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The validity of predicted body fat percent in Chinese children with Caucasian prediction formulas

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Body composition was measured by underwater weighing and by anthropometry and bio-electrical impedance in 165 Chinese boys and 150 Chinese girls, aged 7 to 17 years and living in Beijing. Until age 12 years there were no differences in body weight, body height and body mass index (kg/m^2) between boys and girls, but body fat from density was slightly higher in girls. After age 12 boys had higher body weights, body heights and body mass index but lower body fat as calculated from body density. Predicted body fat from body mass index, body impedance and skinfold thickness was generally slightly lower compared to body fat from body density, except for body fat from impedance, which was both in boys and in girls slightly higher compared to body fat from body density. However, the mean differences were small and maximally reached 2.7% body fat in boys (impedance) and 1.7% in girls (skinfolds). The standard deviations of the differences were within the estimation error of the used methodology and comparable with values obtained in other studies. The differences between measured and predicted values were slightly higher in the youngest and the oldest children, probably indicating invalid assumptions in the used methodologies at these ages. At the lower level of body fatness all prediction formulas systematically overestimated body fat, and at higher fat levels body fat was systematically underestimated. It is concluded that prediction formulas developed in Caucasian subjects are generally valid in Chinese (Beijing) children.

Key words: Body composition, body fat, densitometry, bioelectrical impedance, skinfolds, body mass index, children, Chinese

Introduction

There are numerous methods to assess body composition[1,2]. For body fat and fat free mass the densitometric method is normally regarded as the method of reference. The method is based on a two-compartment model of the body, the fat mass (FM) and the fat free mass (FFM), each with its own assumed constant density. From chemical analysis of adult carcasses the densities of the two compartments have been calculated as 0.9 and 1.1 kg/L for FM and FFM respectively[1,3]. *In vivo* studies using modern methodologies have confirmed these density values[4]. However, for children the density of the FFM is surely lower, due to a higher water content of the fat free mass and a lower level of mineralisation of the bones[1,5,6]. In adults the percent body fat from body density can be calculated with Siri's[3] formula, but in children and adolescents an adaptation of this formula is necessary to correct for the lower density of the FFM[6,7]. As the measurement of body density by hydro-densitometry is not an easy task, and the method is not suitable to use in larger studies[2], predictive methods have been developed with which an assessment of the amount of body fat can be obtained from simple measurements. These methods include the measurements of the subcutaneous fat layer by skinfold thickness measurements, the use of weight-height indices and, recently, also the measurement of the total body impedance[8-11]. The principle of these methods is based on a statistical relationship of measured body parameters with the densitometric measured body fat or fat-free mass. Most prediction formulas described in the literature are developed in Caucasian populations, and it can be argued that the validity of these methods may be inadequate in other ethnic groups, due to differences in the relationship between subcutaneous fat and total fat (skinfold measurements) and differences in body build (weigh-height indices and impedance). Recently, Eston *et al*[12] used bioelectrical impedance to predict body composition in a group of Chinese boys and girls. They found bio-electrical impedance to be a good method of estimating fat free mass and fat mass in Chinese youth. However, skinfolds were used as the method of reference.

Assuming that the densities of the FM and the FFM are not different in Asians (Chinese), the validity of the prediction methods can better be tested by comparing measured values of body fat from body density with predicted values. Aim of this study was to test the validity of predicted body fat from skinfolds, body mass index and bio-electrical impedance from prediction equations developed in Caucasian children in Chinese children living in Beijing.

