Original Article

Validation of skinfold thickness and hand-held impedance measurements for estimation of body fat percentage among Singaporean Chinese, Malay and Indian subjects

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Body fat percentage (BF%) was measured in 298 Singaporean Chinese, Malay and Indian men and women using a chemical four-compartment model consisting of fat, water, protein and mineral ($BF\%_{4C}$). In addition, weight, height, skinfold thickness and segmental impedance (from hand to hand) was measured. Body fat percentage was predicted using prediction equations from the literature (for skinfolds $BF\%_{SKFD}$) and using the manufacturer's software for the hand-held impedance analyser ($BF\%_{IMP}$). The subjects ranged in age from 18–70 years and in body mass index from 16.0 to 40.2 kg/m^2. Body fat ranged from 6.5 to 53.3%. The biases for skinfold prediction ($BF\%_{4C}$–$BF\%_{SKFD}$, mean ± SD) were –0.4 ± 3.9, 2.3 ± 4.1 and 3.1 ± 4.2 in Chinese, Malay and Indian women, respectively, the Chinese being different from the Malays and Indians. The differences were significant from zero ($P < 0.05$) in the Malays and Indians. For the men, the biases were 0.5 ± 3.8, 0.0 ± 4.8 and 0.9 ± 4.0 in Chinese, Malays and Indians, respectively. These biases were not significantly different from zero and not different among the ethnic groups. The biases for hand-held impedance BF% were –0.7 ± 4.5, 1.5 ± 4.4 and 0.4 ± 3.8 in Chinese, Malay and Indian women. These biases were not significantly different from zero but the bias in the Chinese was significantly different from the biases in the Malays and Indians. In the Chinese, Malay and Indian men, the biases of $BF\%_{IMP}$ were 0.7 ± 4.6, 1.9 ± 4.8 and 2.0 ± 4.4, respectively. These biases in Malay and Indian men were significantly different from zero and significantly different from the bias in Chinese men. The biases were correlated with level of body fat and age, and also with relative arm span (arm span/height) for impedance. After correction, the differences in bias among the ethnic groups disappeared. The study shows that the biases in predicted BF% differ between ethnic groups, differences that can be explained by differences in body composition and differences in body build. This information is important and should be taken into account when comparing body composition across ethnic groups using predictive methods.

Key words: body composition, Chinese, ethnic groups, impedance, Indians, Malays, Singapore, skinfolds, validation.

Introduction

The assessment of body composition in populations, as well as in individuals, is important as it provides information about nutritional status and health risks.[1–3] In many Asian countries, the prevalence of obesity is increasing, especially in the higher socioeconomic classes and in urban areas.[3–5] Population studies, mainly in Europe and the USA, have shown that increases in relative weight or body mass index (BMI, weight kg/height m^2) produce corresponding increases in morbidity and mortality.[1] This has recently been confirmed in various Asian populations as well.[4,6,7] The WHO defines the cut-off points for overweight and obesity as 25 kg/m^2 and 30 kg/m^2, respectively,[3,8] as morbidity and mortality starts to increase in (Caucasian) populations beyond these values. However, there is growing evidence that these cut-off values are not valid for all populations.[8–14] The relationship between BMI and BF% differs among ethnic groups and it is the amount of body fat, rather than the amount of excess weight, that determines the health risks of obesity.[1,3] For this reason body fat measures are preferable to weight measures (corrected for height) in determining possible health risks in individuals as well as in populations.

Measuring body composition is challenging and, depending on the chosen technique, requires sophisticated and expensive instrumentation[15,16] as well as experienced operators. In contrast, assessment methods are more suitable for epidemiological studies because they are relatively low cost. However, their accuracy is generally lower.[15,17] Three methods are suitable for epidemiological measurements, in principle. These are BMI, skinfold measurements and bioelectrical impedance. Body fat percentage can be predicted from BMI,

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Accepted 2 May 2001

but equations need to be age, sex and ethnic specific.[9,12,13,18–20] Skinfold thickness measurements provide good estimates of body fat,[21] but the observer needs to be skilled to obtain reliable measurements. In contrast, bioelectrical impedance is relatively easy to perform.[22,23] In bioelectrical impedance measurements, a small alternating current is passed through the body and its conductance is measured.[24] The conductance is mainly determined by the amount of water in the body, which is only present in the fat-free mass. Impedance measurements therefore allow assessment of the fat-free mass and, by difference with body weight, assessment of body fat percentage.[24]

