Original Article

Prediction of percentage body fat from anthropometry and bioelectrical impedance in Singaporean and Beijing Chinese

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Body composition was measured in 205 male and female Beijing Chinese and in 148 male and female Singaporean Chinese, age 34 (mean) (range 18–68) years and body mass index (BMI) 22.3 (15.9–38.5) kg/m². In Beijing Siri's two-compartment model based on densitometry was used as a reference technique and in Singapore Siri's three-compartment model based on densitometry and deuterium oxide dilution was used. In addition, body composition was predicted using equations based on anthropometry and bioelectrical impedance developed in Caucasian populations. Percentage body fat (BF%) predicted from BMI was systematically underestimated by about 1% in Beijing Chinese and by about 3.5% in Singaporean Chinese. The difference in bias (measured minus predicted BF%) between the two population groups could be explained by differences in frame size. The Durnin and Womersley equations for BF% based on skinfold thickness predicted BF% in the male and female Chinese groups adequately, with only a slight (less than 1% body fat) and not significant bias. The prediction of BF% based on the waist circumference (Lean's formula) resulted in an unbiased estimate of BF% in females (bias about 1% body fat), whereas in males the formula systematically underestimated BF% by 3.5–5%. Bioelectrical impedance underestimated BF% systematically by 3%, in males and females to about the same extent. The bias of all prediction formulas was positively correlated with the level of body fatness and, except for impedance, also negatively correlated with age. The negative association of the bias with age indicates that the age-related increase in body fatness is lower in Chinese than in Caucasians. It can be concluded of the studied prediction techniques that only the skinfold methodology using the equations of Durnin and Womersley give valid mean estimates for both Chinese males and females. The other techniques require the development of population-specific prediction formula.

Key words: anthropometry and bioelectrical impedance, body composition, body mass index, percentage body fat.

Introduction

The measurement of body composition is an important tool in the assessment of the nutritional status.[1,2] Historically, interest in body composition focuses on the measurement of body fat (for example in relation to obesity) or fat free mass (for example in relation to energy metabolism). There are a large number of techniques available for the assessment of body fat percentage (BF%), but many of these techniques are not applicable in epidemiological studies for various reasons.[3–5] Unfortunately, the most accurate techniques such as densitometry, isotope dilution or dual energy X-ray absorptiometry (DXA) are expensive and/or need specific skill of the operator and/or adequate cooperation of the subject.

For the detection of the prevalence of obesity in a population or in obesity management programmes, predictive methods for BF% are adequate tools as they are less costly and relatively easy to apply to large population groups. One main disadvantage of prediction formulas is that their validity is only proven in the population in which they were developed. If they are to be used in other populations, it is important to validate the formulas in subsamples before they can be generally applied.

Most prediction formulas are developed in Caucasian populations and their use and applicability in other ethnic groups is too often just assumed. There are indications that the validity of prediction equations is different among ethnic groups,[6–9] but this was not found in all studies.[10,11] Also, within one ethnic group differences in body parameters may exist which can lead to differences in the validity of predictive equations.[12]

The aim of the current comparative study was to test the validity of a few predictive methods for BF% based on simple anthropometric measurements and based on im-

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pedance in Beijing Chinese and in Singaporean Chinese adult subjects.

Subjects and methods

In total 353 subjects participated in this study, 205 Beijing Chinese (124 females and 81 males) and 148 Singaporean Chinese (75 females and 73 males). Characteristics of the subjects are shown in Table 1. The studies in the Beijing Chinese took place in 1994 and 1995 in the Institute of Preventive Medicine. Some of their data have been published earlier.[11] The Singaporean Chinese participated in body composition studies in 1998 as part of the National Health Survey and were measured in the School of Physical Education, Nanyang Technological University. Subjects in Beijing and in Singapore were not specially selected but volunteered after informed consent was obtained. Medical Ethical Committees in Beijing and Singapore approved the study protocols. All body composition measurements were done after the subject had fasted for at least 5 h.

