The validity of predicted body composition in Chinese adults from anthropometry and bioelectrical impedance in comparison with densitometry

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Body composition was measured by densitometry in a group of eighty-one healthy Chinese males and 124 healthy Chinese females, aged 18–67 years. Biceps, triceps, subscapular and suprailiac skinfolds were measured as well as total body bioelectrical impedance at 50 kHz. Mean heights were 1·71 (SD 0·05) and 1·61 (SD 0·06) m, body weights 66·1 (SD 9·1) and 57·2 (SD 9·4) kg and BMI 22·7 (SD 3·0) and 22·0 (SD 3·3) kg/m^2 in males and females respectively. Body fat values from body density were 20·1 (SD 6·2) and 29·7 (SD 7·5)% in males and females respectively. Mean predicted body-fat values from skinfolds, bioelectrical impedance and BMI, using prediction formulas developed in Western populations, did not differ or differed only slightly from body-fat values estimated from body density. The SD of the difference for each method was 5% body fat or 3·3 kg fat-free mass (CV 6%), which is approximately equal to the accuracy level of each predictive method. Compared with densitometry the predictive methods overestimated body fat at the lower levels of body fatness, whereas at the higher levels of body fat the predictive methods tended to underestimate body fatness. It is concluded that prediction formulas for estimating body fat from skinfolds, impedance or BMI developed in Western populations are applicable and valid in the adult Chinese population. However, in very lean subjects the predictive methods overestimate body fat compared with values obtained from body density.

Body composition: Densitometry: Bioelectrical impedance

For the assessment of nutritional status, information on body composition is important (Forbes, 1987; Lukaski, 1987). As a standard method for the measurement of body fat and fat-free mass (FFM), underwater weighing can be used to determine body density, from which the amount of fat can be calculated (Siri, 1961). A disadvantage of hydrodensitometry is that the method is rather laborious. Therefore a number of methods have been developed to predict body fat or FFM from skinfold thicknesses (Durnin & Womersley, 1974), body impedance (Lukaski *et al.* 1985; Segal *et al.* 1988; Deurenberg *et al.* 1991*a*) or weight–height ratio indices such as the BMI (Womersley & Durnin, 1977; Deurenberg *et al.* 1991*b*). The prediction formulas described in the literature have mostly been developed in Caucasian populations (Europe, USA) and it may be questioned whether the formulas are valid in populations with a different ethnic background. There are indications in the literature that the density of the FFM is higher in black Americans compared with white Americans (Seale, 1959; Trotter & Hixon, 1974). There may also be

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differences between ethnic groups in the ratio of subcutaneous to total fat, which would violate assumptions used in the skinfolds methodology. Differences in body build, for example differences in relative extremity length, may result in differences in body impedance, as leg and arm show the highest contribution to total body impedance (Baumgartner *et al.* 1989; Fuller & Elia, 1989). Recently Heymsfield & Wang (1994) showed that body impedance is higher in black males than in white males matched for weight, height and age.

In an earlier study, performed in a small group of Chinese female workers, it was shown that body fat could be validly predicted from skinfolds, impedance and BMI (de Waart *et al.* 1993) using deuterium oxide dilution as a reference method. In the present study body composition was measured in a larger group of healthy Chinese males and females by underwater weighing, and the results were compared with predicted values from skinfolds, impedance and BMI using formulas from the literature.

SUBJECTS AND METHODS

The study was performed at the Institute of Nutrition and Food Hygiene of the Chinese Academy of Preventive Medicine in Beijing in 1993–4. Body composition was measured in 205 healthy males (*n* 81) and females (*n* 124) from different social classes, aged 18–67 years. Some characteristics of the subjects are given in Table 1. The study protocol was approved by the Medical Ethical Committee of the Chinese Academy of Preventive Medicine.