The classical (total body) bioelectrical impedance method measures impedance from foot to hand.[22] Earlier studies[25,26] have shown that segmental impedance measurements (measuring defined parts of the body, such as the legs or the arms) also provide an assessment of body composition. Based on these observations, impedance analysers have been developed to measure segmental impedance. Instrumentation is commercially available in which impedance of the legs (from foot to foot) is simultaneously measured with body weight while the subject stands on a weighing scale.[27,28] Other instruments measure impedance of the arms (from hand to hand) and software in the instrument allows assessment of body fat percentage,[29] using weight, height, age and sex as additional parameters. Such segmental impedance instruments are easy to use and have the advantage of being relatively inexpensive as they are designed for consumer use. Generally, prediction formulae for body composition tend to be population specific due to cross-population differences in the parameters that are used in the equation.[17,30]

The aim of the present study was to test the validity of predicted body fat using a commercial (hand-held) impedance analyser and the skinfold methodology among Singaporean Chinese, Malay and Indian subjects. A chemical four-compartment model was used as the method of reference.

Materials and methods

In total, 298 Singaporean Chinese, Malay and Indian subjects, aged 18–69 years, participated in the study. Subjects were selected from a bigger sample that took part in a national nutrition survey. Selection criteria were: a wide range in BMI over the age range of 18–70 years and approximately equal numbers in the three ethnic and two gender groups. Subjects fasted from food and drink for at least 6 hours and voided prior to the measurement session. Trained observers performed all measurements. The National Medical Research Council approved the study protocol and all subjects gave their written informed consent.

Body weight was measured to the nearest 0.1 kg in light indoor clothing using a digital scale. A correction of 0.5 kg was made for clothing. Body height was measured using a wall-mounted stadiometer to the nearest 0.1 cm. Arm span was measured to the nearest 0.5 cm, from middle fingertip to middle fingertip, using a wall-mounted grid card with the subjects standing erect against the wall and arms spread horizontally. BMI was calculated from weight and height. Relative arm span was calculated as span/height (cm/cm).

Four skinfolds (biceps, triceps, subscapular and suprailiac) were measured over the left side of the body and the sum of skinfolds was used to assess body fat percentage.[21] Body fat was estimated using a hand-held impedance analyser ($BF\%_{IMP}$), following the instructions provided by the manufacturer (Omron BF306, Omron Healthcare Europe BV, Hoofddorp, Netherlands). Personal particulars (weight, height, age and sex) were keyed into the instrument. The device was held while both arms were stretched horizontally in front of the body. The instrument recorded the impedance from hand to hand and subsequently calculated body fat percentage within seconds, based on the entered personal particulars and impedance value. The incorporated formula is not known. As a reference method for body fat measurements, a chemical four-compartment model was used[31,32] and body density, bone mineral content (BMC) and total body water (TBW) were determined.

Body density was derived from air displacement plethysmography (BODPOD® Body Composition System, Life Measurement Instruments, Concord, CA, USA). This method is comparable with underwater weighing for measuring body density.[33–35] A concise description of the principles of the air displacement plethysmography is provided by Sardinha *et al.*[36] Body volume was calculated as weight/body density.

Bone mineral content (BMC) was measured using a Hologic whole body dual energy X-ray absorptiometer (QDR-4500, software version V8.23a:5, Hologic, Waltham, MA, USA). As Hologic measurements result in systematically lower BMC measurements than Lunar DXA measurements,[37] the BMC data were corrected to 'Lunar values' using a correction factor (1.167) based on phantom measurements.[12] This was necessary as the equation for Baumgartner's four-compartment model uses Lunar DXA.[31] Using BMC, total body mineral was calculated as 1.235 × BMC.[31,38]