Bodyweight was measured with subjects in underwear or in light indoor clothing to the nearest 0.1 kg using calibrated digital scales. Height was measured without shoes using a wall-mounted stadiometer (Lamersis; Utrecht, The Netherlands) to the nearest 0.1 cm with the Frankfurt plane horizontally. Body mass index (BMI) was calculated as weight/height^2 (kg/m^2). From BMI, age and sex BF% was predicted using an equation developed in Dutch Caucasians:[13]

$$BF\% = 1.2 \times BMI + 0.23 \times age - 10.8 \times sex - 5.4,$$

where age is in years and sex = 0 in females and 1 in males.

Sitting height was measured while sitting on a hard-boarded stool, Frankfurt plane horizontally, using a wall-mounted stadiometer. The distance from the seat to the floor was subtracted from the measurement. Relative sitting height as a measure of leg length relative to total height was calculated as sitting height/standing height.

Wrist width was measured with an anthropometric calliper (Lamersis; Utrecht, The Netherlands) at the left and the right side over the distal ends of the radius and the ulna to the nearest 0.1 cm. Knee width was measured at the left and right side in the sitting position, lower legs relaxed with the knee flexed at a 90° angle, over the femur condyles to the nearest 0.1 cm. The mean values of left and right widths were used in the statistical calculations.

Biceps, triceps, subscapular and supra iliac skinfolds were measured in triplicate according to Durnin and Womersley.[14] The mean values were used in calculations. BF% was predicted from skinfolds using the Durnin and Womersley equations.[14] Waist circumference was measured to the nearest 0.1 cm using a flexible tape, the subject standing erect, after a normal expiration, midway the distance between the iliac-crest and the lower rib margin. Hip circumference was measured to the nearest 0.1 cm at the level of the greater trochanters. The waist/hip ratio (WHR) was calculated as an indicator of body fat distribution. Body fat was predicted from waist circumference (cm) and age (years) using sex-specific formulas as published by Lean *et al.*:[15]

$$\text{Males: } BF\% = 0.567 \times waist + 0.101 \times age - 31.8,$$
$$\text{Females: } BF\% = 0.439 \times waist + 0.221 \times age - 9.4.$$

Tetrapolar, total body bioelectrical impedance, was measured at 50 kHz using a HumanIm impedance analyser (DS Dietosystem, Milan, Italy) at the left side of the body, using the electrode positioning as described by Lukaski *et al.*[16] Measurements were done with legs and arms slightly spread, within 5 min after lying supine. Measurements were performed at 20–22°C. From impedance total body water (TBW) was calculated as:

$$TBW = 0.557 \times height^2/impedance + 5.9,$$

where height is in cm and impedance at 50 kHz is in Ohms.[17] BF% was calculated as 100 × weight/(weight –TBW/0.73).

In Beijing body fat was determined using a two-compartment model (fat mass and fat-free mass), based on densitometry (underwater weighing with simultaneous lung volume determination). The methodology and the system used are described in detail elsewhere.[11] Siri's formula[18] was used to convert body density into BF%. In Singapore, BF% was measured using a three-compartment model based on densitometry (using air displacement, BODPOD[19]) and deuterium oxide dilution. The procedures are described in detail in an earlier publication.[12] Siri's[18] formula for a three-compartment model (fat mass, water and dry fat-free mass) was used for the calculation of BF%.

SPSS for Windows, Version 8.01[20] was used for statistical analyses. Differences in parameters between different groups (geographically or gender) were tested by analysis of covariance. Correlations between variables are Pearson's product moment correlations or partial correlations where appropriate. Differences between methods are shown in Bland and Altman plots.[21] Data are shown as mean ± SD unless otherwise indicated. The level of significance is set at 0.05%.

Results

Table 1 gives some characteristics of the subjects. Age did not differ between the Beijing and Singapore subjects.

