Comparison of body composition assessments by bioelectrical impedance and by anthropometry in premenopausal Chinese women

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Fat-free mass (FFM) was estimated in forty-seven premenopausal Chinese women, aged 18–43 years, from anthropometric data (skinfolds, body mass index (weight/height^2; BMI)) or bioelectrical impedance, using several prediction formulas for body composition from the literature, and values compared with the mean of these three individual methods used as a frame of reference. In thirty-six women these values could be compared with FFM calculated from total body water (TBW) determined by D_2O dilution. The prediction formulas used were developed from studies on Caucasian adults and their validity will have to be shown in populations with different ethnic backgrounds. The mean difference between FFM predicted from BMI and the frame of reference was 0·1 kg (95% confidence interval (CI) −0·1, 0·4), from bioelectrical impedance it was 0·5 kg (95% CI 0·3, 0·7), and from skinfolds it was −0·6 kg (95% CI −0·9, −0·4). The mean difference between FFM calculated from TBW and the frame of reference was higher (2·2 kg, 95% CI 1·2, 3·3). The results of the present study indicate that the three methods may be valid for predicting body composition in adult Chinese females, but further research is needed on development and cross-validation of prediction equations for body composition for Chinese.

Body composition: Anthropometry: Bioelectrical impedance

Many methods are available for the assessment of body composition, but only a few, e.g. anthropometry and bioelectrical impedance, are useful in field studies (Forbes, 1987; Lukaski, 1987). The advantages of these methods are that they are relatively inexpensive, non-invasive, and portable. Furthermore, bioelectrical impedance does not require highly skilled technicians. However, it should be mentioned that recently the advantage of using bioelectrical impedance above simple weight–height indices for assessing body composition has been questioned (Diaz *et al.* 1989; Deurenberg *et al.* 1991). It is of great importance that simple and cheap methods are validated for different populations.

Many equations have been developed for predicting body composition using bioelectrical impedance (Lukaski *et al.* 1985; Pasco & Rutishauer, 1985; Segal *et al.* 1988) or anthropometric indices such as skinfold measurements (Durnin & Womersley, 1974; Jackson & Pollock, 1978; Jackson *et al.* 1980) or body mass index (weight/height^2; BMI) (Womersley & Durnin, 1977; Deurenberg *et al.* 1991).

These equations were all developed from studies on adult Caucasian populations and may, therefore, only be valid for this particular group. Only a few studies have been reported where the applicability of these prediction formulas was validated in black populations (Zillikens & Conway, 1990, 1991).

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In a study on Chinese subjects by Jiang *et al.* (1991) body composition was studied using a multiple-tracer dilution method measuring total body water, extracellular water, plasma volume, and erythrocyte volume. Healthy Chinese male and female subjects were compared with a group of healthy Americans previously evaluated by similar dilution techniques. Jiang *et al.* (1991) concluded that Chinese have comparable body composition but no additional fat burden. The study by Jiang *et al.* (1991) was conducted on a relatively small number of subjects and the multiple-tracer techniques used are expensive and laborious, although they are highly accurate.

To our knowledge, no studies have been done on the validity of using Western prediction formulas for assessing body composition by anthropometry and bioelectrical impedance in Chinese people.

In the present study fat-free mass (FFM; kg) estimated by several prediction formulas from the literature using anthropometric values (skinfolds, BMI) or bioelectrical impedance measurements was compared in forty-seven premenopausal Chinese women. In thirty-six women these values could be compared with the FFM calculated from total body water (TBW) determined by D_2O dilution.

SUBJECTS AND METHODS

Subjects

Forty-seven non-pregnant premenopausal women aged 18–43 years, living in Beijing, China, were selected for this study. In thirty-six women TBW was determined by D_2O dilution and FFM was calculated from TBW by dividing TBW by 0·725 (Pace & Rathbun, 1945). All subjects had participated in a study on energy metabolism in relation to Fe deficiency. The subjects were involved in relatively heavy work in a cotton factory. They had no abnormalities in alanine aminotransferase (*EC* 2.6.1.2), chest X-ray, folic acid concentration in erythrocytes and serum, stool occult bleeding, or numbers of hookworm eggs in the stools. The subjects came to the hospital the night before the measurements were performed and stayed overnight. Each subject completed all tests in the same morning after voiding and after an overnight fast.

Methods

Anthropometry. Height and body weight were measured to the nearest 0·001 m and 0·1 kg respectively with a beam weighing scale and measuring system (SECA 220; Lameris, Utrecht, The Netherlands). The weight of the subject's clothes was measured separately and subtracted from the total weight. Percentage body fat was calculated from BMI using the age- and sex-specific prediction formula (Deurenberg *et al.* 1991). From percentage body fat the FFM was calculated.