Total body water (TBW) was determined using deuterium oxide dilution.[16] The subjects took an accurately weighed dose of 10–15 g deuterium oxide orally and, after a 2.5–3 h dilution time, a venous blood sample of 10 mL was drawn. Plasma was separated and stored at –20 °C prior to analysis. Deuterium was determined by infrared spectroscopy[39] after sublimation of the plasma. TBW was calculated using a 0.95 correction factor for nonaqueous dilution of deuterium.[16]

BF% was calculated using the four-compartment model, as described by Baumgartner *et al.*[31] and Wang *et al.*:[38]

$$BF\% = 100\times(2.75 \times BV - 0.714 \times TBW + 1.148 \times M - 2.05 \times BW)/BW$$

where BV = body volume, TBW = total body water, M = total body mineral and BW = body weight.

Statistical analyses were performed using SPSS Version 10.0.[40] Differences in parameters between ethnic groups and between men and women were tested using ANOVA with Bonferroni posthoc analyses. A one-sample *t*-test was used to test the bias of predicted BF% for significance. Pearson's correlation and partial correlation analyses were used to study the dependency of the bias on other parameters. Analysis of covariance (ANCOVA) was used to correct for variables. Bland and Altman plots[41] are used to visualise the validity of predicted BF% at an individual level. Results were expressed as mean ± SD, unless otherwise indicated. Significance was set at $P < 0.05$.

Results

The characteristics of the study population are shown in Table 1. The normal physiological differences between men and women were observed within each ethnic group, with women having lower body heights, lower body weights and higher body fat percentages than men. Cross-comparison between the ethnic groups revealed that all parameters were significantly different within gender, except age in women. Notable was the much higher BMI and BF% in the Malay and Indian subjects, compared to the Chinese. Indians had significantly longer arms (compared to their height) than Chinese and Malays.

The correlation between $BF\%_{4C}$ and $BF\%_{IMP}$ was 0.87 ($P < 0.001$) and the standard error of estimate (SEE) of the regression between these two parameters was 4.5%. The correlation between $BF\%_{4C}$ and $BF\%_{SKFD}$ was 0.88 ($P < 0.001$) and the SEE of the regression was 4.2%.

Table 2 provides the biases of estimated BF% from skinfolds and from impedance (bias = $BF\%_{4C} - BF\%_{PREDICTED}$) for each gender and ethnic group. For $BF\%_{IMP}$, the biases were positive and significantly different from zero in Malay and Indian men. For $BF\%_{SKFD}$, the biases were positive and significant from zero in Malay and Indian women. The biases were not significantly different between the ethnic groups in the men for both impedance and skinfold prediction. The biases in impedance and skinfold prediction for the Chinese women differed from those of the Malay and Indian women.

Bland and Altman plots were used to show the bias of each prediction method (Fig. 1). These were correlated with the level of body fat. The overall correlations for the women were 0.60 for impedance and 0.53 for skinfold, while those for the men were 0.54 for impedance and 0.23 for skinfolds (all correlations $P < 0.01$).

Table 3 outlines the (partial) correlation of the bias with confounding variables. The bias of $BF\%_{IMP}$ is correlated with the level of body fat, age and relative arm span. Correlation with the level of body fat remains strong even after controlling for age and relative arm span. The correlation of the bias with age can be partly explained by the effect of body fat, as body fat increases with age. The correlation of the bias with relative arm span also remains after correction for age and BF%, but is more pronounced in women than in men. The biases of $BF\%_{SKFD}$ in both men and women are correlated with the level of body fat and age, with correlations being independent of each other.

As there are differences among the ethnic groups, such as age (in men), body fat and relative arm span, the biases were corrected for these variables using analysis of covariance. Figure 2 shows the bias before and after correction for the confounders. It is obvious that the differences in bias for impedance are due to differences in BF%, age (for men only) and relative arm span. The bias in predicted BF% from skinfolds can be explained by differences in BF% and age among the ethnic groups.

