Body mass index as predictor for body fat: comparison between Chinese and Dutch adult subjects

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The relation between body mass index (kg/m^2) and body fat from body density was compared in a group of Chinese and Dutch healthy subjects in relation to sex and age. The Dutch group was selected in relation to the Chinese group in that age, weight, height and body mass index did not exceed the maximal observed values of the Chinese subjects. Mean weight, height and body mass index was higher in the Dutch group, but body fat from density did not differ between the groups. Body fat predicted from body mass index, age and sex did not differ from the value obtained by densitometry in both countries. The correlation between measured body fat and predicted body fat was 0.84 ($p<0.001$) in the Chinese and 0.90 ($p<0.001$) in the Dutch. The difference between measured and predicted body fat was related to the level of body fatness ($r=0.55$, $p<0.001$), but did not differ between the countries. In different age groups there were slight differences in the measured minus predicted values of the countries, but these differences were less after correcting for differences in the level of body fatness in each age group. It is concluded that the relation between body fatness and body mass index is not different between the two studied populations.

Key words: Body density, underwater weighing, body mass index, body fat, body composition, adult, comparison, Siri's formula, Chinese, Dutch

Introduction

For population studies the body mass index, defined as weight (kg) divided by height (m) squared (kg/m^2), is regarded to be a simple but adequate measure of body fat[1-4]. Several studies have shown a good relation between densitometric determined body fat and the body mass index or between skinfold thickness and body mass index [5], correlation coefficients generally ranging from 0.6 to 0.9. However, the relationship between body fat and body mass index (BMI) is dependent on gender and on age[1,2,4] and may be different between different ethnic groups. The advantage of the BMI over other predictive methods to assess body fat like skinfold thickness or bioelectrical impedance is that the method requires no other instruments then a weighing scale and a stadiometer, and that the measurements are easy to perform with no or with only minor between-observer variance. In an earlier study we reported that in populations body fat can be predicted from BMI with an error comparable to skinfold thickness measurements, as long as sex and age specific formulas are used [4]. We were able to confirm this result in several other studies, performed in Dutch populations[6,7] as well as in a group of female Chinese workers[8]. As the BMI in developing countries is generally much lower compared to the BMI in western societies[5] and recently also a low mean body mass index was reported in a large population study in China[9] we analysed data of BMI and body fat from body density in a combined Chinese and Dutch population. The aim of the study was to test whether the relationship between body fat and BMI is different between a Caucasian population (Dutch) and an Asian population (Chinese)[4].

Subjects and methods

In the present study the data of 205 recently measured[10] healthy adult males and females living in the capital of China, Beijing were compared with the data of a healthy adult Dutch population. The Dutch subjects (n=189) were selected from a larger sample[4] in that body height, body weight, age and body mass did not exceed anthropometric values of the Chinese subjects and that they were comparable in age. Age ranged from 18 to 67 years, and was divided into age groups of 18-24, 25-34, 35-44 45-54 and 55+ years. Table 1 gives some characteristics of the two populations. The measurements in each country were approved by the Medical Ethical Committees of the Institutions.

In both studies the subjects were measured in the morning in the fasting state. Body weight and body height were measured accurate to 0.1 kg and 0.1 cm respectively. Body mass index (BMI, kg/m^2) was computed as weight divided by height squared. Body density was derived from underwater weighing. In Beijing the subjects were weighed completely immersed under water to the nearest 0.001 kg using a digital scale (Model IC34, Sartorius, Göttingen, Germany) while breathing through a respirometer (Volugraph VG 2000, Mijnhardt, Bunnik, The Netherlands) for simultaneous measurements of the residual lung volume (accurate to 0.1L). The lung volume measurement is based on helium dilution. The measurements in most subjects were performed in duplicate. The reproducibility (within subject variability) of body density measurements was 0.0024 kg/L[10]. In the Netherlands the underwater weighing system and the performance of the measurements is comparable; residual lung volume was measured also by helium dilution using a Spiro Junior respirometer (Jaeger GmbH, Würtzburg, Germany) with an accuracy of 0.01 L. The underwater weight was measured in duplicate to the nearest 0.001 kg with a digital scale (3826 MP 81 Sartorius, Göttingen, Germany). The reproducibility of the measurement is 0.0019 kg/L[11]. Body fat (BF%) was calculated from body density using Siri's[12] formula. Body fat was predicted from BMI using the Formula 1 equation[4]:

$$BFbmi = (1.20 * BMI) + (0.23 * age) - (10.8 * sex) - 5.4$$

In addition in the Chinese subjects the body fat percent was also predicted by a formula (Formula 2) developed in the present Dutch subjects (n=189):

$$BFbmi = (1.38 * BMI) + (0.25 * age) - (12.1 * sex) - 8.1$$

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and in the Dutch subjects by a formula (Formula 3) developed in the present Chinese subjects (n=205):