Skinfold thickness was measured to the nearest 0·2 mm in triplicate at the triceps, biceps, subscapular and suprailiac on the right side of the body using a Holtain skinfold calliper (Holtain Ltd, Crymych, Dyfed, UK). The average of the three consecutive measurements was used in further analysis. One observer (F.D.W.) performed most of the measurements but a small number (< 10%) were performed by a second observer who had been trained by the same person to use similar techniques.

Body density (kg/l) was predicted from the logarithm of the sum of the four skinfold thickness measurements using the equations of Durnin & Womersley (1974). Percentage body fat was calculated from the body density values obtained using Siri's (1961) equation:

$$\text{percentage body fat} = (495/\text{body density}) - 450.$$

FFM was calculated from percentage body fat.

Bioelectrical impedance. All bioelectrical impedance measurements were performed with a bioelectrical impedance analyser (BIA 101; RJL Systems, Detroit, MI, USA) following the procedures described by Lukaski *et al.* (1985). The measurements were performed in duplicate without removing the electrodes and the mean value was used in further analyses. Measurements were taken on the right side of the body. FFM was calculated using the generalized regression equation of Segal *et al.* (1988), which includes resistance, height, weight, age and sex.

D_2O dilution. Thirty-six subjects received orally an accurately weighed 10 g dose of D_2O (999 g/kg) (Isotec, Miamisburg, OH, USA). Before administration of D_2O, urine was collected and a portion of the sample (blank) was retained. After administration of D_2O the subjects had breakfast consisting of two slices of bread, an egg, some jam, and 250 ml soya-bean milk. Urine was collected 2·5 h after administration of D_2O and a portion of the sample was retained . All urine samples were stored at $-20°$. D_2O analyses were performed by infrared absorption (Lukaski & Johnson, 1985).

TBW was calculated from the difference in concentration of D_2O in the urine before and after the dose (ΔD_2O), and the amount of D_2O given:

$$TBW = (given\ dose\ D_2O)/\Delta D_2O \times 0·95.$$

A 5% correction for non-aqueous dilution of D_2O was made. FFM was calculated from TBW with the assumption that FFM is hydrated to the extent of 720 g/kg (Pace & Rathbun, 1945).

Statistical analysis

The data were analysed using the Statistical Package for Social Sciences/PC (1988) programme. The estimates of FFM (kg) by skinfolds, bioelectrical impedance and BMI were compared with the individual mean of these three methods, which was used as a frame of reference, according to the method described by Bland & Altman (1986). Because of the lack of a 'gold' standard, it is assumed that the most valid estimate of FFM may be the mean of the three methods. Values are expressed as means and standard deviations. Differences in variables were tested using Student's *t* test; $P < 0·05$ was regarded as significant.

RESULTS

Table 1 shows some characteristics of the subjects. BMI was 21·4 (SD 4·2; range 17·6–29·5) kg/m².

In Table 2, values for FFM (kg) calculated using different prediction formulas are given. FFM from skinfold thickness was slightly lower than those of FFM from bioelectrical impedance (Segal-prediction) and BMI. The FFM estimated by bioelectrical impedance was 40·3 (SD 3·7) kg. The FFM of the thirty-six women calculated from the TBW measured by D_2O dilution was 42·1 (SD 4·6) kg.

Table 3 shows the mean differences between FFM predicted using a single method and the frame of reference, i.e. the mean of the three individual methods (BMI, bioelectrical impedance and skinfolds). The differences were small, although statistically significant for the FFM predicted by skinfolds and bioelectrical impedance. The mean difference between FFM calculated from D_2O dilution (*n* 36) and the frame of reference (in these thirty-six women) was somewhat higher (2·2 (SD 3·2) kg (95% confidence intervals (CI) 1·2, 3·3); $P < 0·001$).

Fig. 1 shows the plot of the difference between predicted FFM and mean of the three individual methods *v.* the frame of reference. The differences were not related to the mean FFM.

Table 1. *Physical characteristics of the subjects*

(Mean values and standard deviations)

	Mean	SD	Range
Age (years)	29·3	6·2	18–43
Height (m)	1·61	0·05	1·51–1·72
Wt (kg)	55·4	7·1	42·2–74·9
Body mass index (wt/height^2; kg/m^2)	21·4	2·8	17·6–29·5
Sum of four skinfolds (mm)*	55·7	18·9	24·9–97·7
Body impedance (Ω)	621	56	516–775

* Triceps, biceps, subscapular and supra-iliac.