Table 1. Mean values for the physical characteristics of Singaporean Chinese, Malay and Indian subjects

	Women			Men		
	Chinese (*n* = 68)	Malay (*n* = 32)	Indian (*n* = 39)	Chinese (*n* = 72)	Malay (*n* = 40)	Indian (*n* = 47)
Age (years)	34.6 ± 12.4	35.0 ± 13.8	35.6 ± 8.6	34.8^a ± 13.8	41.7^b ± 12.0	42.4^b ± 11.0
Height (m)	1.58^a ± 0.05	1.54^b ± 0.06	1.56^a ± 0.06	1.71^a ± 0.06	1.66^b ± 0.07	1.69^a ± 0.06
Weight (kg)	54.3^a ± 9.6	57.5^a ± 11.2	61.4^b ± 14.0	65.7 ± 9.5	69.7 ± 12.4	69.8 ± 10.1
BMI (kg/m^2)	21.8^a ± 4.2	24.3^b ± 4.7	25.2^b ± 5.2	22.5^a ± 3.1	25.1^b ± 3.8	24.4^b ± 3.4
RAS	0.992^a ± 0.022	1.002^a ± 0.028	1.017^b ± 0.028	1.014^a ± 0.021	1.017^a ± 0.022	1.024^b ± 0.022
BF%	32.4^a ± 7.6	37.7^b ± 6.4	39.1^b ± 6.5	22.4^a ± 6.7	26.5^b ± 7.4	28.3^b ± 5.1

Each value is the mean ± SD. For each row and gender group a, b and c indicate significant differences ($P < 0.05$) between the ethnic groups. BF%, body fat percentage from four-compartment model; BMI, body mass index; RAS, relative arm span.

Table 2. Bias of predicted body fat percentage using impedance or skinfolds on Singaporean Chinese, Malay and Indian subjects

	Women			Men		
	Chinese (*n* = 68)	Malay (*n* = 32)	Indian (*n* = 39)	Chinese (*n* = 72)	Malay (*n* = 40)	Indian (*n* = 47)
$BF\%_{4C} - BF\%_{IMP}$	– 0.7^a ± 4.5	1.5^b ± 4.4	0.4^b ± 3.8	0.7 ± 4.6	1.9* ± 4.8	2.0* ± 4.4
$BF\%_{SKFD}$	– 0.4^a ± 3.9	2.3^{*b} ± 4.1	3.1^{*b} ± 4.2	0.5 ± 3.8	0.0 ± 4.8	0.9 ± 4.0

Each value is the mean ± SD. *$P < 0.05$. For each row and gender group a, b and c indicate significant differences ($P < 0.05$) between the ethnic groups. $BF\%_{4C}$, body fat percentage measured using a chemical four-compartment model consisting of fat, water, protein and mineral; $BF\%_{IMP}$, body fat percentage measured using impedance analyser; $BF\%_{SKFD}$, body fat percentage measured using skinfold thickness.

