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The impact of body build on the relationship between body mass index and percent body fat

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OBJECTIVE: The objective of the study was to test the hypothesis that differences in the relationship between percent body fat (%BF) and body mass index (BMI) between populations can be explained (in part) by differences in body build.
DESIGN: Cross-sectional, comparative study.
SUBJECTS: 120 age, gender and BMI matched Singapore Chinese, Beijing Chinese and Dutch (Wageningen) Caucasians.
MEASUREMENTS: From body weight and body height, BMI was calculated. Relative sitting height (sitting height/height) was used as a measure of relative leg length. Body fat was determined using densitometry (underwater weighing) in Beijing and Wageningen and using a three-compartment model based on densitometry and hydrometry in Singapore. Wrist and knee widths were measured as indicators for frame size and skeletal mass was calculated based on height, wrist and knee width. In addition, a slenderness index (height/sum of wrist and knee width) was calculated.
RESULTS: For the same BMI, Singapore Chinese had the highest %BF followed by Beijing Chinese and the Dutch Caucasians. Singaporean Chinese had a more slender frame than Beijing Chinese and Dutch Caucasians. Predicted %BF from BMI, using a Caucasian prediction formula, was not different from measured %BF in Wageningen and in Beijing, but in Singapore the formula underpredicted %BF by 4.0 ± 0.8% (mean $\pm$ s.e.m.) compared to Wageningen. The difference between measured and predicted %BF (bias) was related to the level of %BF and with measures of body build, especially slenderness. Correction for differences in %BF, slenderness and relative sitting height, decreased the differences between measured and predicted values compared to the Dutch group from 1.4 ± 0.8 (not statistically significant, NS) to -0.2 ± 0.5 (NS) in Beijing and from 4.0 ± 0.8 ($P < 0.05$) to 0.3 ± 0.5 (NS) in Singapore (all values mean $\pm$ s.e.m.).
CONCLUSIONS: The study results confirm the hypothesis that differences in body build are at least partly responsible for a different relationship between BMI and %BF among different (ethnic) groups.

Keywords: body mass index; percent body fat; body build; comparison; ethnicity

Introduction

Obesity is characterised by a percent body fat (%BF) > 25% in males and > 35% in females.[1–3] Normally, in epidemiological studies, the Quetelet index[4] or body mass index (BMI, weight/height^2, kg/m^2) is used as a measure of body fatness, although it is in fact an index that corrects weight for height.[5,6]

A number of studies found a fairly good relationship between %BF and BMI, as long as gender and age are taken into account.[7–10] There are strong indications that ethnicity may also be an important factor in the relationship between %BF and BMI [2,11–15] but differences between ethnic groups are not found in all studies.[10,16]

Several factors might be responsible for a dependency of the relationship between %BF and BMI on ethnicity, or population groups in general. There could be differences in physical activity level between groups and groups with a higher activity level might have a higher proportion of muscle mass in the body at the same body weight. This would result in an overestimation of %BF from BMI, using prediction equations developed in a less active population.[13,17] A second reason, discussed in the literature, is the impact of relative (to total height) leg length or relative sitting height on the BMI. Subjects with relatively long legs have a lower BMI,[18,19] thus %BF predicted from BMI is underestimated when a formula developed in subjects with 'normal' relative leg length is used. Asians have relatively short legs compared to Caucasians.[20] However, there is a large variation in relative leg length within populations, which may be a reason why some earlier studies failed to show an effect of relative leg length on %BF/BMI relation. A third reason for a different %BF/BMI relationship may be differences in body build. Subjects with a more slender body build

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(smaller frame) will not only have less skeletal mass at the same body height, but are likely to have less muscle mass and connective tissue. Several studies that focussed on the impact of body build on the %BF/BMI relationship could, however, not find an improvement in the prediction of %BF or relative weight,[6,21,22] when parameters of body build were taken into account. The reason may be that the groups studied were too homogeneous to find an effect.

The aim of the present study was to investigate the impact of anthropometric measures of body build on the relationship between %BF and BMI, taking age and gender into account. It was hypothesised that subjects with a smaller frame have higher %BF at the same level of BMI. For this, three different population groups with expected differences in body build were compared, Beijing Chinese, Singapore Chinese and Dutch (Wageningen) Caucasians.

