BF%) and difference with predicted BF% in the two populations of children and the two combined populations of children**

(Means with their standard errors)

	Observed BF%		Difference between predicted and observed BF% when predicted with equation from population†					
			A		B		A+B	
Group *n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE
A 253	18·4	0·4	—		0·5	0·3	0·2	0·3
B 227	18·0	0·4	0·5	0·3	—		0·2	0·3
A+B 480	18·2	0·3	−0·2	0·2	0·2	0·2	—	

* Difference = $BF\%_{observed} - BF\%_{predicted}$.
† Prediction equations from Table 3.

Table 5. *Regression of body fat percentage (BF%) as dependent variable, and body mass index (BMI), age and sex as independent variables in the populations of adults (age ⩾ 16 years)*

(Means and their standard errors)

	Regression coefficients										
	BMI		Sex*		Age		Intercept		SEE		
Group *n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	BF%	CV%	R^2
A 356	+1·61	0·10	—		—		−12·1	2·4	7·2	29	0·40
	+1·63	0·07	−9·8	0·6	—		−8·9	1·8	5·4	22	0·67
	+1·16	0·06	−10·7	0·5	+0·23	0·01	−5·0	1·4	4·2	17	0·80
B 393	+1·45	0·09	—		—		−8·1	2·3	7·0	27	0·36
	+1·63	0·07	−10·0	0·5	—		−8·3	1·7	5·1	20	0·66
	+1·22	0·06	−10·9	0·4	+0·22	0·01	−5·6	1·3	4·0	16	0·80
A+B 747	+1·53	0·07	—		—		−10·1	1·6	7·1	28	0·38
	+1·63	0·05	−9·9	0·4	—		−8·6	1·2	5·2	21	0·67
	+1·20	0·04	−10·8	0·3	+0·23	0·01	−5·4	1·0	4·1	16	0·79

SEE, standard error of estimate; CV%, coefficient of variation; R^2 explained variance.
* Sex: males = 1, females = 0.

categories: a population of children (age ⩽ 15 years) and a population of adults (age ⩾ 16 years). Table 2 shows some physical characteristics of the subjects in the validation and cross-validation sample in children and adults. Neither the two groups of children, nor the two groups of adults differed significantly in physical characteristics. Although the BMI distribution was slightly skewed, log transformation did not improve the fit of the regression equations.

In group A of the population of children the relationship between BF% as dependent variable and BMI, age and sex as independent variables was analysed. Table 3 shows the stepwise multiple regression model. The prediction formula was validated in group B of the population of children. The difference between observed BF% and predicted BF% was not significant (Table 4). Also in group B of the population of children the relationship between BF% as dependent variable and BMI, age and sex as independent variables was analysed.

Table 6. *Observed body fat percentage (BF%) and difference with predicted BF% in the two populations of adults and the two combined populations of adults*†

(Means with their standard errors)

	Observed BF%		Difference between predicted and observed BF% when predicted with equation from population‡					
			A		B		A+B	
Group *n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE
A 356	24·6	0·5	—		−0·5*	0·2	−0·3	0·2
B 393	25·7	0·4	0·5*	0·2	—		0·2	0·2
A+B 747	25·2	0·3	0·3	0·2	−0·2	0·2	—	

* $P < 0{\cdot}05$.
† Difference = $BF\%_{observed} - BF\%_{predicted}$.
‡ Prediction equations from Table 5.

Table 7. *Observed body fat percentage (BF%) and difference with predicted BF% in several age groups*

(Means with their standard errors)

Age (years)	*n*	Observed BF% Mean	Observed BF% SE	Difference with predicted BF% Mean	Difference with predicted BF% SE
7–10	139	18·9	0·5	0·5	0·4
11–15	341	17·9	0·3	−0·2	0·2
16–20	170	21·6	0·5	0·0	0·4
21–25	304	21·8	0·4	−0·1	0·2
26–35	49	24·7	1·6	−0·4	0·7
36–45	95	32·1	0·8	0·5	0·4
46–55	44	30·2	1·0	0·3	0·6
56–65	37	34·5	1·3	−0·3	0·6
⩾ 66	50	34·1	0·9	−0·4	0·6

Table 3 also shows the results of this stepwise multiple regression analysis. The prediction formula obtained was validated in group A of the population of children. The difference between observed and predicted BF% was not significant (Table 4). Therefore the two groups A and B within the population of children were combined and the relationship analysed again. Table 3 also gives the predicted formula based on the total population of children. In the combined population of children, age showed a slightly but statistically significant interaction with BMI ($P < 0{\cdot}05$), indicating a statistically different relationship between BF% and BMI at different ages. Taking this interaction into account in the regression analysis, the R^2 increased only from 0·38 to 0·39, and the SE of the estimate (SEE) of the prediction decreased only by 0·03%. For convenience the prediction formula $BF\% = 1{\cdot}51 \times BMI - 0{\cdot}70 \times age - 3{\cdot}6 \times sex + 1{\cdot}4$ (Table 3), without the interaction term, was used in subsequent analysis.