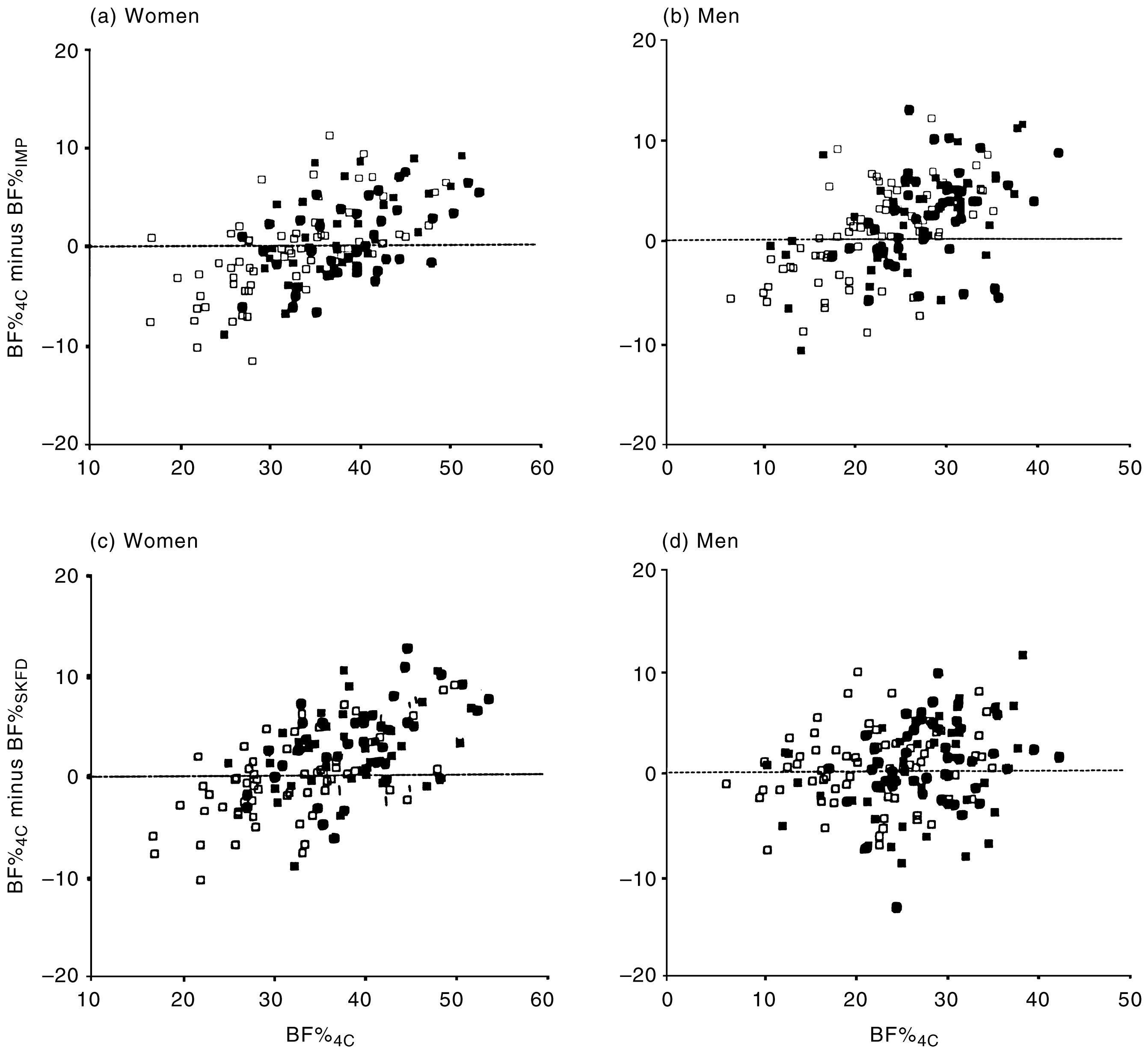

Figure 1. Individual bias of predicted body fat percentage in relation to level of body fat for (a,b) hand-held impedance and for (c,d) skinfold thickness, in (●) Indian, (■) Malay and (□) Chinese subjects.

Discussion

The subjects in the various ethnic groups were specially selected. This was done in order to ensure a wide range in age and BMI within each ethnic group. For a validation study such as the present one, it is better to have a wide range in age and apparent body fat in the study sample than a representative sample of the population with a relatively low representation of minor (ethnic) groups. The differences in weight and BMI among the ethnic groups, as reported in the current study population, are comparable with values in the total population of Singapore, where the Malays and Indians have BMI that are higher than in the Chinese population.[7]

The prediction formula incorporated in the impedance analyser was developed in a Caucasian population (pers. comm: Omron Healthcare Europe BV, Hoofddorp, Netherlands) and has been recently validated in five European populations.[42] Prediction equations for body composition tend to be population specific due to differences in predictors among population groups.[43] Bioelectrical impedance assesses the amount of water in the body and is used to calculate BF%, assuming a constant hydration of the fat-free mass.[28,44] An additional assumption in segmental impedance is that the water content of the measured body segment is representative of the total body.

Table 3. (Partial) correlation coefficient of bias of predicted body fat percentage with other variables, on Singaporean Chinese, Malay and Indian subjects

	Women			Men		
	BF%	Age	RAS	BF%	Age	RAS
Bias of $BF\%_{IMP}$	0.60	0.29	– 0.25	0.54	0.08 NS	– 0.09 NS
Controlling for						
BF%	—	0.02 NS	– 0.32	—	– 0.19	– 0.15
Age	0.55	—	– 0.27	0.55	—	– 0.09 NS
RAS	0.62	0.30	—	0.55	0.08	—
Age and RAS	0.57	—	—	0.57	—	—
BF% and RAS	—	0.03 NS	—	—	– 0.20	—
BF% and Age	—	—	– 0.32	—	—	– 0.16
Bias of $BF\%_{SKFD}$	0.53	– 0.19	—	0.23	—	– 0.42
Controlling for						
Age	0.71	—	—	0.49	—	—
BF%	—	– 0.57	—	—	– 0.58	—

