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Body Mass Index and Waist Circumference Rather Than Body Adiposity Index Are Better Surrogates for Body Adiposity in a Chinese Population

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Abstract

Background: Several studies have found that body adiposity index (BAI) is a better index of body adiposity than body mass index (BMI) in African and Mexican American adults. This study aims to evaluate the ability of BAI to predict body adiposity in Chinese children and adults. *Materials and Methods:* In total, 2425 children and 5726 adults were recruited from rural China. All participants completed whole-body dual-energy X-ray absorptiometry (DXA) and anthropometric measures. The correlation of BMI, BAI, and waist circumference (WC) to DXA adiposity indexes was performed across sex-specific adult and age- and sex-specific child cohorts, using Spearman correlation and linear regression models, respectively. *Results:* Both BMI and WC had a higher correlation with all adiposity indexes (whole body fat, percent body fat [Bfat%], trunk fat, and percent trunk fat [Tfat%]) measured by DXA than did BAI in both adults and children. Meanwhile, most of the linear regression model associations for BMI with Bfat% and Tfat% had a greater adjusted R^2 than those for BAI among both children and adults. *Conclusion:* This study indicates that BMI and WC are better tools than BAI for estimating whole body fat and central body fat in a Chinese population. (*Nutr Clin Pract*. 2015;30:274-282)

Keywords

adiposity; absorptiometry; body fat distribution; adipose tissue; body mass index; body adiposity index; dual-energy X-ray absorptiometry; body fat

The prevalence of obesity has escalated worldwide during recent decades, especially in developed countries.[1–3] Moreover, the proportion of the population that is obese or overweight has steeply increased over the past 10 years in developing counties such as China.[4] There is significant evidence that adiposity is a precursor to many chronic noncommunicable diseases, such as cardiovascular disease, diabetes, musculoskeletal disorders, and some cancers.[5–8] In short, obesity results in a heavy burden of disease worldwide.

Percent body fat (Bfat%), a hallmark of obesity, is a known risk factor for a range of health problems but is difficult to measure.[9] Multiple methods have been employed to estimate Bfat%, such as underwater weighing and dual-energy X-ray absorption (DXA), which are considered gold-standard methods.[10] However, such complex methods are too expensive, time-consuming, and impractical to be applied in routine clinical settings or large epidemiologic studies. And due to imprecision in evaluating body fat, surrogate methods such as impedance analysis and skin-fold thickness are not widely applied in clinic practice or research studies.[11,12]

In the 19th century, Adolphe Quetelet developed the formula of body mass index (BMI) for measuring body fat.[13] BMI correlates highly with percent body fat and is largely independent of height, enabling an unbiased comparison between short and tall population groups.[14] BMI is now routinely applied to anthropometric estimates of general adiposity, not only in epidemiologic studies but also in clinical practice.[15] The cutoff point for overweight and obesity according to the World Health Organization (WHO) is a BMI between 25 and 30 kg/m^2, respectively.[16] BMI, which mainly measures whole-body adiposity rather than central adiposity, is by far the most commonly applied approach to characterize obesity in individual subjects today. However, BMI is limited by not being able to accurately measure adiposity in individuals with high lean

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body mass, such as athletes. Waist circumference (WC) is also a widely accepted index for evaluating central adiposity, and WC is an accepted component of the diagnostic criteria for assessing metabolic syndrome.[17]

Recently, Bergman et al[18] reported that body adiposity index (BAI) is a better index of anthropometric measures for body adiposity than BMI among Mexican and African American adults. BAI is calculated as hip circumference (HC) in centimeters divided by height in meters (HM) to the 1.5th power minus 18: BAI = HC / $(HM)^{1.5}$ – 18. However, Barreira et al[19] recently reported that BMI and BAI performed similarly in predicting body fat among African and white American adults, although conclusions drawn from 2 American studies were inconsistent.[18,19] Of note, body composition in an Asian population differs from that in a non-Asian population. For example, Wang and colleagues[20] showed that Chinese people originating from the Shanghai region and living in New York City had a lower BMI but a higher percentage of body fat than did whites of the same age and sex. Furthermore, Lam et al[21] found BMI to be a better index for general body fat than BAI in a small sample of Singapore Chinese adults. As such, the question of whether BMI is a better index of body adiposity for use in a Chinese population still needs to be addressed in a larger sample size, particularly among children. As well, no study that we are aware of has assessed the predictiveness of BAI in measuring body fat among Chinese children.