Table 1. Characteristics of the subjects

	Singapore		Beijing		Singapore		Beijing	
	Females				Males			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	34.1	12.6	34.2	11.1	34.6	13.8	32.1	11.7
Height (cm)	158.0	5.5	161.2*	6.1	170.8	5.8	170.7	5.4
Weight (kg)	54.3	10.1	57.1*	9.4	65.5	9.6	66.1	9.1
BMI (kg/m^2)	21.8	4.4	22.0	3.2	22.4	3.2	22.7	3.0
Percentage body fat	31.7	7.3	29.7*	7.5	22.3	6.8	20.1*	6.2
WHR	0.78	0.07	0.79	0.07	0.86	0.06	0.86	0.05

BMI, body mass index; WHR, waist/hip ratio. * $P < 0.05$ within gender group between regions.

Beijing females were slightly taller, but also slightly heavier than the Singapore females. Although BMI did not differ significantly between the Beijing and Singapore males and females, BF% tended to be higher in Singaporeans, especially in the males. There was no significant difference in WHR between Beijing and Singapore Chinese.

Table 2 shows that skinfold thickness tended to be lower in Singaporeans, but the differences were only significant for the biceps (for males and females) and for the supra iliac (for females). Relative sitting height was not different between Beijing and Singaporean females, but was significantly lower in Singaporean males than in Beijing males. Most striking is the difference in impedance values, showing higher values in Singaporeans than in their Beijing counterparts.

Table 3 shows the bias for predicted BF% using different formulas from the literature.

BF% from BMI was significantly underestimated in Singaporean males and females, but not in Beijing females and only slightly in Beijing males. Skinfolds slightly overestimated BF% in females only, whereas BF% calculated from waist circumference was underpredicted in males only. Bioelectrical impedance underestimated BF% in males and females from Beijing and Singapore with about 3% body fat. Figure 1 shows for the four prediction methods the individual biases (measured minus predicted BF%) for males and females separately, plotted against the level of body fatness as measured by the reference technique.

For most methods the bias of predicted BF% was strongly correlated with the level of actual BF%. The correlation coefficients of the bias of predicted BF% from BMI, skinfold thickness, waist circumference and impedance with the level of body fatness were 0.41 ($P < 0.05$), 0.56 ($P < 0.05$), 0.51 ($P < 0.05$), 0.14 (NS) and 0.66 ($P < 0.05$), 0.59 ($P < 0.05$), 0.58 ($P < 0.05$) and 0.49 ($P < 0.05$) for the Singaporeans and Beijing females, respectively. For males these values were 0.60 ($P < 0.05$), 0.17 (NS), 0.39 ($P < 0.05$), and 0.07 (NS) for Singaporeans and 0.63 ($P < 0.05$), 0.34 ($P < 0.05$), 0.58 ($P < 0.05$) and 0.21 (NS) for Beijing males.

The bias of predicted BF% from BMI was in all subgroups related to body build. The strongest partial correlation (after correcting for level of body fatness) was found with wrist diameter ($r = –0.39$, $P < 0.05$) and with knee diameter ($r = –0.38$, $P < 0.05$. The difference in bias between the Beijing and Singapore population (mean ± SE: 2.1 ± 0.7, $P < 0.05$, see Table 3) disappeared after correcting for differences in wrist and knee diameter between the two population groups (0.3 ± 0.7, NS). The bias of predicted BF% from BMI was negatively correlated with age ($r = –0.20$, $P < 0.001$), also after correction for level of body fatness and parameters of body build.

The negative correlation of the bias with age was also found for predicted BF% from skinfolds ($r = –0.25$, $P < 0.001$) and became higher after correction for the level of body fatness in females ($r = –0.53$, $P < 0.001$)) as well as in males ($r = –0.63$, $P < 0.001$).

The bias of predicted BF% from waist circumference was correlated with age (females $r = –0.24$ $P < 0.01$; males $r = –0.20$ $P < 0.01$), and also after correction for level of BF% ($r = –0.74$ and $r = -0.50$ in females and males, respectively, $P < 0.001$). The bias was not correlated with height ($r = –0.11$ in both males and females, NS)

The bias of predicted BF% from impedance was comparable in all four subgroups and was in contrast to the abovementioned biases not related to age, and also not after correction for level of BF%.