All correlations significant ($P < 0.05$) unless otherwise indicated. Ethnic groups are combined and controlled for in the analyses. BF%, body fat percentage; $BF\%_{4C}$, BF% measured using chemical four-compartment model consisting of fat, water, protein and mineral; $BF\%_{IMP}$, BF% from impedance; $BF\%_{PREDICTED}$, BF% predicted from impedance and skinfolds; $BF\%_{SKFD}$, BF% from skinfolds; bias, $BF\%_{4C} - BF\%_{PREDICTED}$;; NS, not significant; RAS, relative arm span.

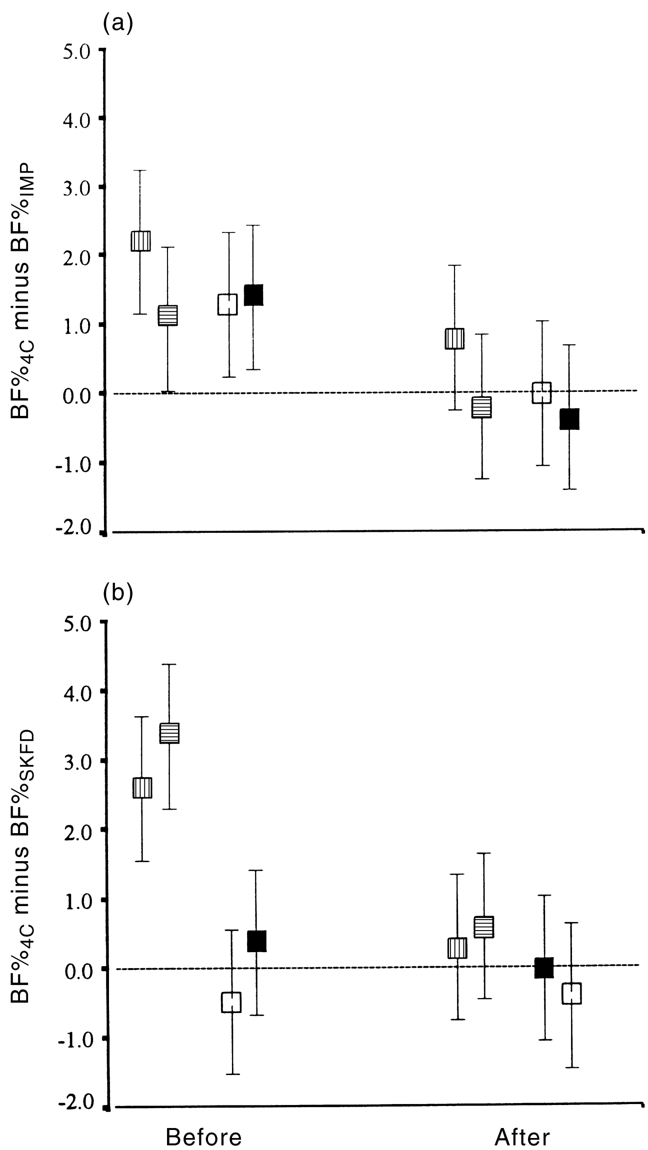

Figure 2. Biases (mean, SE) of predicted body fat percent from (a) hand-held impedance and from (b) skinfold thickness before and after correction for confounders. Biases are relative to Chinese (set to zero). Before, before correction; After, after correction for body fat percentage, relative arm length and age (for hand-held impedance) and for body fat percentage and age (for skinfolds). Male: (■) Indian, (□) Malay. Female: (▤) Indian, (▥) Malay.