This study aimed to evaluate whether BAI is a better index of body adiposity than BMI or WC among Chinese adults and children, using body fat indexes determined by DXA as the gold standard.

Materials and Methods

Study Population

Our study population included 2425 children and 5726 adults recruited from China as part of a previous twin study. A detailed description of the large-scale, community-based twin study has been previously introduced elsewhere.[22,23] Briefly, this study was conducted from September 1998 to May 2000 in Anqing and Luan areas, Anhui province, China. All original data were collected during the period from September 1998 to May 2000. All participants were ethnic Han Chinese. Inclusion criteria for twins included in the main study were as follows: (1) aged 6–60 years; (2) both twins were available for the survey; (3) both twins (or parents/guardians of children) agreed and consented to participate in the survey; (4) no history of stroke or cardiovascular, renal, hepatic, or malignant diseases; and (5) females were not nursing or pregnant. This report excluded twins without data for any of the following: age, sex, and BMI, BAI, WC, and DXA indexes of adiposity. Written informed consent was obtained from each participant or parents/guardians of children prior to any data collection. The study was reviewed and approved by the Institutional Review Boards of Children's Memorial Hospital and Biomedical Institute, Anhui Medical University.

Anthropometric and DXA Measures of Adiposity

Eligible twins were invited to a central office to complete a questionnaire interview, DXA scan, and physical examination, including anthropometric measures. Questionnaires that covered sociodemographic characteristics and lifestyle information were administered by trained interviewers.

For all individuals, height and weight measurements were taken using standard methods after the removal of shoes and outerwear. Body weight was measured to the nearest 0.1 kg on a scale and standing height to the nearest 0.1 cm on a stadiometer. WC and hip circumference were measured at the level of the omphalos and trochanters, respectively. BMI was calculated as weight in kilograms divided by the square of the height in meters (kg/m^2). BAI was calculated as hip circumference in centimeters divided by height in meters to the 1.5th power minus 18: BAI = HC / $(HM)^{1.5}$ – 18. Body fat was measured using DXA (GE Lunar Prodigy, Waukesha, WI) according to the standard operating protocol. DXA can precisely measure lean body mass, whole-body fat mass, trunk lean mass, and trunk fat mass. Percent body fat (Bfat%) was calculated as 100 times fat mass divided by whole-body mass. Percent truncal to total fat (Tfat%) was calculated as 100 times truncal fat mass divided by whole-body fat mass.

The main difference between BMI and BAI is that weight and hip circumference are used as the numerators of the calculating formulas for BMI and BAI, respectively. However, weight may be a better reflection of general adiposity distribution, while hip circumference may better reflect central adiposity distribution. Whole-body fat and trunk fat represent general and central adiposity, respectively. In this report, whole body fat, Bfat%, trunk fat, and Tfat% were used as estimated adipose surrogates of BMI, BAI, and WC.

Statistical Analyses

All analyses were conducted in participants stratified by sex and age. The continuous and categorical variables were presented as means (standard deviation) and frequencies, respectively. Body composition obviously varies with age among boys and girls, and thus evaluation of adiposity indexes must be performed in each age group of boys and girls, respectively. Due to the considerable sample size, children were pooled into 6 consecutive year age groups as follows: 6–7, 8–9, 10–11, 12–13, 14–15, and 16–17 years. The sex- and age-specific correlations of BMI, BAI, and WC to body fat, Bfat%, trunk fat, and Tfat% were examined using a Pearson correlation. The adjusted R^2 of the linear regression model was computed to estimate the goodness of fit of the line for BMI, BAI, and WC to Bfat% and Tfat% in sex- and age-specific equations. In addition, due to high correlation between