Subjects and methods

For a body composition study in Singapore 40 subjects (14 female, 26 male) were pair-matched for gender, age (± 3 y) and BMI ($\pm 2\,kg/m^2$) with Beijing Chinese and Dutch Caucasians, measured in earlier studies.[9,16] The different study sites are indicated as Singapore, Beijing and Wageningen in this paper. All subjects were apparently healthy and were measured at least four hours post-prandial, most of them in the morning after an overnight fast. The participants in Singapore and Wageningen were mostly university students, not specially selected. In Beijing, the subjects were of a mixed socio-economic background. Unless otherwise stated, the measuring procedures were the same at each site. Medical Ethical Committees in Wageningen (also for Beijing) and Singapore, approved the body composition measurements.

Body weight was measured to the nearest 0.1 kg on an electronic scale, with subjects wearing only a swimsuit. Body height was measured barefoot with a wall-mounted stadiometer to the nearest 0.1 cm. BMI was calculated as weight divided by height squared (kg/m^2). From BMI, age (y) and gender (coded as 0 for female and 1 for male), %BF was predicted, using a prediction formula developed in a Dutch population:

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

The formula has a prediction error of 4.5% of body weight.[9]

Sitting height was measured using a wall mounted stadiometer with the subject sitting on a small chair with a flat and hard seat and their lower legs hanging relaxed. The height of the chair was subtracted from the reading. Relative sitting height was calculated as sitting height/standing height.

Wrist width was measured with an anthropometric calliper 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 femoral condyles to the nearest 0.1 cm. The mean values of left and right widths were used in the statistical calculations. From height, knee width and wrist width, skeletal weight was calculated using the formula of von Döbeln.[23] A parameter for slenderness was calculated as height/(sum of wrist and knee widths) (cm/cm): Obviously, a higher index indicates a more slender body build or frame.

Biceps, triceps, sub-scapula and supra-iliac skinfolds, were measured in triplicate at the left side of the body and the mean of the values was used in the calculations. %BF was assessed from skinfold thickness using the equations of Durnin and Womersley.[24]

In Beijing and Wageningen, %BF was measured using densitometry only (underwater weighing[25]). The two systems in Wageningen[9] and Beijing[16] are comparable in construction and residual lung volume is measured simultaneously with the underwater weighing using helium dilution.[9,16] From body density (D_{body}, kg/l) %BF was calculated using the formula of Siri[26]:

$$\%BF = 495/d_{body} - 450$$

In Singapore, a three-compartment model based on densitometry and deuterium oxide dilution was used, again following Siri[26]:

$$\%BF = (2.118/D_{body} - 0.78 \times A - 1.351) \times 100$$

where A is the water fraction of body weight. Body density in Singapore was determined using air displacement (BODPOD®).[27] Total body water (TBW) was determined using deuterium oxide.[5] For this, an exactly weighed dose of about 10 g deuterium oxide was given to the subjects and after three hours, a venous blood sample was taken. Deuterium in plasma was analysed using infrared analysis[28] and TBW was calculated using a 5% correction for non-aqueous dilution of the tracer.[29]

SPSS for Windows[30] was used for calculations. Differences in variables within the same groups were tested by paired *t*-test. Differences between groups were tested with ANOVA and, where appropriate, the separate groups were compared with Bonferroni test. Correlation coefficients are Pearson's product moment correlations or partial correlations, where indicated. The difference between measured and predicted %BF (residual) was tested by the method described by Bland and Altman.[31] The impact of body build on the difference between measured and predicted %BF was tested using analysis of covariance. Values are given as mean $\pm$ s.d. unless otherwise indicated. Significance levels are set at $P < 0.05$ (two sided).

Results

Table 1 shows some characteristics of the subjects. The Beijing and Singapore Chinese do not differ in any of the basic characteristics, but the Wageningen Caucasians are significantly taller and have higher body weight, although their BMI is not different from the two Chinese groups. Singaporeans have the highest %BF, but the difference is only significant compared to Wageningen. In Wageningen, predicted %BF from skinfolds was lower compared to measured %BF, but this was not found in Singapore and Beijing. In Singapore, %BF from densitometry (BODPOD), deuterium oxide dilution and the three-compartment model was 20.1 ± 7.7%, 23.0 ± 7.7% and 22.1 ± 7.7%, respectively. The values are significantly ($P < 0.05$) different from each other.

Table 1 Characteristics of the subjects

	Beijing		*Singapore*		*Wageningen*	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Males/females	26/14		26/14		26/14	
Age (y)	24.2	4.4	23.9	3.9	23.3	1.9
Height (cm)	168.4	7.6	169.1	8.7	176.5[a]	9.7
Weight (kg)	61.5	8.7	61.3	9.2	65.0	8.5
BMI (kg/m^2)	21.6	2.3	21.4	2.3	20.9	2.1
%BF Siri	19.9	6.0	22.1	7.7	17.4[b]	7.7
%BF skinfolds	20.4	6.1	21.4	8.3	15.9[a,b]	10.1

BMI = body mass index; %BF = body fat percent.
Body fat Siri: %BF from 2- or 3-compartment model (26).
%BF skinfolds: %BF using Durnin and Womersley[24] equations.
[a]Significantly different from Singapore and Beijing, ($P < 0.05$).
[b]Significantly different from Singapore, ($P < 0.05$).
[c]Significantly different from body fat Siri[26], ($P < 0.05$).