For the population of adults the same analyses were performed, that is, development of a prediction formula in group A, which was validated in group B and vice versa. Table 5

Table 8. *Observed body fat percentage (BF%) and difference with predicted BF% in different body mass index (BMI) categories*

BMI category (kg/m²)	*n*	Observed BF%		Difference with predicted BF%	
		Mean	SE	Mean	SE
< 20	540	18·2	0·3	0·1	0·2
20–25	531	23·2	0·3	−0·1	0·2
26–30	109	32·4	0·8	0·3	0·3
⩾ 30	49	39·4	2·0	−0·5	0·6

Table 9. *External validation of the prediction formulas in different populations from the literature**

(Means with their standard errors)

Age (years) Mean	Sex	Reported BF%		Predicted BF%	Reference
		Mean	SE		
10	♂	19·0	1·1	18·0	Slaughter *et al.* (1988)
10	♀	23·0	1·7	20·9	Slaughter *et al.* (1988)
12	♂	17·0	1·3	17·8	Slaughter *et al.* (1988)
12	♀	24·0	1·3	22·6	Slaughter *et al.* (1988)
15	♂	14·0	0·8	13·3	Slaughter *et al.* (1988)
15	♀	24·0	1·0	22·2	Slaughter *et al.* (1988)
22	♂	16·0	1·2	17·6	Slaughter *et al.* (1988)
22	♀	26·0	1·1	26·6	Slaughter *et al.* (1988)
34	♂	17·7	0·3	19·2	Segal *et al.* (1988)
24	♀	20·6	0·4	18·7	Segal *et al.* (1988)
50–72	♂	28	1·7	30·3	Durnin & Womersley (1974)
50–72	♀	39	1·3	40·0	Durnin & Womersley (1974)
25	♂	29·6†		30·3	Gray *et al.* (1989)
62	♀	42·8†		43·7	Gray *et al.* (1989)

* For the ages ⩽ 15 years the prediction formula from Table 4 was used, for the ages ⩾ 16 years the prediction formula was from Table 6.

† Only the mean value is given by the authors.

shows the stepwise multiple regression analysis performed in groups A and B, and Table 6 gives the cross-validation results. Although in the population of adults the differences between observed BF% and predicted BF% were sometimes statistically significant ($P < 0·05$), they were very small (less than 0·5%). Therefore, the values for the two groups of adults were also combined. Table 5 also gives the prediction formula for the total population of adults. In the population of adults, sex ($P < 0·001$) and age ($P < 0·05$) slightly interacted with BMI, but taking both interactions into account the R^2 only increased from 0·79 to 0·80, and the SEE decreased only from 4·06 to 4·03%. For reasons of convenience the prediction formula without interaction terms (BF% $= 1·20 \times \text{BMI} - 10·8 \times \text{sex} + 0·23 \times \text{age} - 5·4$, Table 5) was used in subsequent analysis.

Table 7 shows the observed BF% and the difference between observed and predicted BF% in several age groups. The predicted BF% did not differ significantly from the observed BF% in all age groups. Also when comparing observed and predicted BF% in males and females in different age groups, no differences were observed (results not shown).

Table 8 shows the validity of the predicted BF% in groups of different apparent body fatness, based on the BMI. The BF% in obese subjects (BMI > 30 kg/m^2) was slightly overestimated by the prediction formulas. This difference became statistically significant in obese subjects with a BMI $\geqslant 33$ kg/m^2 (n 19, ΔBF% $= -1{\cdot}9$ (SE 0·8), $P < 0{\cdot}05$).

In Table 9 the observed BF% and the predicted BF% using the final prediction equations from Table 3 and Table 5 for children and adults respectively are given for some populations described in the literature. The mean differences were in general less than 2% BF%, and the predicted value was always within the 95% confidence interval of the observed value.