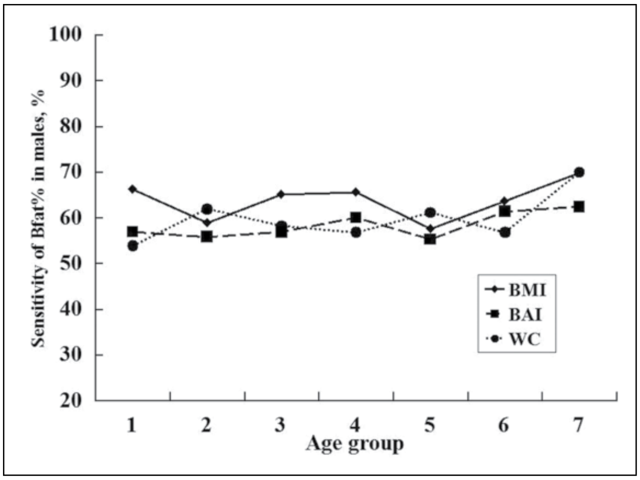

Figure 1. The x-axis shows age group (1 = 6–7 years; 2 = 8–9 years; 3 = 10–11 years; 4 = 12–13 years; 5 = 14–15 years; 6 = 17–18 years; 7 = 18–65 years), and the y-axis shows higher body mass index (BMI), higher body adiposity index (BAI), and higher waist circumference (WC) predicted sensitivity of higher percent body fat (Bfat%) in males.

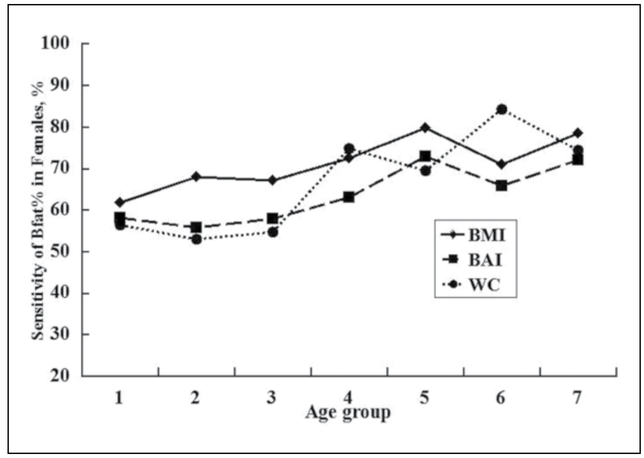

Figure 2. The x-axis shows age group (1 = 6–7 years; 2 = 8–9 years; 3 = 10–11 years; 4 = 12–13 years; 5 = 14–15 years; 6 = 17–18 years; 7 = 18–65 years), and the y-axis shows higher body mass index (BMI), higher body adiposity index (BAI), and higher waist circumference (WC) predicted sensitivity of higher percent body fat (Bfat%) in females.

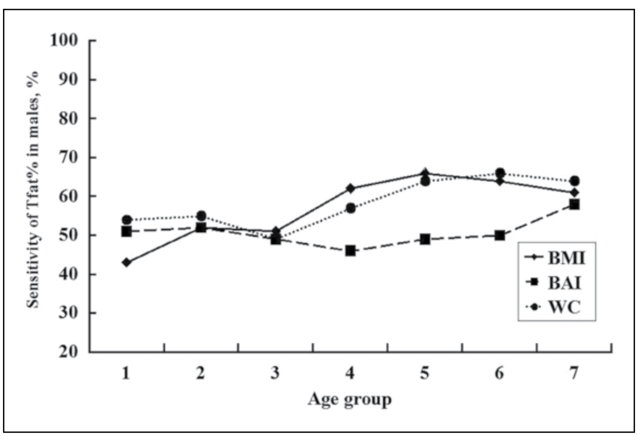

Figure 3. The x-axis shows age group (1 = 6–7 years; 2 = 8–9 years; 3 = 10–11 years; 4 = 12–13 years; 5 = 14–15 years; 6 = 17–18 years; 7 = 18–65 years), and the y-axis shows higher body mass index (BMI), higher body adiposity index (BAI), and higher waist circumference (WC) predicted sensitivity of higher percent trunk fat (Tfat%) in males.