The subjects were invited to come to the Institute in the morning in the fasting state. Body weight was measured in a swim suit, after voiding, to the nearest 0·1 kg using a digital scale (Tefal, SC3218, Rumilly, France). Height was measured to the nearest 1 mm with a wall-mounted stadiometer (Lameris, Utrecht, The Netherlands). BMI (kg/m^2) was computed as weight/height^2. From BMI, body fat was calculated using age- and sex-specific formulas (Deurenberg *et al.* 1991*b*). Skinfold thicknesses (biceps, triceps, subscapular and suprailiac) were measured in triplicate at the left side of the body as described by Durnin & Womersley (1974) using Holtain skinfold callipers (Holtain Ltd, Crymych, Dyfed). When triplicate values differed by more than 10% the measurements were repeated. The mean values were used for the calculation of percentage body fat (BF%), using the prediction equations of Durnin & Womersley (1974). Total body impedance at 50 kHz (Humanim, Dietosystem, Milano, Italy) was measured immediately, with the subject lying supine at the left side of the body. Aluminium foil spot electrodes (3M, Medical Device Division, St Paul, MN, USA) were placed on the dorsal surfaces of the left hand and left foot at the distal metacarpals and metatarsals respectively, and also between the distal prominences of the radius and the ulna, and between the medial and lateral malleoli at the ankle. Single measurements were performed as the reproducibility of impedance measurements is very high (Lukaski, 1987). From height and impedance the impedance index (height^2/Z, m^2/Ω) was computed. From impedance index, weight, height, age and sex (females 0, males 1) FFM was calculated using the prediction equations published by Deurenberg *et al.* (1991*a*).

Body density was derived from underwater weighing. The subjects were weighed (Sartorius, Model IC34, Göttingen, Germany) while lying supine on a stretcher completely immersed in water. Residual lung volume was measured simultaneously (Volugraph VG 2000, Mijnhardt, Bunnik, The Netherlands). The measurements were, in most subjects, performed in duplicate. The within-subject, within-day variability in body density, measured separately in five subjects, was 0·0021 kg/l. Body fat was calculated from body density using Siri's (1961) formula. The SPSS-program (Statistical Package for the Social Sciences, 1990) was used for statistical calculations. Differences in variables between groups

Table 1. *Characteristics of the subjects*

	Males (n 81)			Females (n 124)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	32·1	11·6	18–67	34·2	11·1	18–67
Weight (kg)	66·1	9·1	42·3–94·6	57·2***	9·4	41·4–90·7
Height (m)	1·71	0·05	1·55–1·82	1·61***	0·06	1·45–1·84
BMI (kg/m²)	22·7	3·0	17·4–31·3	22·0	3·3	15·9–31·3
Impedance (Ω)	481	45	388–591	580***	72	441–776
Biceps skinfold (mm)	5·0	1·9	3·9–28·5	8·5***	3·7	3·8–31·1
Triceps skinfold (mm)	10·5	4·6	2·2–11·2	17·8***	5·3	2·6–22·7
Subscapular skinfold (mm)	17·2	7·4	6·4–39·7	19·6***	7·6	7·3–40·4
Suprailiac skinfold (mm)	17·4	8·5	4·0–36·6	16·5	7·7	5·1–36·5
Sum of four skinfolds (mm)	50·0	20·6	16·9–110·3	62·5***	21·9	27·1–122·1

*** Mean values were significantly different from those for males, $P < 0·001$.

were tested with Student's t test. Differences between measured and predicted values (bias) were tested by Student's paired t test and with the technique described by Bland & Altman (1986). Correlations are Pearson's product moment correlations. Values are expressed as means and standard deviations.