Table 2. *Calculated fat-free mass (FFM) (kg) of premenopausal Chinese women using different prediction formulas*

(Mean values and standard deviations)

Prediction formula for FFM derived from:	Source	Mean	SD
Body mass index	Deurenberg *et al.* (1991)	40·2	3·3
Bioimpedance	Segal *et al.* (1988)	40·5	3·1
Skinfolds	Durnin & Womersley (1974)	39·4	3·3

For details of subjects and procedures, see Table 1 and pp. 658–659.

Table 3. *Mean difference* between predicted fat-free mass (FFM) and the mean of the three individual methods used for premenopausal Chinese women†*

(Mean values and standard deviations)

Predicted FFM derived from:	Source	Mean	SD	95%CI
Body mass index	Deurenberg *et al.* (1991)	0·1	0·8	−0·1–0·4
Bioimpedance	Segal *et al.* (1988)	0·5	0·7	0·3–0·7
Skinfolds	Durnin & Womersley (1974)	−0·6	0·8	−0·9–0·4

CI, confidence intervals.
* Difference = predicted minus the mean of the three individual methods.
† For details of subjects and procedures, see Table 1 and pp. 658–659.

In Fig. 2 the relationship between the frame of reference and the FFM calculated from TBW, determined by D_2O dilution, is given. The standard error of the estimate (3·3 kg) of this relationship was relatively large.

DISCUSSION

The prediction equations used in the present study were developed in Caucasian adults with hydrodensitometry as the reference method. They are based on a two-compartment model (body weight = fat mass + FFM), and may contain errors related to deviations in the composition of the FFM from the fixed values that are assumed (Coward *et al.* 1988). These
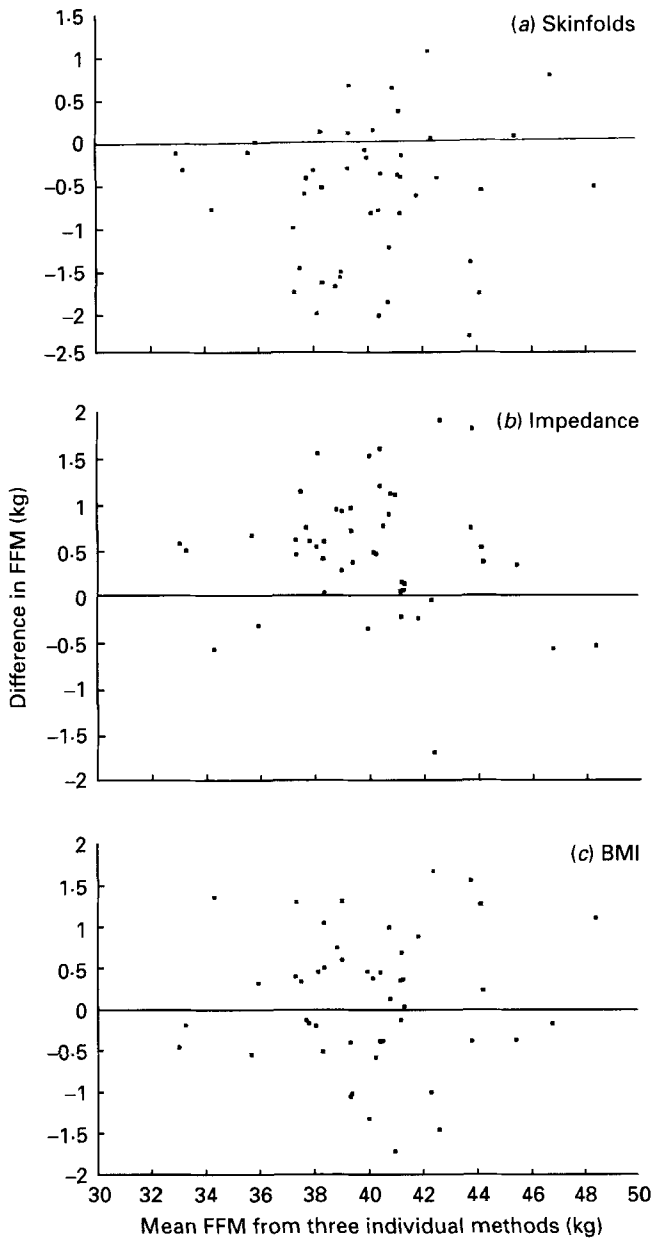
Fig. 1. Individual differences between predicted fat-free mass (FFM) from bioelectrical impedance (Segal *et al.* (1988), skinfold thickness (Durnin & Womersley, 1974), body mass index (BMI) (Deurenberg *et al.* 1991) and the frame of reference (mean of the three individual methods) for premenopausal Chinese women. For details of subjects and procedures, see Table 1 and pp. 658–659.