Subjects and methods

In total 315 children and adolescents, 165 boys and 150 girls, aged 7 to 17 years, were measured at the Institute of Nutrition and Food Hygiene, Beijing, China. They were invited to come to the Institute in the morning in the fasting state. The study protocol was approved by the Medical Ethical Committee of the Chinese Academy of Preventive Medicine. Body weight was measured after voiding to the

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nearest 0.1 kg using a digital scale (Tefal, SC3218, Rumilly, France). Body height was measured to the nearest 0.1 cm with a wall mounted stadiometer (Lameris, Utrecht, The Netherlands). Body mass index (kg/m^2) was computed as weight divided by height squared. From body mass index body fat was calculated using age and sex specific prediction formulas[13]. Skinfold thicknesses (biceps, triceps, subscapular and supra-iliac) were measured in triplicate at the left side of the body using a Holtain skinfold caliper (Holtain Ltd, Crymych, Dyfed, UK). The mean values were used for the calculation of body fat percent (BF%), using the prediction equations from the literature from triceps and subscapular skinfolds[14], and from all four skinfolds[7]. Total body impedance at 50 kHz (Humanim, Dietosystems, Milan, Italy) was measured immediately after lying supine at the left side of the body. From height and impedance the impedance index (height^2/Z, m^2/Ω) was computed. From impedance index, weight, height, age and sex (females=0, males =1) fat free mass (FFM) was calculated[11]. Body density was derived from underwater weighing. The subjects were weighed lying supine and completely immersed in water using a digital scale (Model IC34, Sartorius, Gottingen, Germany) while breathing through a respirometer (Volugraph VG 2000, Mijnhardt, Bunnik, The Netherlands) for simultaneous measurements of the residual lung volume. The lung volume method is based on helium dilution. The measurements were in most subjects performed in duplicate. The within-subject within-day variability in measured body density of the system, calculated from triplicate measurements in 5 children was 0.0024 kg/L, equivalent to an error in percent body fat of about 1%. Body fat was calculated from body density using an adapted formula for children and adolescents[7].

The SPSS-program[15] was used for statistical calculations. Differences in parameters between groups were tested with the Student t-test. Differences between measured and predicted values (residuals) were tested by paired Student t-test and with the technique described by Bland & Altman[16]. Correlations are Pearson's product moment correlations. Values are expressed as mean ± standard deviation (SD).

Results

Table 1 gives some characteristics of the children, divided into two age groups, 7-11 years and 12-17 years, for boys and girls separately. In the younger age group age, body weight, body height and body mass index were not different between boys and girls. Percent body fat was higher in girls in the younger age group. In the older age group all parameters were different between boys and girls, boys being older and having a higher weight, height and body mass index, but a lower percent body fat.

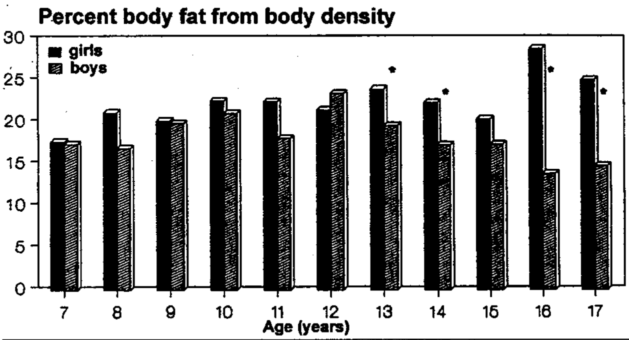
Table 1. Characteristics of the subjects (mean ± SD).

Age group	7-11 years				12-17 years			
	Boys (84)		Girls (81)		Boys (72)		Girls (78)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	9.0	1.5	9.4	1.3	14.7	2.0	13.9*	1.7
Weight (kg)	30.6	9.4	31.4	10.6	56.1	11.4	48.3*	10.0
Height (m)	1.34	0.09	1.36	0.11	1.65	0.10	1.58*	0.07
BMI (kg/m^2)	16.7	3.6	16.6	3.5	20.4	3.1	19.3*	3.5
Body fat %	18.6	8.6	21.3*	8.2	17.8	7.1	22.9*	7.3

* p<0.05 between the sexes

As shown in Table 1, boys between 7 and 11 years, taken as a single group, have a significantly lower percentage of fat than girls, when they are grouped by years as in Figure 1 there are no significant differences until the 13 year old group. From age 7 years, body weight steadily increased to age 16 in girls and to age 15 in boys. Fat-free mass remained constant after age 13 in girls and after age 16 in boys. Body height was not different between boys and girls at ages 7 to 10 years (mean values for boys and girls combined 1.22 ± 0.05 m at age 7 years, 1.39 ± 0.07 m at age 10 years) but was higher in the 11 years old girls (1.48 ± 0.07 m) compared to boys (1.41 ± 0.06 m). After that age boys were taller than girls. After age 13 years body height in girls did not increase and remained stable at 1.60 ± 0.05 m. Boys increased their height until age 16 years, where it stabilised at 1.71 ± 0.06 m.