RESULTS

Table 1 shows some characteristics of the subjects. Males and females had the same mean age and the age distribution was similar. Body weight and height were higher in males than females, whereas body impedance was lower. BMI did not differ between males and females. All skinfolds except the suprailiac were thicker in females than in males. Consequently the sum of four skinfolds was higher in females. In males, biceps, triceps and suprailiac skinfolds did not increase with age (r 0·11, NS) but the subscapular skinfold increased significantly with age (r 0·38, $P < 0·01$). Body fat from body density also increased slightly with age (r 0·30, $P < 0·01$). In females all skinfolds were positively related with age, the correlation coefficients ranged from 0·40 ($P < 0·01$) for biceps to 0·56 for the subscapular skinfold ($P < 0·001$). Also, body fat from body density increased with age (r 0·52, $P < 0·001$).

In Table 2 the BF% and FFM values measured by underwater weighing are listed together with predicted values. Although there were significant differences between measured and predicted values, the differences were generally small. In males predicted BF% was always slightly lower than the measured value, and hence predicted FFM was slightly higher. In females BF% values predicted from impedance and from skinfold thickness were higher than the values measured by underwater weighing. BF% calculated from BMI was slightly lower. The mean differences in predicted FFM in both males and females were in the range of −0·5–1·2 kg (Table 3). Individual differences between predicted values and measured values were higher as can be seen from the standard deviations in Table 3 and from Fig. 1.

The bias of all methods was correlated with body fat from body density (Fig. 1). When body fat from density was corrected for age and level of fatness (Deurenberg *et al.* 1989*a*, *b*), the correlation coefficient of the bias with BF% decreased for all methods about 0·1 to 0·15. When, in accordance with the suggestion of Bland & Altman (1986), the biases were plotted against the mean value of predicted body fat and body fat from density, the

Table 2. *Measured and predicted values of percentage body fat (BF%) and fat-free mass (FFM) from body density, skinfold thickness, impedance and BMI in healthy Chinese subjects*†

(Mean values and standard deviations)

	Males (*n* 81)				Females (*n* 124)			
	BF%		FFM (kg)		BF%		FFM (kg)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Densitometry	20·1	6·2	52·5	6·1	29·7	7·5	39·7	4·9
Skinfold thickness	19·9	6·3	52·5	5·7	30·8*	6·1	39·1*	4·6
Impedance	19·1	6·2	53·1	5·1	32·1*	5·8	38·5*	5·1
BMI	18·4*	4·9	53·6*	5·5	28·9	5·6	40·3*	4·5

* Mean values were significantly different from those for densitometry, $P < 0·05$.
† For details of subjects and procedures, see Table 1 and pp. 176–177.

Table 3. *Differences between percentage body fat (BF%) or fat-free mass (FFM) values predicted from skinfolds, impedance and BMI, and values obtained from body density, for healthy Chinese subjects*†

(Mean values and standard deviations)

	Males (*n* 81)				Females (*n* 124)			
	BF%		FFM (kg)		BF%		FFM (kg)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Density minus:								
Skinfolds	0·2	4·9	0·0	3·2	−1·1*	4·9	−0·6*	2·8
Impedance	1·0	4·9	−0·6	3·3	−2·4*	4·6	1·2*	2·6
BMI	1·7*	5·0	−1·1*	3·2	0·8	4·9	−0·5*	2·8

* Significantly different from zero, $P < 0·05$.
† For details of subjects and procedures, see Table 1 and pp. 176–177.

correlations lowered considerably from 0·63 to 0·28 (males, BMI); 0·39 to 0·00 (males, impedance); 0·36 to 0·00 (males, skinfolds); 0·66 to 0·40 (females, BMI); 0·63 to 0·38 (females, impedance); and 0·59 to 0·31 (females, skinfolds).

Table 4 gives the correlation coefficients between BF% from density and predicted BF% for males (lower left) and females (upper right). The correlations were slightly higher in females.