*BFbmi = (1.45 * BMI) + (0.11 * age) – (10.4 * sex) - 5.9*

in which age is in years and sex is coded as a dummy variable (females = 0, males = 1). The SPSS/PC[13] program was used for statistical analysis. Differences between measured and predicted BF% were tested by paired t-test. Stepwise multiple linear regression was used to analyse the relation between body fat from density and BMI, age and sex. Differences in slopes and intercepts between regression equations of the two countries were tested for significance using 'country' as a dummy variable[14]. Differences in variables between groups were tested by ANOVA. Corrections for confounding variables were made by analysis of co-variance. Correlations are Pearson's product-moment correlations. A probability of <0.05 is regarded to be significant. Values are expressed as mean ± SD.

Results

Table 1 gives the characteristics of the two populations. There were slightly more males in the Dutch population. Age and overall age distribution did not differ between the two groups, however the number of subjects in the different age groups were sometimes different between the two populations (Figure 1). Mean body fat from body density did not differ between the countries. Weight, height, total fat free mass, total fat mass and BMI were higher in the Dutch subjects.

Figure 1. Age distribution of Chinese and Dutch subjects participating in the study.

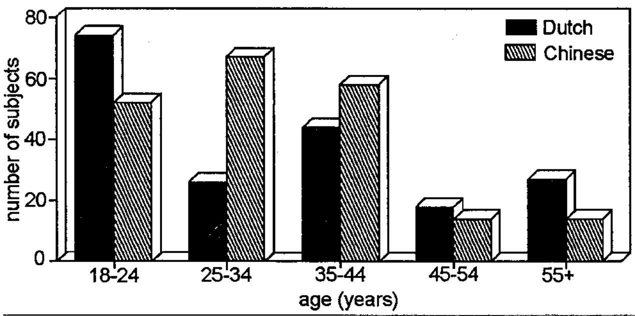

Table 1. Characteristics of the subjects.

	Chinese (n=205)		Dutch (n=189)	
	mean	SD	mean	SD
Age (years)	33.4	11.3	35.3	15.2
Female/male	0.4	0.5	0.5*	0.5
Weight (kg)	60.7	10.2	69.3*	9.8
Height (m)	1.65	0.07	1.72*	0.07
Body mass index (kg/m^2)	22.3	3.1	23.3*	2.9
Body fat %	25.9	8.4	26.5	9.6
Fat mass (kg)	15.9	6.3	18.5*	7.7
Fat free mass (kg)	44.8	8.3	50.8*	9.1

* p<0.05

Figure 2. Mean percent body fat Chinese and Dutch males and females of different age groups.

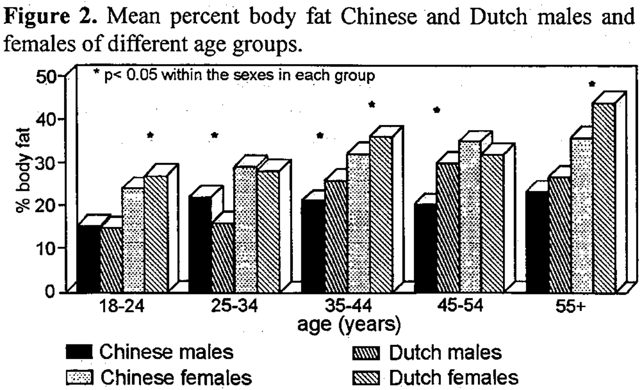

Figure 2 gives the BF% in males and females in the different age groups in the Chinese and the Dutch population. There was an increase in body fat in each sex group within each country, except in the Chinese males, but the correlation of body fat with age in years in each sex group and country was positive and significant. In the Chinese these correlation coefficients were 0.30 (p<0.01) and 0.52 (p<0.001) in males and females respectively, and in the Dutch these correlations were 0.70 (p<0.001) and 0.77 (p<0.001) in males and females respectively.

In the Chinese population body fat could be predicted from BMI, age and sex by stepwise multiple regression, resulting in the prediction equation (Formula 3):

BFbmi = 1.45*BMI + 0.11*age - 10.4*sex - 5.9 (r^2 = 0.83, standard error of estimated = 4.8% body fat).