Table 2 gives parameters of body build in the three groups. Relative sitting height is highest in Beijing, followed by Singapore and Wageningen, indicating relatively shorter legs, especially in the Chinese compared to the Caucasians. Singaporeans tend to have the smaller frame among the two Chinese groups and their frame is significantly smaller than Wageningen. This is especially true for the wrist width. Calculated skeletal mass is lowest in Singaporeans, but the difference between Beijing and Singapore is not significant. Skeletal mass corrected for height is 0.4 kg higher in Wageningen ($P < 0.05$) compared to Beijing and is 0.9 kg higher compared to Singapore ($P < 0.05$). The slenderness index (height/sum of wrist and knee width) is highest in Singapore, followed by Beijing and Wageningen. Beijing and Wageningen do not differ significantly. The ratio between skeletal mass and fat free mass (FFM) is slightly, but significantly, higher in the Dutch.

Predicted %BF from BMI was 19.1 ± 5.2, 18.7 ± 5.2 and 18.0 ± 6.8 in Beijing, Singapore and Wageningen, respectively. The differences between measured and predicted %BF (residuals) of 0.8 ± 2.7, 3.4 ± 5.3 and − 0.6 ± 2.7 were significantly different from zero only in Singapore. The differences tended to be higher in the males of the three groups. In all three groups the residuals were correlated with the level of %BF (correlation coefficients are 0.50, 0.73, 0.49 in Beijing, Singapore and Wageningen, respectively, all $P < 0.001$).

Table 3 gives partial correlation coefficients of the residual for measured %BF with parameters of body build, for males and females separately as well as for the genders combined. The correlation of the residual with body build is obvious and is generally more pronounced in females. In females, relative sitting height is not correlated with the residual. BMI was not correlated with relative sitting height in females (**r** = 0.27, NS), but positively correlated in males (**r** = 0.33, $P < 0.05$).

Table 4 gives the differences between measured and predicted %BF in Beijing and Singapore, compared to Wageningen (which is set to zero in analysis of co-variance), with and without correction for parameters of body build after correction for %BF. Additional correction for sitting height, slenderness and

Table 2 Characteristics of body build in the three groups

	Beijing		*Singapore*		*Wageningen*	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Relative sitting height	0.542[a]	0.011	0.536	0.013	0.522	0.011
Knee width (L + R, cm)	17.7	0.9	17.9	1.0	18.8[b]	1.1
Wrist width (L + R, cm)	10.5[a]	0.9	9.7	1.1	11.0	0.8
Width (cm)	28.2	1.6	27.7	2.1	29.8[b]	1.7
Skeletal mass (kg)	9.9	1.4	9.6	1.7	11.5[b]	1.8
Slenderness	12.0	0.5	12.3[b]	0.6	11.8	0.4
Skeletal mass/FFM	0.20	0.01	0.20	0.01	0.21[b]	0.01

L = left; R = right; Width = sum of left and right knee and wrist widths; Slenderness = height/(sum of knee and wrist widths); FFM = fat free mass (kg).
[a] different between the three groups, ($P < 0.05$).
[b] different from other two groups, ($P < 0.05$).

Table 3 Partial correlation coefficients between residual of predicted percent body fat (%BF) with parameters of body build

	Height	*Rel SH*	*Knee*	*Wrist*	*Width*	*Skeleton*	*Slenderness*
Males[a]	0.21	− 0.31*	− 0.15	− 0.24*	− 0.23*	− 0.07	0.43*
Females[a]	− 0.22	0.20	− 0.56*	− 0.53*	− 0.63*	− 0.49*	0.66*
Males and females[b]	0.07	− 0.15	− 0.26*	− 0.32*	− 0.34*	− 0.19*	0.49*

Rel SH = relative sitting height; knee = sum left and right knee width; wrist = sum left and right wrist width; width = sum of left and right knee and wrist widths; skeleton = skeleton mass (kg)23; slenderness: height/width.
[a]corrected for level of %BF.
[b]corrected for level of %BF and gender.
*significant at $P < 0.05$.