Figure 1. Body fat in Chinese boys and girls of different age.



In Table 2 the percent body fat from density is listed together with the predicted amount of body fat using different prediction equations. All predicted values in boys and girls were different from measured body fat. The correlations between body fat from density and body fat estimates from body mass index, body impedance and skinfolds are given in Table 3.

Table 2. Body fat percent from body mass index and predicted body fat from body mass index, impedance and skinfold thickness (mean ±SD).

	Boys (165)		Girls (150)	
	Mean	SD	Mean	SD
Body fat density	18.3	8.1	22.1	7.8
Body mass index	16.7*	5.4	20.6*	5.2
Body fat impedance	19.4*	6.4	24.8*	5.0
Body fat skinfolds[a]	16.6*	5.4	20.4*	5.8
Body fat skinfolds[b]	18.4	8.3	20.1*	6.7

[a] calculated from biceps, triceps, subscapular and supra-iliac[7]
[b] calculated from triceps and subscapular[14]
* p<0.01 compared to body fat from density

Table 3. Correlation coefficients between body fat from density and predicted body fat*.

males\females	Bfdens	Bfbmi	Bfimp	Bfskfd[a]	Bfskfd[b]
Bfdens	-	0.74	0.71	0.74	0.73
Bfbmi	0.72	-	0.76	0.88	0.86
Bfimp	0.68	0.77	-	0.77	0.75
Bfskfd[a]	0.73	0.88	0.81	-	0.93
Bfskfd[b]	0.73	0.85	0.70	0.90	-

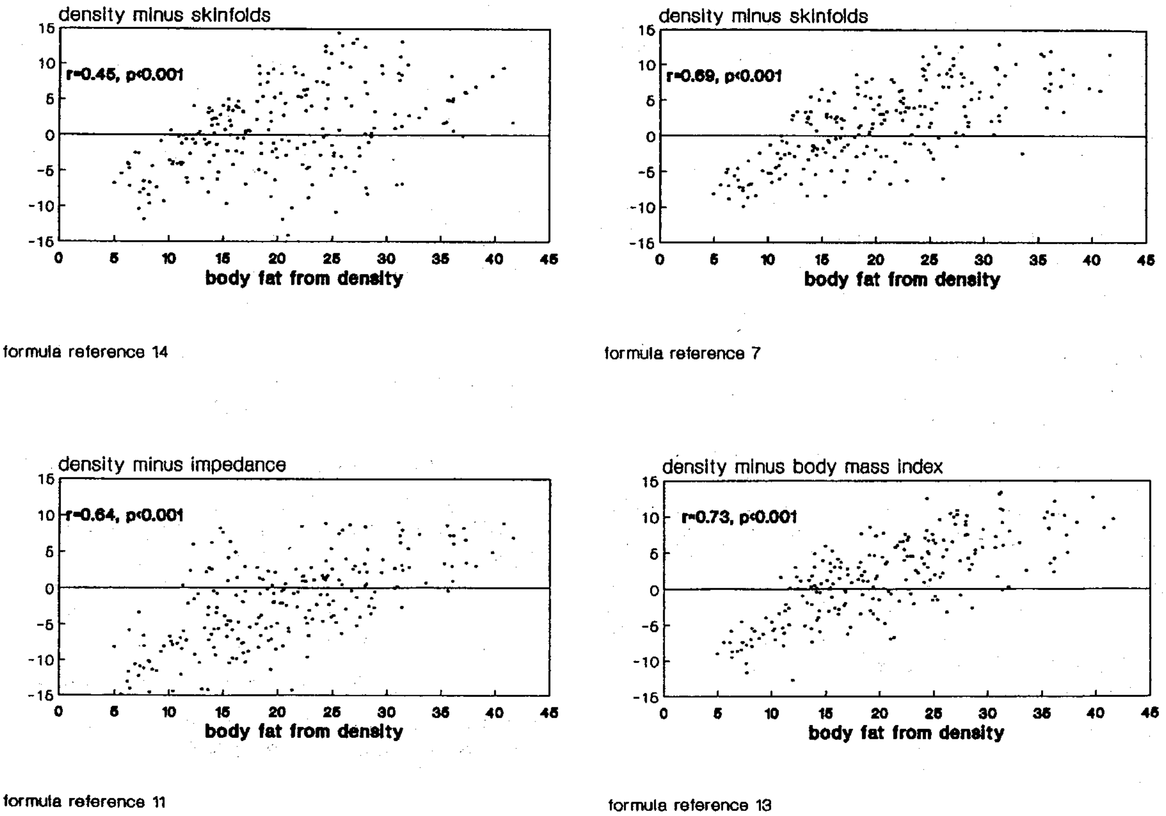
* all values p<0.001
[a] calculated from biceps, triceps, subscapular and supra-iliac[7]
[b] calculated from triceps and subscapular[14]