Table 2. Anthropometric characteristics of the subjects

	Females				Males			
	Singapore		Beijing		Singapore		Beijing	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Biceps (mm)	10.2*	6.1	8.5	3.7	6.3*	2.7	5.0	1.9
Triceps (mm)	19.2	7.2	17.8	5.3	11.5	5.1	10.5	4.6
Subscapular (mm)	19.5	8.8	16.5	7.7	16.9	7.9	17.4	8.5
Supra iliac (mm)	22.8*	7.3	19.6	7.5	19.3	9.5	17.2	7.4
Knee width (cm)	8.9	0.7	8.8	0.6	9.6*	0.5	9.2	0.5
Wrist width (cm)	4.6*	0.3	5.1	0.3	5.3*	0.3	5.7	0.3
Waist circumference (cm)	74.0	10.3	73.1	10.1	80.4	10.0	79.7	8.3
Hip circumference (cm)	94.1	7.7	92.8	5.7	93.7	6.3	92.8	5.3
Relative sitting height	0.544	0.014	0.541	0.014	0.536*	0.013	0.542	0.011
Impedance at 50 kHz (Ω)	641*	91	599	71	506*	57	481	45

Relative sitting height, sitting height/standing height. * $P < 0.05$ within gender group between regions.

Table 3. Differences between measured and predicted body fat using different prediction equations

BF% reference method minus BF% from:	Females				Males			
	Singapore		Beijing		Singapore		Beijing	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Body mass index	3.1*	4.8	0.8	4.9	3.6*	4.5	1.7*	5.0
Skinfolds	–1.0	4.6	–1.0	5.0	0.6	3.7	0.0	5.1
Waist circumference	1.1	4.8	–0.6	5.0	5.0*	4.3	3.5*	4.9
Impedance	3.2*	5.0	3.2*	5.1	3.0*	4.6	3.6*	6.1

BF%, percentage body fat. *Different from zero ($P < 0.05$).

The relative contribution of the separate skinfolds to the sum of skinfolds did not differ between the two Chinese populations within each gender group (Fig. 2). As expected, the contribution of the trunk (subscapular and supra iliac) skinfolds to the total sum of skinfolds was higher in males. The waist circumference and the WHR were correlated with the trunk to total skinfold ratio, but the correlation was low (0.21 ($P < 0.05$) and 0.25 ($P < 0.05$) in females and 0.21 ($P < 0.05$) and 0.21 ($P < 0.05$) in males for waist and WHR respectively). Correcting for age and level of body fatness lowered the correlation.

Discussion

The subjects volunteering in the present study were not specially selected, so they were not specially lean or obese. They cannot, however, be regarded as representative of their respective populations. For a validation study such as the present one, this is also not a prerequisite. The BMI of the Beijing Chinese is comparable with reported mean values of populations in some big cities in China.[22] Weight, height, BMI, waist circumference and WHR of the Singaporean subjects are comparable with results recently obtained in the 1998 National Health Survey.[23]

The bias of all prediction equations was positively related to the level of body fatness (Fig. 1), thus at higher levels of body fatness BF% is underestimated. This underestimation is due to incorrect assumptions. For example, with weight gain (and hence increased BF%) the relative contribution of gained fat mass to gained bodyweight becomes greater, whereas the prediction of BF% from BMI assumes that is