DISCUSSION

In the present study body composition was measured in a group of healthy Chinese males and females, living in the capital Beijing in northern China. The subjects were not specially selected and belonged to both higher and lower socio-economic classes. However, they cannot be regarded as representative of the Chinese population. Weight and height of the males and females in the present study were high compared with the results of a population study in northern China (Li, 1986). However, the mean BMI of the subjects in the present study was comparable with the recently reported mean value of the BMI of the Chinese

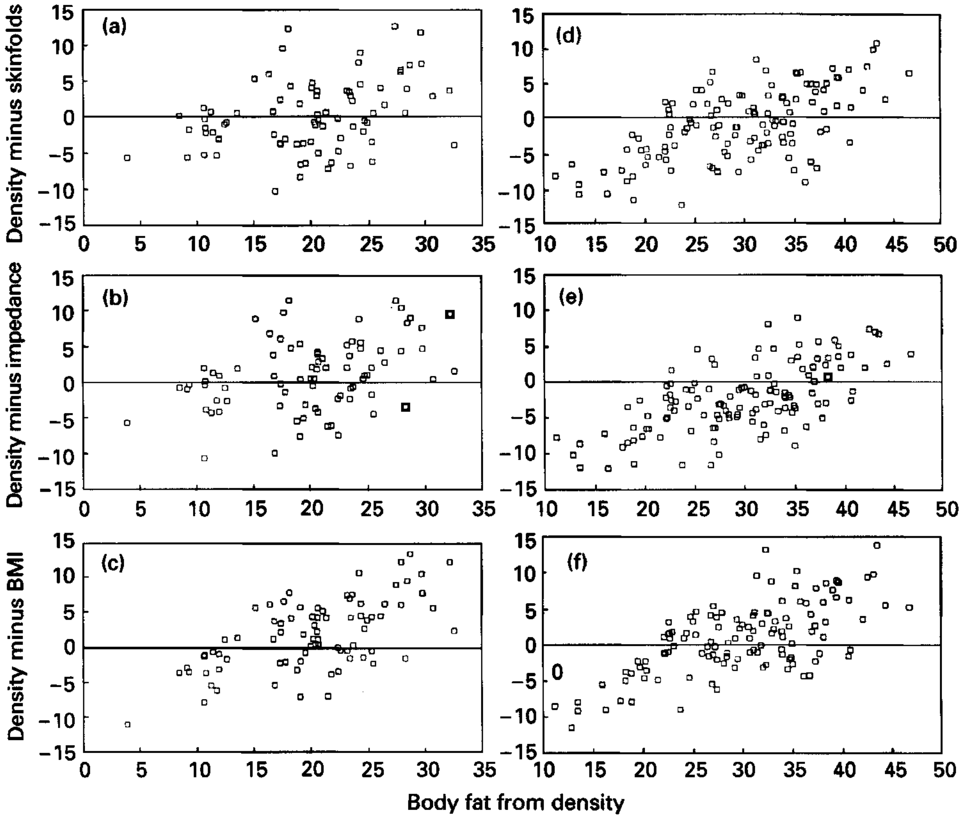

Fig. 1. Bias in percentage body fat values obtained from density and from prediction methods in relation to percentage body fat from density in healthy Chinese subjects. (a), (b), (c), males; (d), (e), (f), females. Correlation coefficients were: (a) r 0·36, $P < 0·01$; (b) r 0·39, $P < 0·01$; (c) r 0·63, $P < 0·01$; (d) r 0·59, $P < 0·001$; (e) r 0·63, $P < 0·001$; (f) r 0·66, $P < 0·001$.

Table 4. *Pearson's correlation coefficients between percentage body fat obtained from body density and percentage body fat predicted from skinfolds, impedance or BMI in healthy male (lower left) and female (upper right) Chinese subjects**

	Density	Skinfolds	Impedance	BMI
Density	—	0·82	0·83	0·82
Skinfolds	0·70	—	0·94	0·94
Impedance	0·69	0·90	—	0·96
BMI	0·62	0·86	0·93	—

* All correlations $P < 0·0001$.