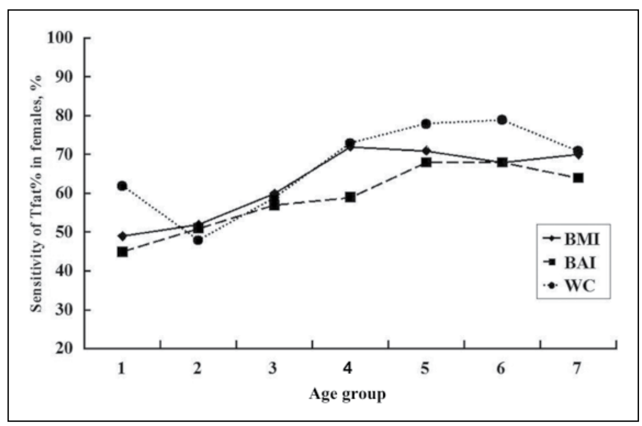

Figure 4. The x-axis shows age group (1 = 6–7 years; 2 = 8–9 years; 3 = 10–11 years; 4 = 12–13 years; 5 = 14–15 years; 6 = 17–18 years; 7 = 18–65 years), and the y-axis shows higher body mass index (BMI), higher body adiposity index (BAI), and higher waist circumference (WC) predicted sensitivity of higher percent trunk fat (Tfat%) in females.

twin pairs, all of the above analyses were repeated among single twin subjects who were selected randomly from the twin pairs. Statistical Analysis System software version 9.1 (SAS Institute, Cary, NC) was used for all statistical analyses. The level of significance was $P < .05$, and statistical tests were 2-sided.

In addition, Bfat%, Tfat%, BMI, BAI, and WC were analyzed as binary variables according to the corresponding median in each sex and age group. Next, the sensitivity of higher Bfat% and higher Tfat% in those with higher BMI, higher BAI, or higher WC was calculated for each sex and age group, respectively. Finally, the figure was plotted, using sensitivity of higher Bfat% (Figures 1 and 2) and higher Tfat% (Figures 3 and 4) relative to age group (the numbers 1–7 indicate the following age groups, in order: 6–7, 8–9, 10–11, 12–13, 14–15, 16–17, and 18–65 years) in males and females.

Results

This study sample included 2425 children (1320 boys, 1105 girls) and 5726 adults (872 men and 4854 women), as shown in Table 1. More than half of the adults were farmers (55.5% for men and 62.2% for women), and those with educational

Table 1. Distributions of General Characteristics, Anthropometrical Examination, and DXA Between Children and Adult Twins.

Variable	Chinese Children		Chinese Adults	
	Boy (n = 1320)	Girl (n = 1105)	Men (n = 872)	Women (n = 4854)
		No. (%)		
Occupation				
Farmer			484 (55.5)	3021 (62.2)
Nonfarmer			388 (44.5)	1833 (37.8)
Educational status				
Illiterate			120 (13.8)	1856 (38.2)
Primary school			351 (40.3)	1578 (32.5)
Middle school			307 (35.2)	1073 (22.1)
≥High school			94 (10.8)	347 (7.1)
Cigarette smoking			551 (63.2)	59 (1.2)
Alcohol drinking			277 (31.8)	119 (2.5)
		Mean ± SD		
Age, y	10.7 ± 2.8	10.9 ± 2.7	36.5 ± 11.3	31.3 ± 8.3
Height, m	1.3 ± 0.2	1.3 ± 0.1	1.6 ± 0.1	1.5 ± 0.1
Weight, kg	29.6 ± 10.5	29.4 ± 9.7	55.1 ± 6.8	51.8 ± 7.6
BMI, kg/m^2	16.0 ± 2.2	16.0 ± 2.4	21.1 ± 2.2	21.9 ± 2.8
BAI	24.4 ± 3.2	25.7 ± 3.1	23.3 ± 2.7	28.8 ± 3.3
Whole body fat, g	2738.7 ± 1774.8	4545.3 ± 3508.7	5696.1 ± 3610.5	13514 ± 5067.4
Percent body fat, %	8.9 ± 3.5	13.9 ± 6.1	10.0 ± 5.1	25.4 ± 6.4
Trunk fat, g	1051.2 ± 826.6	1814.7 ± 1707.8	3023.2 ± 2086.7	6816.9 ± 2885.7
Percent trunk fat, %	37.6 ± 5.6	37.1 ± 5.9	52.1 ± 4.6	49.6 ± 4.7
Lean mass, kg	26.9 ± 9.3	24.9 ± 6.7	49.4 ± 5.0	38.3 ± 3.9
Percent lean mass, %	91.1 ± 3.5	86.1 ± 6.1	90.0 ± 5.1	74.6 ± 6.4
Waist circumference, cm	55.5 ± 5.9	55.0 ± 6.6	70.7 ± 6.3	71.8 ± 7.9
Hip circumference, cm	65.5 ± 8.8	67.4 ± 9.7	84.8 ± 4.8	88.9 ± 5.8
Waist-to-hip ratio	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1