DISCUSSION

When using a weight–height index to assess body fat, it is necessary that this index has a high correlation with BF%, but also that this index is not correlated with body height (Keys *et al.* 1972), unless one assumes that body height and BF% are correlated (Garrow & Webster, 1985). These two criteria hold in general for the Quetelet index or BMI more than for other weight–height indices (Keys *et al.* 1972; Norgan & Ferro-Luzzi, 1982). However, in children from about 7 years onwards, the BMI is positively related with age (Rolland-Cachera *et al.* 1982). In those children the increase in body-weight is faster compared with the increase in body height, and the BMI is theoretically positively correlated with body height. This was also observed in the present study. After the age of 16 years the positive correlation of the BMI with body height disappeared and became even slightly, but significantly negative.

In growing prepubertal children the BF% generally remains fairly constant and slightly increases only in pubertal girls (Forbes, 1987; Deurenberg *et al.* 1990), whereas the BMI increases during this period. It can be questioned therefore, whether the BMI is a suitable predictor for BF% in children under the age of 16 years. Therefore, the relationship between BF% and BMI was analysed separately for children and adults, i.e. for subjects aged $\leqslant 15$ years and subjects aged $\geqslant 16$ years.

The negative correlation of the BMI with body height in adults was shown to be a negative correlation with BF% and was also found in some other studies (Womersley & Durnin, 1977; Sonsbeek 1985). However Keys *et al.* (1972) and Norgan & Ferro-Luzzi (1982) generally found no correlation between BMI and body height. This disagreement between studies could be due to differences in age of the subjects studied. Both in the present study and in the study of Womersley & Durnin (1977), this negative correlation was more pronounced in the older age groups. The correlation between BF% and body height shows that the statement that a weight–height index as a measure of body fat has to be independent of height, is not necessarily true, as also indicated by Garrow & Webster (1985).

In a population of children the explained variance of the regression model was rather low (0·38–0·42, Table 3) compared with that of adults (0·79–0·80, Table 5). Although the absolute prediction error (SEE) seemed comparable in children and adults, it was remarkably larger in children (24% v. 16%, expressed as percentage of variation, Tables 3 and 5). For this reason it may be questioned whether the BMI is a valid determinant for BF% in children.

Both in the population of children and in the population of adults the prediction formulas obtained in the validation sample A predicted the BF% in the cross-validation sample B quite well, and vice versa (Tables 4 and 6). Consequently, the prediction formulas based on the total population of children and adults were used in further calculations.

The explained variances of the final regression models were, at least in the population of adults, rather high, but, more importantly, the prediction error (SEE) in BF% was rather low. There were significant interactions between BMI and age in children, and between BMI and age and sex in adults, indicating that the relationship between BF% and BMI was not identical at all ages, and statistically different between sexes in adults. These effects, however, had only a small impact on the prediction of the BF%, and were neglected.

The slight overestimation of the BF% in the obese subjects may be explained by the fact that the relationship between BF% and BMI is theoretically asymptotic at higher values of BMI. However, using BMI^2 or log BMI instead of BMI did not improve the percentage explained variance and hence the accuracy of prediction (results not shown).

Validation of the prediction formulas in populations described in the literature, showed predicted BF% values close to the observed values. They were always within the 95% confidence interval of the reported value, indicating that the prediction formulas also have a high external validity.

In the prediction formula obtained for the children, sex effects were less pronounced than in adults. This demonstrates the fact that in children the differences in body composition between the sexes are small compared with adults (Forbes, 1987). Another difference between the prediction formulas for children and adults is that the regression coefficient for age was positive in children, and negative in adults. This means that, even when body-weight (and thus BMI) is constant in adults, the amount of body fat increases with age. This is in accordance with the fact that the relative amount of fat-free mass (i.e. muscle mass) decreases with advancing age (Forbes, 1987). In children the negative effect of age on the predicted BF% is the consequence of the height-related increase in BMI, due to the unproportional increases in weight and height.

The SEE values from the prediction equations in the present study are comparable with those found in other studies in which the relationship between BF% and BMI was studied, as in males only (Norgan & Ferro-Luzzi, 1982) or in groups of subjects with a smaller age range (Womersley & Durnin, 1977; Deurenberg *et al.* 1989*a*).