population in the cities Beijing, Tianjin and Shanghai (K. Ge, personal communication; Shetty & James, 1994). Weight, height and BMI of the subjects in the present study were considerably lower than mean values in Western societies such as the USA (Frisancho, 1984). Body impedance values were comparable with values measured in other groups (Segal *et al.* 1988). The females in the present study had low impedance values compared with values measured previously in Chinese females (de Waart *et al.* 1993). However, in the study of de Waart *et al.* (1993) body weight, and hence probably body water, was lower. The higher mean values of skinfold thicknesses in females than in males, as well as the increase in skinfold thickness with age, are generally observed (Durnin & Womersley, 1974; Frisancho, 1984). Also, the increase in body fat from body density with age is a normal observation and has been found in many studies (Durnin & Womersley, 1974; Deurenberg *et al.* 1991*b*). These results confirm the findings of Jiang *et al.* (1991) who showed that the body composition of the Chinese is comparable with that of the Americans except for an additional fat burden in the Americans.

The predicted mean values of body fat from skinfolds (Durnin & Womersley, 1974), BMI (Deurenberg *et al.* 1991*b*) and impedance (Deurenberg *et al.* 1991*a*) were comparable with mean values obtained by underwater weighing (Table 2). Although for some methods the mean differences were statistically significant, differences in FFM did maximally exceed 1·1 (SD 3·2) kg in males and 1·2 (SD 2·6) kg in females. The results are in accordance with the study of de Waart *et al.* (1993), who showed that in Chinese females BF % calculated from skinfolds, impedance or BMI differed only slightly from BF % calculated from total body water from deuterium oxide dilution.

The prediction formulas for body fat from BMI and impedance used in the present study are based on body fat from density, corrected for age and body fatness effects in the density of the FFM (Deurenberg *et al.* 1989*a*, *b*). To enable a fair comparison, body fat from density in the present study was also corrected, resulting in a 0·6 % lower mean BF %, both in males and in females. Thus in males the bias in predicted BF % from BMI and impedance became smaller and was no longer significant. In females the bias in predicted BF % from BMI after these corrections was also lower and no longer significant. However, for body fat from impedance the bias increased. Despite this, the observed biases are all within the reported accuracy range of the methods and can hardly be regarded as biologically relevant. Also the individual biases did not reach extreme values, as can be seen from Fig. 1. The dependency of the bias on BF % from density (Fig. 1) is observed in many studies (McNeill *et al.* 1991; Lukaski, 1993) and can be explained by violations of assumptions of the prediction formulas. The method of reference can also give rise to errors in the extreme ranges of body fat. In very thin subjects Siri's (1961) formula is likely to underestimate body fat, whereas in fat subjects and at greater age the formula is likely to overestimate fat (Deurenberg *et al.* 1989*a*, *b*). The fact that the biases of the three predicted values were highly correlated (correlation coefficients ranging from 0·77 to 0·96) shows that an error in body fat from body density is at least partly responsible for the individual bias and for the relation of the biases with the level of body fatness. The overestimation of body fat in the lean subjects using predictive methods shows the necessity to develop specific prediction formulas especially for very lean subjects for use in populations with a high prevalence of low weight (low fat) subjects.

When using other prediction formulas from the literature, the predicted values for body fat were comparable. For example, the prediction formulas of Segal *et al.* (1988) yielded BF % values of 16·4 (SD 5·2) and 27·3 (SD 6·2) in males and females respectively. Body fat predicted from BMI using the age- and sex-specific equations of Womersley & Durnin (1977) resulted in BF % values of 18·5 (SD 4·8) and 27·1 (SD 5·7) in males and females respectively. Although the differences with the measured values were higher ($P < 0.001$), they are of a magnitude often found in other studies (McNeill *et al.* 1991; Svendson *et al.* 1991; Tagliabue *et al.* 1992).

In conclusion, predicted values of BF % and FFM in the studied sample did not differ or differed only slightly from values obtained by densitometry. Thus it is likely that prediction formulas developed in Western populations can be used in the adult Chinese population. However, predicted individual values must be regarded with caution.

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