Table 4 Differences between measured and predicted body fat percent (%B) in Singapore and Beijing before and after correction for parameters of body build compared to Wageningen[a]

	Correction[b]									
	1		*2*		*3*		*4*		*5*	
	Mean	*s.e.m.*	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*
Beijing	1.4	0.8	− 0.2	0.5	0.4	0.6	− 0.6	0.4	− 0.2	0.5
Singapore	4.0*	0.8	0.9*	0.5	1.4*	0.5	0.0	0.5	0.3	0.5
Explained variance %	16.6		75.7		76.6		80.8		81.1	

[a]Wageningen is set to zero in analysis of co-variance.
*$P < 0.05$.
[b]Corrections:
1. For gender
2. For gender and level of %B
3. For gender, level of %B and relative sitting height
4. For gender, level of %B and slenderness
5. For gender, level of %B, slenderness and relative sitting height.

specially slenderness plus sitting height decreases the error and increases the percent explained variance to more than 80%.

Discussion

For this study, three relatively small population groups were compared for their body composition and body build. The studied groups are by no means representative for their population and thus any general conclusions about Chinese compared to Caucasians, or about northern (Beijing) and southern (Singapore) Chinese cannot be drawn. The study only shows that differences in body build (shape) have an impact on the relation between BMI and %BF.

%BF was determined by underwater weighing using comparable equipment and procedures in Beijing and Wageningen and it can be assumed that the results are fully comparable.[32] In Singapore, no underwater weighing was available and body composition was measured by air displacement using a BODPOD[27] system and by deuterium oxide dilution.[5,29] BODPOD is a relatively new method and results comparing body density values from underwater weighing and BODPOD are not consistent.[33–36] Therefore it was decided to use a three-compartment model instead of deuterium oxide dilution or densitometry (BODPOD) alone, to avoid extreme errors in the method of reference for %BF. As shown by several authors,[26,37,38] a three compartment model consisting of water, dry FFM and fat mass (FM) is more reliable than a two compartment model and bias in one of the two methods used (deuterium oxide, densitometry) is levelled out.[39] The observed lower %BF values from BODPOD are consistent with some data in the literature.[34,35]

The Beijing Chinese could be easily matched with the Singapore Chinese, in terms of weight and height. The Wageningen group, however, is taller and has a higher body weight. These differences in height and weight reflect true differences between the three populations, as the Dutch are taller than the Chinese.[16] However, BMI is not different between the three study groups.

Body build parameters are clearly different between the three groups, Singaporeans having the most slender body build, which can be read from skeletal widths, as well as from the slenderness index. Calculated skeletal mass, using the prediction formula of von Döbeln,[23] is remarkably higher in Wageningen, compared to Singapore and Beijing. Also, after correction for the differences in body height, these differences remained and even became slightly higher between the two Chinese groups, again indicating the more slender body build in the Singapore group. It can be argued that the differences in skeletal widths are even higher, as it is known that skeletal width measurements, specially the knee width, are biased to higher values in subjects with higher %BF levels,[6,22] and %BF was highest in the Singapore group.

As known from the literature, relative sitting height is higher in Asians,[17,19] indicating relatively shorter legs. The described[18] relationship, of relative sitting height with the BMI could, however, not be found, except in males.

%BF predicted from BMI, was underestimated in Singapore, but not in Beijing. This confirms an earlier finding, that in the Northern Chinese, the used Dutch (Caucasian) prediction formula, gives valid results of %BF.[16] The residual of %BF (measured minus predicted %BF), was correlated with the level of %BF, which is found in earlier studies.[9,16] In testing for other explaining factors for the level of the residual, %BF was therefore taken into account. Partial correlation, correcting for %BF, shows that parameters of body build are relatively strongly correlated with the residual (Table 3). Analysis of co-variance (Table 4) finally shows that the differences in residuals between the three groups are markedly reduced after correcting for differences in body build, which confirms the formulated hypothesis that subjects with a smaller frame have higher %BF at the same level of BMI.

Earlier studies aimed to find effects of body build on the relation between BMI and %BF,[5,20,21] but failed to find an effect. The reason is most probably that the studied groups were too homogenous in body build and because of the relative high between-subjects-variability in body build, no effects could be found.

As can be read from Table 4, small, but not significant, differences in the residuals remain between the three groups. Apart from the fact that factors other than body build can have an impact on the validity of the BMI prediction formula in populations, it cannot be excluded that the method of reference, which was not the same in all three groups, is partly responsible for the remaining differences.

Conclusion

The present study confirms that the relationship between BMI and %BF is not only dependent on age and gender,[7–10] but also on ethnicity.[11,15,17] In fact, differences in body build between ethnic groups are important explaining variables. Further studies in larger population groups should aim to incorporate parameters of body build in the prediction of %BF from BMI.

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