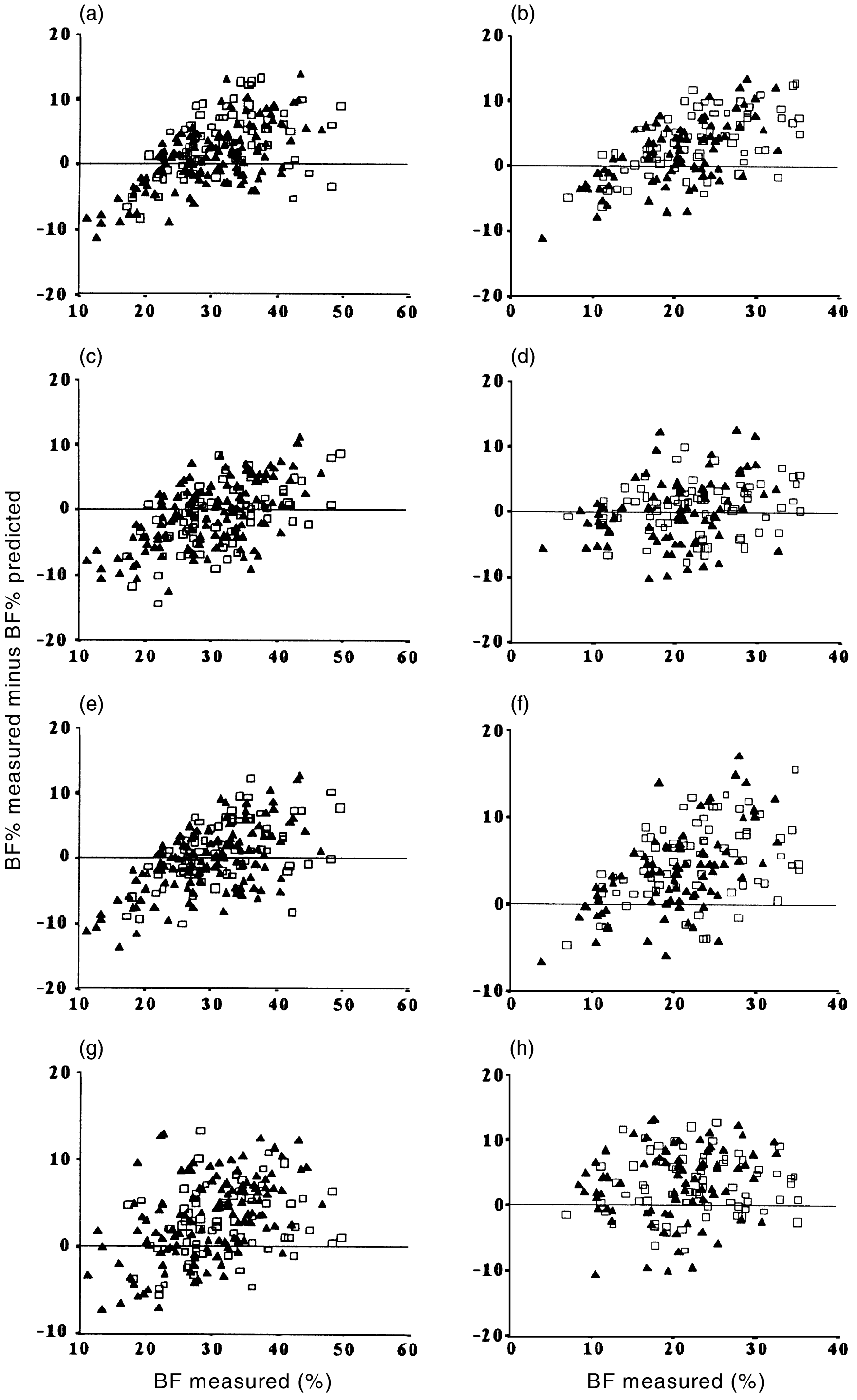

Figure 1. Individual bias of predicted body fat percent using different methods in females and males in (□) Singaporean Chinese and (▲) Beijing Chinese. (a) BMI in females; (b) BMI in males; (c) skinfold thickness in females; (d) skinfold thickness in males; (e) waist circumference in females; (f) waist circumference in males; (g) impedance in females; (h) impedance in males.

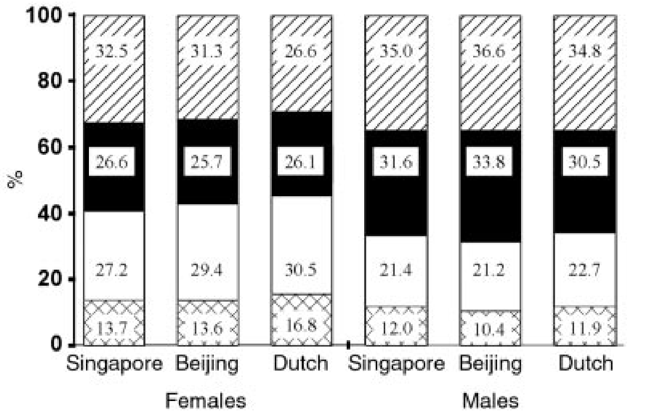

Figure 2. Distribution of relative skinfold thickness in the two Chinese groups in comparison with data from the Netherlands. (▨) Supra-iliac; (■) subscapular; (□) triceps; (▨) biceps.