All correlation coefficients were highly significant and were slightly higher in girls. Mean errors in predicted body fat, using either method, were slightly lower in the middle age (11 to 14 years) groups, but did never exceed 2.7 % body fat in boys (using impedance) and 1.7% body fat in girls (using skinfolds). The standard deviation of the differences was in boys and girls for each method between 4 and 5% body fat. Figure 2 shows the individual differences of predicted body fat percent measured minus predicted) with body fat from density. For all methods the correlations were positive, indicating that at low levels of body fat the prediction equations generally overestimated body fat, and at higher levels of body fat the predicted values generally underestimated body fat.

Discussion

The measured children were a non specially selected sample of school children living in Beijing, the capital of China. However, no attempts were made to obtain a representative sample of the children population in Beijing. Compared to data of a recently performed nation wide survey in China the children were about 5kg heavier and 5cm taller, depending on age and gender (Ge, personal communication). There are known differences between weight and height of the rural and urban population in China[17], which explain these differences. As the validity of predictive methods based on impedance and body mass index depends on body build, results could be different in Chinese children with different body shape. When comparing the mean values of weight and height of the children in this study with the data of children in comparable studies in western countries[13,14] the values in China are remarkably lower. This observation is also made for body height and body weight at adult age in the Chinese[17-19]. The body mass index in boys and girls in both age groups in this study was comparable with the values reported in Dutch children of comparable age[7]. Percent body fat from body density was both in boys and in girls in both age groups slightly higher compared to Dutch children[13] and comparable or only slightly lower compared to American children[14]. Mean triceps skinfold thickness at each age was between the 25th and 50th percentile of the references values for American children[20]. The observed non-differences in weight, height and body mass index between boys and girls aged <12 years are found in most anthropometric studies in pre-pubertal children. The significant differences between the sexes in all parameters in the older age groups, reflects the normal gender differences in these parameters after the onset of puberty[1,7,21,22]. At 17 years, both boys and girls had reached the body height and fat free mass also observed in Chinese adults, aged 18-25 years, which is 1.62 ± 0.06m and 39.0 ± 3.7 kg for height and fat free mass respectively in females and 1.71 ± 0.06 m and 51.7 ± 5.9 kg in males[19]. Predicted body fat using body mass index, bio-electrical impedance or skinfolds was highly correlated in both boys and girls. The observed correlation coefficients are comparable with those found in other studies in which predictive methods were compared with reference methods[10,23,24]. The mean difference between measured and predicted body fat, as can be read from Table 2 were well within mean errors observed in other studies[10,25]. It seems typical that the lowest mean errors both in boys and girls are found in the middle of the age range that was studied. It could be that in the lower and higher age ranges, the formulas used are less valid. This is confirmed by the fact that, in girls older then 15 years, when the prediction equation of Durnin and Womersley[23] was used instead of the used equation for young adolescents, the mean error in girls was 0.0 ± 3.6% instead of 3.3 ± 3.8%. The higher individual error (SD) in children compared to Chinese adults[19] could be due to violations of the assump-