In the Dutch population this relationship was (Formula 2):

BFbmi = 1.38*BMI + 0.25*age - 12.1*sex - 8.1 (r^2= 0.89, standard error of estimate = 4.3% body fat). In Table 2 the BF% from density and BF% predicted from the BMI using a general formula from the literature (Formula 1)[4] and using the developed prediction formulas of the other country group (Formulas 2 and 3) are listed. There were no significant differences between measured and predicted BF%, using either formula, indicating that there are no differences in the relationship between body fat and BMI when sex and age are taken into account. Also when country was used as a dummy variable in a regression model in the combined subjects, country did not enter into the model (p>0.95). The mean differences between measured and predicted body fat for the total group are listed separately in Table 3.

Table 2. Body fat from density and body fat predicted from body mass index using different prediction equations.

	Chinese				Dutch			
	mean	SD	range		mean	SD	range	
BFdens	25.9	8.5	3.9	46.8	26.5	9.6	5.7	50.2
BFbmi[a]	24.7	7.4	9.6	42.2	25.2	7.8	12.6	45.8
BFbmi[b]	26.2	8.3	9.2	45.6	26.7	8.7	12.6	49.8

a: Formula 1; b: Formula 2 for the Chinese subjects and Formula 3 for the Dutch subjects; BFdens, body fat percent from density; BFbmi, body fat percent from body mass index

Table 3. Differences between measured and predicted body fat in males and females in each population.

	Chinese				Dutch			
	males		females		males		females	
	mean	SD	mean	SD	mean	SD	mean	SD
BFdens-BFbmi[a]	1.7	5.0	0.8	4.9	0.7	4.6	1.9	4.1
BFdens-BFbmi[b]	0.9	5.1	-1.1	4.9	-0.8	5.0	0.9	4.4

a: Formula 1; b: Formula 2 for the Chinese subjects and Formula 3 for the Dutch subjects; BFdens, body fat percent from density; BFbmi, body fat percent from body mass index

The correlation coefficients between body fat from density and predicted body fat (Formula 1) were for the total study group 0.86 (p<0.001), for the Dutch subjects 0.90 (p<0.001) and for the Chinese subjects 0.81 (p<0.001). When using the country specific prediction formulas from the other country (Formulas 2 or 3), these correlation coefficients were 0.83 (p<0.001) in the Chinese subjects and 0.90 (p<0.001) in the Dutch subjects. Figure 3 shows the dependency of the difference between measured and predicted body fat and the level of body fatness using the general prediction Formula 1 in the combined Chinese and Dutch subjects. In Table 4 the differences between measured and predicted body fat using the general prediction Formula 1 are listed for each age group. Although the differences were significant in some age groups, they disappeared except in age group 4 (45-54 years) after correction for differences in level of body fatness between the countries in that age group.

Figure 3. Individual differences between body fat from density and from body mass index.

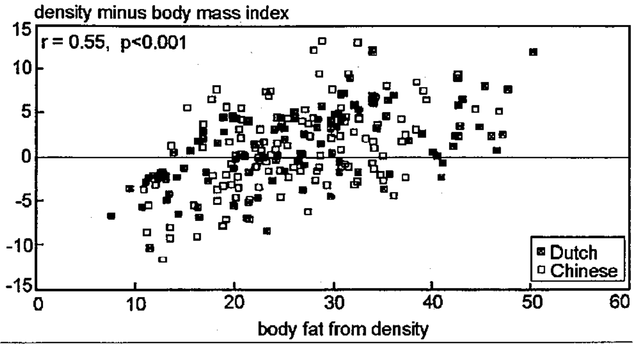

Table 4. Differences between measured and predicted body fat[a] in Chinese and Dutch subjects in different age groups.

	Chinese			Dutch		
Age group	mean	mean[a]	SD	mean	mean[a]	SD
18-24	1.1	1.2	5.4	0.7	0.8	4.6
25-34	2.7	2.5	4.9	0.9	1.4	3.8
35-44	0.9	1.0	4.6	2.1	2.0	4.4
45-54	-2.1	-2.2	3.4	2.0*	2.1*	4.5
55+	-1.6	-0.3	2.7	1.7*	1.1	4.2
all	1.2	1.1	4.9	1.3	1.2	4.4

*p<0.05; a: using the general prediction Formula 1; b: after correction for differences in body fat from density between the age groups