BAI, body adiposity index; BMI, body mass index. BAI = hip/height$^{1.5}$ – 18. Whole body fat and trunk fat were examined by dual-energy X-ray absorptiometry (DXA) scan. Percent body fat = whole body fat ÷ weight × 100%. Percent trunk fat = trunk fat ÷ whole body fat × 100%. Lean mass = weight – whole body fat. Percent lean mass = lean mass ÷ weight × 100%.

attainment greater than high school only accounted for 10.8% of the men and 7.1% of the women. Cigarette smoking (63.2%) and alcohol drinking (31.8%) were very popular among adult men but accounted for only 1.2% and 2.5% of adult women, respectively. Among children, age was comparable between boys and girls; whole body fat, Bfat%, and trunk fat of boys were less than those of girls, but height, BMI, BAI, Tfat%, WC, and hip circumference were similar between boys and girls, although Tfat% for boys was greater than for girls. Among adults, men were older, taller, and heavier than women, and BAI, whole body fat, Bfat%, trunk fat, and hip circumference for men were less than those of women, while BMI and WC were similar between the 2 sexes.

The sex and age correlations of BMI, BAI, and WC to whole body fat, Bfat%, trunk fat, and Tfat% are presented in Table 2. The correlation coefficient between BMI and Bfat% ranged from 0.07–0.66 in males and from 0.25–0.77 in females; furthermore, it increased with age, particularly among males. The correlation coefficient between BAI and Bfat% ranged from 0.09–0.44 in males and from 0.12–0.64 in females. The correlation coefficient between BMI and Bfat% in each age and sex group was greater than the corresponding coefficient between BAI and Bfat%, except for the 14- to 15-year-old age group. The age- and sex-specific correlation coefficients of BMI to Bfat and Tfat were greater than those of BAI to Bfat and Tfat as well. The correlation between BMI and Tfat% was also stronger than that between BAI and Tfat% for each age and sex group, except in male groups aged <12 years. In particular, all correlation coefficients of BMI to the 4 adipose indexes (range, 0.40–0.74 in men and 0.47–0.88 in women) were greater than their counterparts for BAI relative to the 4 adipose indexes (range, 0.25–0.44 in men and 0.36–0.64 in women) for both sexes in adults. All correlation coefficients of WC to the 4 adipose indexes were similar to those for BMI. Overall, the correlation coefficients of BMI to Bfat and Bfat% were slightly greater than those for WC, and the correlation coefficients of WC to Tfat and Tfat% were slightly greater than those for BMI.

Results from the linear regression are shown in Table 3, with anthropometry parameters of fat (Bfat% and Tfat%) as dependent variables and BMI, BAI, or WC as independent

Table 2. Pearson's Correlation Coefficient of BMI, BAI, and WC With Bfat, Bfat%, Tfat, Tfat%, and WC Among Chinese Children and Adults.