Garrow & Webster (1985) found that the BMI was better correlated with body fat mass (kg) compared with BF%. Also in this population, fat mass divided by height squared (FM/H^2) correlated more strongly ($R^2 = 0{\cdot}89$) with BMI than did BF%, after taking age and sex into account. However, the SEE, expressed as coefficient of variation, was only marginally lower (15·9% compared with 16·2%). It seems more convenient, therefore, to use the BMI as a measure of BF% and not of fat mass (kg).

The prediction error in the estimated BF% using formulas based on the BMI is comparable with the prediction error when using formulas based on skinfold thickness measurements (Durnin & Womersley, 1974; Pollock *et al.* 1975; Jackson & Pollock, 1978; Slaughter *et al.* 1988; Deurenberg *et al.* 1990), for which in general a SEE of 3–5% BF% is reported. A prediction error of about 3–5% BF% has also been found in studies using the bioelectrical impedance technique (Lukaski *et al.* 1986; Jackson *et al.* 1988; Segal *et al.* 1988; Guo *et al.* 1989; Houtkoper *et al.* 1989).

The estimation of the BF% from BMI is less dependent on intra- and inter-observer errors than skinfold measurements. Body-weight and body height are relatively easy to measure, but a well-trained observer is necessary for the measurement of skinfold thicknesses. Body impedance has to be measured under strictly standardized conditions to obtain reproducible results (Caton *et al.* 1988; Deurenberg *et al.* 1988) and is largely determined by the impedance of the extremities (Baumgartner *et al.* 1989; Fuller & Elia, 1989), thus any inaccurate placement of the electrodes will cause relatively large errors. Well-trained observers are also necessary when using this method.

In summary, the assessment of BF% from BMI, sex and age provides accurate estimates of body composition. The use of different prediction formulas for children and adults is necessary. Prediction is more accurate for adults than children. The method is inexpensive and does not rely on well-trained observers, whereas the prediction error is comparable with other methods such as skinfold thickness measurements or bioelectrical impedance.

REFERENCES

Baumgartner, R. N., Chumlea, W. C. & Roche, A. F. (1989). Estimation of body composition from bioelectrical impedance of body segments. *American Journal of Clinical Nutrition* **50**, 221–226.

Caton, J. R., Molé, P. A., Adams, W. C. & Heustis, D. S. (1988). Body composition analysis by bioelectrical impedance: effect of skin temperature. *Medical Sciences in Sports and Exercise* **20**, 489–491.

Conway, J. M., Norris, K. H. & Bodwell, C. E. (1984). A new approach for the estimation of body composition by infrared interactance. *American Journal of Clinical Nutrition* **40**, 1123–1130.

Deurenberg, P., Leenen, R., van der Kooy, K. & Hautvast, J. G. A. J. (1989*c*). In obese subjects the body fat percentage calculated with Siri's formula is an overestimation. *European Journal of Clinical Nutrition* **43**, 569–575.

Deurenberg, P., Pieters, J. J. L. & Hautvast, J. G. A. J. (1990). The assessment of the body fat percentage by skinfold thickness measurements in childhood and young adolescence. *British Journal of Nutrition* **63**, 293–303.

Deurenberg, P., van der Kooy, K., Hulshof, T. & Evers, P. (1989*a*). Body mass index as a measure of body fatness in the elderly. *European Journal of Clinical Nutrition* **43**, 231–236.

Deurenberg, P., Weststrate, J. A., Paymans, I. & van der Kooy, K. (1988). Factors affecting bioelectrical impedance measurements in humans. *European Journal of Clinical Nutrition* **42**, 1017–1022.

Deurenberg, P., Weststrate, J. A. & van der Kooy, K. (1989*b*). Is an adaptation of Siri's formula for the calculation of body fat percentage from body density in the elderly necessary? *European Journal of Clinical Nutrition* **43**, 559–567.

Durnin, J. V. G. A. & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness, measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition* **32**, 77–97.

Elia, M., Parkinson, S. A. & Diaz, E. (1990). Assessment of body composition: near infra-red interactance. *Proceedings of the Nutrition Society* **49**, 197A.

Forbes, G. B. (1987). *Human Body Composition*. New York: Springer Verlag.

Fuller, N. J. & Elia, M. (1989). Potential use of bioelectrical impedance of the whole body and of body segments for the assessment of body composition, comparison with densitometry and anthropometry. *European Journal of Clinical Nutrition* **43**, 779–792.

Garrow, J. S. & Webster, J. (1985). Quetelet's index (W/H^2) as a measure of fatness. *International Journal of Obesity* **9**, 147–153.