Figure 2. Individual differences between percent body fat from density and from predictive methods.



tions made in the calculation of the percent body fat from body density. Generally, it is better to use biological age instead of calender age[7,14], but no attempts were made to measure biological age in this group of children. When using two other equations (Houtkoper *et al*[26] and Cordain *et al*[27]) from the literature to predict body fat from impedance, the mean difference of these methods with body fat from density in boys was 3.0 ± 6.3% with a range of -13 to ± 22%[26] and 11.6 ± 10.0% with a range of -17 to ± 42[27]. In girls these figures were 2.6 ± 6.1% (range -12 to +30) and 9.7 ± 10.0% (range -12 to +56) respectively. These results are not in agreement with the results of the study of Eston *et al*[12] who reported a very low mean error in both Chinese boys and girls using the Houtkoper[26] formula. However, the method of reference in their study was based on skinfold measurements[28]. With the formula of Cordain *et al*[27] 13 out of 165 boys and 27 out of 150 girls had a negative value of percent body fat, thus the formula seems not to be adequate in Chinese youth. The observed relationship of the residuals with the level of body fatness from density (Figure 2) is found in several studies[29-30], also in Chinese[19]. It can be explained by violations of assumptions made in the several predictive methods techniques[1]. Apart from the predictive methods, the method of reference can also give rise to errors in the extreme ranges of body fat[1]. The fact that the correlation between the residuals of the three predicted values were highly correlated (correlation coefficients ranging from 0.75 to 0.90) indicates that the error in body fat from body density is at least partly responsible for the individual errors as well as for the relation of the residuals with the level of body fatness. The overestimation of body fat in the lean subjects using predictive methods shows the necessity to develop specific prediction formulas for use in populations with a high prevalence of low weight (low fat) subjects.

In summary, the prediction of body fat from body mass index, bioelectrical impedance and skinfolds thickness, using equations from the literature showed comparable mean values with body fat calculated from body density. Further studies are necessary to show whether in Chinese children from other regions, possibly having a different body build, these prediction formulas are also valid.

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中國兒童預測體脂百分數與高加索白人預測公式的確實性

摘要

由人體密度（水下稱重法測量〕，人體測量學和生物電阻抗等方法測量兒童7至17歲中國北京兒童的體成分（男性165名，女性150名〕．12歲以下兒童的體重，身高和體質指數（Kg/M^2〕，男女之間無差別．但是女性的體脂含量較男性高（密度法測量結果〕．12歲以上，男孩的身高，體重和體質指數較女性高，而體脂含量則較低．

由體質指數，人體生物電阻抗和皮摺厚度推算體脂含量時，處生物電阻抗方法推算體脂結果，男女都較密度法的結果略高外，其余一般較密度法結果低．然而，平均差异都很小．生物電阻抗值推算結果差值最高爲2.7%（男性兒童〕，皮摺厚度推測結果的差值最高爲1.7%(女性兒童〕．所有差值的標準差（SD〕都在測量方法允許的誤差範圍之內．而且這一結果與研究結果相一致．測量結果和推測結果的差异，在小年齡段和大年齡段内更明顯．或許表明在這些年齡段内，使用這些方法推算體脂含量還存在一定問題．對低體脂含量的兒童，所有推算方法都系統性地高估了體脂含量．而對高體脂含量的兒童又系統性地低估了體脂含量．

總之，通過高加索白人推導出的體脂預測公式，在一般情況下是可以用于中國兒童的．

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