	Males					Females				
Variable	n	Bfat	Bfat%	Tfat	Tfat%	n	Bfat	Bfat%	Tfat	Tfat%
					Children aged 6–7 y					
BMI	129	0.43[a]	0.31[a]	0.42[a]	−0.11	109	0.59[a]	0.42[a]	0.62[a]	0.10
BAI	129	0.28[b]	0.29[c]	0.32[c]	0.06	109	0.02	0.17	0.01	−0.05
WC	129	0.43[a]	0.33[a]	0.45[a]	0.04	109	0.38[a]	0.18	0.47[a]	0.29[b]
					Children aged 8–9 y					
BMI	393	0.52[a]	0.35[a]	0.53[a]	−0.03	293	0.43[a]	0.25[a]	0.36[a]	0.06
BAI	393	0.02	0.09	0.02	0.02	293	0.01	0.12[d]	0.02	0.01
WC	393	0.40[a]	0.24[a]	0.45[a]	0.11[d]	293	0.24[a]	0.16[b]	0.23[a]	0.12[d]
					Children aged 10–11 y					
BMI	291	0.64[a]	0.53[a]	0.61[a]	−0.01	255	0.69[a]	0.52[a]	0.70[a]	0.37[a]
BAI	291	0.23[a]	0.31[a]	0.24[a]	−0.04	255	0.19[b]	0.26[a]	0.21[c]	0.12
WC	291	0.49[a]	0.40[a]	0.52[a]	0.17[b]	255	0.44[a]	0.29[a]	0.47[a]	0.29[a]
					Children aged 12–13 y					
BMI	249	0.70[a]	0.46[a]	0.70[a]	0.29[a]	254	0.81[a]	0.73[a]	0.80[a]	0.53[a]
BAI	249	0.27[a]	0.38[a]	0.24[a]	−0.05	254	0.37[a]	0.44[a]	0.38[a]	0.30[a]
WC	249	0.63[a]	0.42[a]	0.64[a]	0.32[a]	254	0.63[a]	0.56[a]	0.65[a]	0.55[a]
					Children aged 14–15 y					
BMI	170	0.37[a]	0.07	0.44[a]	0.35[a]	118	0.77[a]	0.63[a]	0.77[a]	0.59[a]
BAI	170	0.16[d]	0.23[b]	0.18[d]	0.07	118	0.57[a]	0.59[a]	0.58[a]	0.49[a]
WC	170	0.55[a]	0.31[a]	0.60[a]	0.34[a]	118	0.63[a]	0.57[a]	0.66[a]	0.59[a]
					Children aged 16–17 y					
BMI	88	0.72[a]	0.59[a]	0.72[a]	0.44[a]	76	0.80[a]	0.67[a]	0.80[a]	0.55[a]
BAI	88	0.23[d]	0.30[b]	0.19	−0.01	76	0.34[c]	0.41[c]	0.40[c]	0.52[a]
WC	88	0.73[a]	0.63[a]	0.74[a]	0.42[a]	76	0.70[a]	0.63[a]	0.74[a]	0.61[a]
					Adults aged 18–65 y					
BMI	872	0.73[a]	0.66[a]	0.74[a]	0.40[a]	4854	0.88[a]	0.77[a]	0.87[a]	0.47[a]
BAI	872	0.42[a]	0.44[a]	0.43[a]	0.25[a]	4854	0.61[a]	0.64[a]	0.61[a]	0.36[a]
WC	872	0.71[a]	0.65[a]	0.73[a]	0.41[a]	4854	0.80[a]	0.70[a]	0.82[a]	0.53[a]

BAI, body adiposity index; Bfat, body fat; Bfat%, percent body fat; BMI, body mass index; Tfat, trunk fat; Tfat%, percent trunk fat; WC, waist circumference.
[a]$P < .0001$.
[b]$P < .01$.
[c]$P < .001$.
[d]$P < .05$.

variables for males and females, respectively. In different age groups with Bfat% as the dependent variable, the β of BMI was nearly twice that of BAI, except for the male 14- to 15-year-old age group. For females, only the 16- to 17-year-old age group had a BAI coefficient greater than that for BMI (1.97 vs 1.65). The βs for Bfat% relative to BMI and BAI were 0.94 and 0.43, respectively, for males. Tfat% presented similar patterns in all age groups. A between-sex comparison showed that the relationship of BMI and Bfat% in females was stronger than that in males. Most important, the adjusted coefficient of determination, R^2, in the regression model of BMI relative to Bfat% was much greater than that for BAI in each age and sex group, except in children aged 14–15 years. The R^2 of BMI reached up to 60% in female adults, while the R^2 of BAI reached only 41% in female adults. Similar R^2 patterns of BMI and BAI to Tfat% were also observed, but the overall R^2 of Tfat% was smaller than that of Bfat%, regardless of BMI or BAI. WC had a similar adjusted R^2 in most of the linear regression model associations for Bfat% and Tfat%. However, adjusted R^2 values of BMI were overall higher than those of WC.