Gray, D. S., Bray, G. A., Gemayel, N. & Kaplan, K. (1989). Effect of obesity on bioelectrical impedance. *American Journal of Clinical Nutrition* **50**, 255–260.

Guo, S., Roche, A. F. & Houtkoper, L. B. (1989). Fat free mass in children and young adults predicted from bioelectrical impedance and anthropometric variables. *American Journal of Clinical Nutrition* **50**, 435–443.

Houtkoper, L. B., Lohman, T. G., Going, S. B. & Hall, M. C. (1989). Validity of bioelectrical impedance for body composition assessment in children. *Journal of Applied Physiology* **66**, 814–821.

Jackson, A. S. & Pollock, M. L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition* **40**, 497–504.

Jackson, A. S., Pollock, M. L., Graves, J. & Mahar, M. (1988). Reliability and validity of bioelectrical impedance in determining body composition. *Journal of Applied Physiology* **64**, 529–534.

Keys, A., Fidanza, F., Karvonen, M. J., Kimura, N. & Taylor, H. L. (1972). Indices of relative weight and obesity. *Journal of Chronic Diseases* **25**, 329–343.

Khosla, T. & Lowe, C. R. (1967). Indices of obesity derived from body weight and height. *British Journal of Preventive and Social Medicine* **21**, 122–128.

Kleinbaum, D. G. & Kupper, L. L. (1978). *Applied Regression Analysis and Other Multivariable Methods*. North Scituate, Massachusetts: Duxbury Press.

Lukaski, H. C. (1987). Methods for the assessment of body composition, traditional and new. *American Journal of Clinical Nutrition* **46**, 437–456.

Lukaski, H. C., Bolonchuck, W. W., Hall, C. B. & Siders, W. A. (1986). Validation of tetrapolar bioelectrical impedance method to assess human body composition. *Journal of Applied Physiology* **60**, 1327–1332.

Lukaski, H. C., Johnson, P. E., Bolonchuck, W. W. & Lykken, G. E. (1985). Assessment of fat free mass using bio-electrical impedance measurements of the human body. *American Journal of Clinical Nutrition* **41**, 810–817.

Norgan, N. G. & Ferro-Luzzi, A. (1982). Weight–height indices as estimates of fatness in men. *Human Nutrition: Clinical Nutrition* **36C**, 363–372.

Pollock, M. L., Laughridge, E. E., Coleman, B., Linnerud, A. C. & Jackson, A. (1975). Prediction of body density in young and middle aged women. *Journal of Applied Physiology* **38**, 745–749.

Quetelet, L. A. (1869). *Physique Sociale*, vol. 2, p. 92. Brussels: C. Muquardt.

Rolland-Cachera, M. F., Sempe, F., Guillod-Bataille, M. M., Patois, E., Pequignot-Guggenbuhl, F. & Fautrat, W. (1982). Adiposity indices in children. *American Journal of Clinical Nutrition* **36**, 178–184.

Segal, K. R., van Loan, M., Fitzgerald, P. I., Hodgdon, J. A. & van Itallie, T. B. (1988). Lean body mass estimated by bioelectrical impedance analysis, a four site cross validation study. *American Journal of Clinical Nutrition* **47**, 7–14.

Siri, W. E. (1961). Body composition from fluid spaces and density, analysis of methods. In *Techniques for Measuring Body Composition*, pp. 223–244 [J. Brozek and A. Henschel, editors]. Washington, DC: National Academy of Sciences.

Slaughter, M. H., Lohman, T. G., Boileau, R. A., Horswill, C. A., Stillman, R. J., van Loan, M. D. & Bemben, D. A. (1988). Skinfold equations for estimation of body fatness in children and youth. *Human Biology* **60**, 709–723.

Sonsbeek, J. L. A. (1985). *The Dutch by Height and Weight*. (In Dutch.) *Maandberichten Gezondheidsstatistiek (CBS)* **6**, 5–18.

Statistical Package for Social Sciences/PC (1988). *Base Manual + V2.0.* Chicago, Illinois: SPSS Inc.

Weststrate, J. A. & Deurenberg, P. (1989). Body composition in children, proposal for a method for calculating body fat percentage from total body density or skinfold-thickness measurements. *American Journal of Clinical Nutrition* **50**, 1104–1115.

Womersley, J. & Durnin, J. V. G. A. (1977). A comparison of the skinfold method with extent of overweight and various weight–height-relationships in the assessment of obesity. *British Journal of Nutrition* **38**, 271–284.

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