BF% as predicted by the BF306 impedance analyser was close to the measured value given by the four-compartment model. However, in Malay subjects and Indian men the biases in predicted BF% were remarkably high and significantly different from zero. In both men and women, the bias is dependent on the level of body fat. This dependency of bias on the level of body fat has been found for many prediction formulae, and can be explained by various factors. The hand-held impedance analyser measures impedance from hand to hand, assuming that the amount of body water in the arms is representative of the total body. With increasing age, the amount of body fat in the trunk increases,[3,7,16] and this is not taken into account when segmental impedance is measured. In addition, the amount of intra-muscular fat increases with increasing age, also in the arms, which will affect the relationship between arm impedance and total body water/fat-free mass. Further, the distribution of extra- and intracellular water changes toward a higher relative amount of extracellular water with increasing age,[16,17] and impedance at 50 kHz frequency is not fully capable of distinguishing between the two.[17,24]

Segmental impedance measurements, like total body impedance measurements, are also affected by the length of the extremities.[22,25,26] Subjects with relatively longer arms or with thinner arms have higher arm impedance values compared to their counterparts with shorter or thicker arms, also when the total amount of water in the arms is equal.[43] This was confirmed in the present study by the correlation between the bias and relative arm span (Table 3). There were differences in age (in men), in body fat and in relative arm span between the ethnic groups (Table 1). Taking these factors into account in the statistical analyses resulted in remarkably smaller and non-significant differences in bias among the ethnic groups (Fig. 2). This shows that although the validity of the assessed body fat percentage is reasonable, the prediction can be improved if population-specific prediction equations are incorporated in the instrument. However, from a practical perspective this is nearly impossible as there might be as many equations needed as there are population groups. In addition, the variation in factors causing bias among groups is also high within groups.[30]

The bias in BF% predicted from skinfolds also differs among the ethnic groups (Table 2), with age and level of body fat as confounders (Table 3). Many studies have found a relationship between bias and both body fat level and skinfolds,[44,45,46] and this can be explained. With increasing body fat, relatively more fat is stored internally and this fat escapes the measurements taken when using skinfold calipers.[17] In many studies using a two-compartment model as method of reference, the method of reference may be biased too.[17,31,32] It is likely that in extreme obesity the composition of the fat-free mass changes, and with that, the assumptions of a constant density[47] and a constant hydration.[44] The use of a four-compartment model, as in the current study, prevents bias due to violation of assumptions in the reference method.[48] The observation that the bias correlates with age is also important. It shows that the stratification in age groups noted by Durnin and Womersley[21] is not optimal in this population, and that the age-related increase in body fat percentage that they observed in the Caucasian (Scottish) population does not apply to the present population. Other studies in Asian countries suggest that the increase in body fat with age is lower in Asians than in Caucasians.[9,12,13,49] This suggests that Asian sex- and age-specific prediction equations for predicting body fat from skinfolds may be needed for better predictions. The observation that the distribution of the subcutaneous fat layer may differ slightly between Asians and Caucasians[50] is another reason to consider the development of ethnic specific prediction formulae.

The overall correlation between $BF\%_{4C}$ and $BF\%_{SKFD}$ was slightly higher than the correlation between $BF\%_{4C}$ and $BF\%_{IMP}$ and the SEE of the regression was slightly lower, indicating a slightly better predictive power from skinfolds. Experienced observers performed the skinfold measurements in this study and it may well be possible that in the hands of less experienced observers, the impedance methodology would result in better estimates of body fat percentage than skinfold thickness measurements. The SEE for both methods used in this study are comparable with prediction errors for various methods found in other studies.[18,21,28,46] As individual biases for both methods can be high (see also Fig. 1), individual results should be interpreted with caution.

Conclusion

The bias of body fat percentage predictions from both skinfold and segmental arm impedance measurements differs among Singaporean Chinese, Malay and Indian subjects. The observed bias is, however, relatively small and can be explained by differences in body composition, body build and age among the study groups. This observation shows that comparison of body composition across groups should be interpreted with caution. Individual biases are sometimes large with both predictive methods.

Acknowledgements. The study was granted by the National Medical Research Council Singapore. Deuterium analyses were performed by Frans JM Schouten, Wageningen University, The Netherlands. Fu Poh Lin (Ministry of Health, Singapore) assisted with practical measurements. DXA analyses and BODPOD® analyses were made possible by the provision of Dr Gordon Schmidt (National Technological University, Singapore).

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