constant. With skinfolds, the thickness of the subcutaneous fat layer is measured, which is assumed to be representative for total body fat. With increasing total body fat the relative amount of internal fat increases,[14] leading to an underestimation of BF% from skinfolds at higher levels of BF%. Storage of body fat in the abdominal region is limited, and the waist circumference does not take into account the fat storage in other locations of the body, thus BF% predicted from waist circumference will be an underestimation at high levels of body fat. In addition, with increasing fatness, there will be a shift in water distribution towards more extracellular water,[24] which lowers body impedance.[17] This will result in an overestimation of total body water, hence in an underestimation of BF%. The relationship of bias with the level of BF% is reported in most other studies and is a potential drawback of any prediction method.

Although BMI was comparable between the different study sites, BF% was higher in Singaporeans. Body fat predicted from BMI using a Caucasian prediction formula is known to underestimate body fat in Chinese subjects, and in Singaporeans it is more pronounced than in Beijing Chinese.[12] As in an earlier study using a selected study population matched on sex, age and BMI, the differences could be explained by differences in frame size.[12] The negative correlation of the bias with age shows that the age effect in the Dutch prediction equation used (regression coefficient for age = 0.23) is too high for Chinese, which is in accordance with earlier findings in Beijing Chinese[25] and with recent findings in Singapore.[23]

Percentage body fat predicted from skinfolds gave the best results, both in terms of mean bias as well as individual bias (Table 3 and Fig. 1). Although the prediction equations from Durnin and Womersley slightly overestimated BF% in females, the bias was not significant. In males the bias was less than 1% body fat. However, for skinfolds the bias also was negatively correlated with age, a correlation that became even higher when the level of body fatness was accounted for. Again this indicates that with age the increase in body fat in Chinese is less than in Caucasians.

The contribution of the separate skinfolds to the sum of skinfolds in the Chinese groups is slightly different when compared to a Dutch Caucasian group (Fig. 2). In the Dutch group, in females the contribution of the biceps and triceps seems to be slightly higher and the contribution of the supra-iliac skinfold slightly lower. However, it cannot be excluded that these differences are due to observer bias.

Also the prediction of BF% from waist circumference was negatively related with age, and also here the effect became stronger after correcting for the level of body fatness. Again this is evidence that in Chinese the age-related increase in body fatness is lower than in Caucasians. From the very low and statistically not significant correlation of the bias of predicted BF% from waist circumference with height, it can be concluded that the validity of Lean's prediction equation[15] is not impacted by height. This is found in an earlier publication in Caucasians from the UK and the Netherlands.[26] The reason for the difference in validity of Lean's equation between males and females (Table 3) is unclear.

Bioelectrical impedance underestimates BF% in all four subgroups to about the same extent. A possible explanation may be the relatively short legs of the Chinese subjects in relation to the Caucasians in which the prediction formula was developed. It is well known that Asians have relatively short legs[12,27] compared to Caucasians. As the legs contribute to a disproportionate part (in relation to body water) to total body impedance,[28] impedance values in subjects with short legs will be relatively low. Hence, TBW is overestimated and BF% will be underestimated. An overestimation of TBW from impedance using a Caucasian prediction equation was recently also found in Indonesians.[29]

It can be concluded that of the tested predictive methods, only the skinfold methodology using the Durnin and Womersley equation[14] gives valid estimates of percentage body fat in the studied Chinese groups. Lean's formula[15] based on the waist circumference appeared to be valid only in females and not in males, whereas the use of impedance or BMI require the development of new, population-specific equations. The negative association of the individual bias of all tested predictive methods with age shows that the age-related increase in BF% is lower in Chinese people than in Caucasians.

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