assumptions may not be valid in particular for: children; elderly people, who may have serious bone demineralization (Deurenberg *et al.* 1989); subjects with disturbed water homeostasis; ethnic groups (Harsha *et al.* 1978; Shutte, 1980; Davies *et al.* 1988; Zillikens & Conway, 1990, 1991; Baumgartner *et al.* 1991; Deurenberg *et al.* 1992). Baumgartner *et al.* (1991) suggested that loss in accuracy when equations developed in one sample are

Fig. 2 Regression between fat-free mass (FFM) estimated by deuterium oxide dilution and the frame of reference (mean from the individual methods; skinfolds, bioelectrical impedance, body mass index) for premenopausal Chinese women. For details of subjects and procedures, see Table 1 and pp. 658–659. $Y = 1\cdot1135X - 2\cdot28$, r $0\cdot74$, SE of estimate $3\cdot3$ kg.

applied to another may be due to differences between the samples in the distributions of components of the FFM that are not accounted for when criterion estimates are obtained using two-compartment models. They suggested that prediction equations for body composition for groups in which the assumptions are doubtful should be calibrated against estimates from multi-compartment models that consider variability in FFM composition. The most important constituents to consider in this respect are water, because it is the largest component, and mineral, because it is the most dense.

Zillikens & Conway (1990) have investigated the accuracy of generalized skinfold equations in black subjects and compared the fat pattern of black and white adults. D_2O dilution was used as the reference method. They demonstrated differences in fat pattern and fat distribution between black and white adults, with black adults showing more upper-body fat deposition marked by lower values for supra-iliac:subscapular skinfold thickness compared with white adults. Despite these differences in fat distribution between black and white adults, Zillikens & Conway (1990) found no reason to develop race-specific skinfold prediction equations. The Durnin & Womersley (1974) equations predicted percentage body fat, estimated by D_2O dilution, accurately. In another study Zillikens & Conway (1991) compared various bioelectrical impedance prediction equations and showed that TBW was significantly underestimated in black subjects by using equations developed in white populations.

Until now no systematic body composition studies in Chinese people have been performed to check the applicability of the commonly used prediction formulas for determining body composition by anthropometry or bioelectrical impedance and, eventually, to develop new, population-specific prediction formulas.

In the present study prediction formulas developed in Caucasian adults for estimating body composition from skinfold thickness, BMI and bioelectrical impedance were compared with a frame of reference (the mean of three individual prediction formulas). For skinfold measurements the age- and sex-specific equations for Durnin & Womersley (1974) were used; for bioelectrical impedance the prediction formula from Segal et al. (1988) was chosen because it had been cross-validated in four laboratories and a large study group was used (n 1567, of which 498 were women). The advantage of the relatively expensive bio-

electrical impedance method over simple anthropometric measures such as weight, height and/or skinfolds has been questioned (Diaz *et al.* 1989; Deurenberg *et al.* 1991). Therefore, the sex- and age-specific prediction formula for body composition from BMI (Deurenberg *et al.* 1991) was also included in the analysis. Estimates of body composition from skinfold thickness, bioelectrical impedance, and BMI are based on different principles, so each estimate is independent of those produced by one of the other methods. Despite these differences in principles these methods produced estimates of FFM which differed only slightly (Tables 2 and 3, Fig. 1). In a subgroup of thirty-six women TBW was determined by D_2O dilution and FFM was calculated from TBW. Because of the possible unreliability of some samples, caused by a transportation problem with weighed D_2O dose and urine samples, this method was not used as the reference method. The mean FFM calculated from D_2O dilution for the thirty-six women was 42·1 (SD 4·6) kg. The mean FFM from the frame of reference in this subgroup was 39·9 (SD 3·2) kg. The difference of 2·2 (SD 3·2) kg, ($P < 0.001$) may be due to errors in the prediction formulas as well as errors in the dilution technique caused by differences in hydration and/or bone mass density for Chinese women compared with Caucasian women.

Information on body composition and methods to predict body composition in Chinese subjects is very scarce. There is a need for validation of non-invasive methods that can be used in epidemiological and clinical studies on populations other than Western societies. The results of the present study indicate that the three methods used to predict body composition are comparable and reliable for the estimation of body composition in female Chinese adults. Further research is needed, however, on the development and cross-validation of prediction equations for Chinese subjects.

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