Discussion

The data of the Dutch subjects used in this study were selected on criteria based on the anthropometric data of the Chinese subjects. As matching on body weight, body height or BMI was found to be not possible because of the generally low values of these parameters in the Chinese, the selection was based on the observed minimum and maximum values of body weight, body height and BMI as found in the Chinese group. This selection finally resulted in a Chinese and Dutch group which differed only slightly in BMI, and which did not differ in body fat from densitometry (Table 1). The subjects of the two populations participating in this comparative study can not be regarded as representative for their countries. However they were not specially selected, and they both cover a broad range of weight, height and BMI compared to the normal adult values in their representative countries[9,15]. Body weight, body height and BMI were higher in the Dutch compared to the Chinese, and as a consequence the absolute amounts of fat mass and fat free mass were also higher. These differences in anthropometric variables between the two countries are not surprising, as in many developing countries anthropometric parameters are generally lower[5]. In both studied groups there was an increase of body fat with age, which was more pronounced in the Dutch. An age dependent increase in body fat is normally seen[16] and can be regarded as biologically normal. The different age dependency between the countries can also be read from the two country specific prediction formulas for body fat from BMI, in which the age effect is slightly more pronounced in the Dutch. However, the difference is not large and would, at age 70 years, result in a difference not higher then 5% body fat. The reason for the smaller age effect in the Chinese may be a more physically active life style, as in China the mechanisation and motorisation level is probably lower compared to the Netherlands.

Both with a general prediction formula for body fat from BMI (Formula 1)[4] as well as with the prediction formula developed in the population of the other country (Formulas 2 and 3) predicted body fat did not differ from the measured body fat by densitometry. Also when a prediction formula was generated with all subjects from both countries and 'country' was offered as a dummy variable[14], it was not included in the prediction formula. This also shows that the relationship between body fat and BMI, when sex and age is taken into account, is not different between the two populations under study. The regression coefficients of the two 'country specific' prediction equations were not different for BMI, and sex, nor was the intercept, but as discussed before, the regression coefficient for age was lower in the Chinese. The somewhat higher prediction error and the lower explained variance of the Chinese prediction formula is probably due to the slightly less accurate body density measurements in the Chinese subjects. The reproducibility of the Beijing system is 0.0021 kg/L[10] and that of the Wageningen system 0.0019 kg/L[11]. This difference may be partly due to a less accurate measurement of the residual lung volume by the used respirometer in China (0.1 L in China; 0.01 L in the Netherlands).

The difference between measured and predicted body fat (general prediction Formula 1)[4] with the level of body fatness is shown in Figure 3. At low levels of body fatness body fat from BMI is overestimated and at high levels it is underestimated. This is accordance with data reported by James *et al*[17] and is also found in many other studies in which predicted values are compared with measured values[18,19]. The bias at low and high levels of body fat can be explained by the fact that the 'normal', healthy ratio of lean to fat in the body, which is the basis for the prediction formula, is disturbed in the very lean as well as in the very obese subject. On the other hand the densitometric method will probably also be biased at very low (underestimation) and very high (overestimation) levels of body fat, as well as at higher age, due to violations of the assumptions used in the calculation formula[20,21]. When Siri's formula[12] was adapted for age effects[22] and effects of level of body fatness[21], the correlation between measured and predicted value with the level of body fatness as shown in Figure 3 reduced from 0.55 to 0.41, and the differences in measured and predicted body fat (Table 3) reduced significantly from 1.2±4.9 to 0.3±4.6% (p<0.001) in the Chinese and from 1.3±4.3 to 0.4±4.0% (p<0.001) in the Dutch (results not shown).

After correction for the dependency of the residuals on the level of body fatness (Figure 3), the differences of the residuals between the countries lowered and remained only significant in the 45 to 54 years old group (Table 4). Compared to the estimation error of the used prediction formula which is about 4 percent body fat[4], these differences are small. They represent only a small absolute amount of body fat or fat free mass (about 1-2kg) and may be regarded as being hardly biological relevant.

In summary, the relation between percent body fat and body mass index, corrected for age and sex is not found to be different between a selected group of Chinese and Dutch subjects. In both groups the prediction of body fat from body mass index was valid and the predicted values were highly correlated with body fat from densitometry.

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體重指數作爲體脂的預測值：中國與荷蘭成人的比較

摘要

作者選擇了一組中國和荷蘭健康成人爲對象，參照性別與年齡，比較他們的體脂與體重指數（公斤／米2）的關係。選擇荷蘭對象時，其年齡、體重、身高和體重指數不超過中國對象的最大值。荷蘭對象平均體重、身高和體重指數雖較中國對象大，但兩組體脂沒有區别。從體重指數，年齡和性別預測的體脂值與由密度計得出的體脂值，兩個國家的對象沒有區別。中國對象測得的體脂和預測的體脂間的相關係數爲 0.84（$p < 0.001$），荷蘭對象爲 0.90（$p < 0.001$）。測量與預測體脂值的不同與身體肥胖的程度有關（$r = 0.55$，$p < 0.001$），但與國籍無關。在不同年齡組，如果將測定值減預測值，中國對象與荷蘭對象稍有差異，但這些差異經校正（根據每一年齡組的身體肥胖程度校正）後已減低，最後作者得出結論：這兩種人群中，身體肥胖與體重指數間的關係沒有差異。

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