Due to the high correlation between twin pairs, all above-the-line regression analyses were repeated among a subset of single twin subjects selected randomly from the twin pairs (Table 4). Results shown in Table 4 are very similar to those in Table 3.

Figure 1 shows that BMI was a better predictor of Bfat% than BAI in each male age group. Among females (Figure 2), a similar pattern was observed. WC predicted higher Bfat% but

Table 3. Parameters for Sex- and Age-Specific Equations Relating Bfat% and Tfat% to BMI or BAI Among Chinese Children and Adults (Both Twins).[a]

	Males							Females						
		BMI		BAI		WC			BMI		BAI		WC	
Variable	n	β	R^2	β	R^2	β	R^2	n	β	R^2	β	R^2	β	R^2
Twin children aged 6–7 y														
Bfat%	128	0.49	0.09	0.29	0.08	0.25	0.10	108	0.83	0.17	0.11	0.02	0.10	0.02
Tfat %	128	−0.28	0.004	0.10	0.004	0.05	−0.01	108	0.37	0.001	−0.06	0.007	0.31	0.08
Children aged 8–9 y														
Bfat%	391	0.77	0.12	0.09	0.006	0.18	0.06	294	0.68	0.06	0.17	0.01	0.16	0.02
Tfat %	391	−0.10	0.001	0.04	0.001	0.14	0.01	294	0.18	0.001	0.01	0.003	0.13	0.01
Children aged 10–11 y														
Bfat%	290	1.29	1.30	0.40	0.10	0.33	0.16	254	1.52	0.27	0.40	0.06	0.22	0.08
Tfat %	290	−0.03	0.004	−0.08	0.002	0.21	0.02	254	1.48	0.13	0.26	0.01	0.30	0.08
Children aged 12–13 y														
Bfat%	248	1.04	0.21	0.63	0.14	0.38	0.17	253	2.11	0.52	0.84	0.19	0.55	0.31
Tfat %	248	0.74	0.08	−0.10	0.003	0.33	0.10	253	1.73	0.28	0.65	0.09	0.61	0.30
Children aged 14–15 y														
Bfat%	169	0.09	0.005	0.32	0.05	0.20	0.09	117	1.56	0.40	1.20	0.34	0.70	0.31
Tfat %	169	0.80	0.12	0.18	0.005	0.40	0.11	117	1.11	0.34	0.76	0.23	0.56	0.34
Children aged 16–17 y														
Bfat%	87	0.94	0.34	0.43	0.08	0.39	0.40	75	1.65	0.44	1.97	0.16	0.69	0.40
Tfat %	87	1.24	0.18	−0.03	0.01	0.46	0.17	75	1.09	0.29	0.98	0.26	0.53	0.36
Adults aged 18–65 y														
Bfat%	871	1.57	0.43	0.85	0.20	0.53	0.42	4853	1.73	0.60	1.24	0.41	0.56	0.49
Tfat %	871	0.85	0.16	0.44	0.06	0.30	0.17	4853	0.78	0.22	0.51	0.13	0.31	0.28

BAI, body adiposity index; Bfat, body fat; Bfat%, percent body fat; BMI, body mass index; Tfat, trunk fat; Tfat%, percent trunk fat; WC, waist circumference. β and R^2 respectively represent the slope and adjusted R^2 of the regression line.
[a]Modeled using linear regression model.

was not as good and stable as BMI and BAI across age groups in both sexes. Overall, BMI and WC were better predictors of Tfat% than BAI in both males and females, and WC was even superior to BMI in females 11 years and older (Figures 3 and 4).

Discussion

This study found that despite the R^2 fluctuation across BMI and BAI models, BMI was more highly correlated with whole body fat (Bfat and Bfat%) and central body fat (Tfat and Tfat%) than BAI in a Chinese population of children and adults. Furthermore, most of the R^2 in the linear regression models of BMI for whole body fat (Bfat%) and central body fat (Tfat%) exceeded those of BAI across all age and sex groups. Meanwhile, the R^2 in linear regression models of WC for whole body fat (Bfat and Bfat%) were slightly lower than those for BMI but much more accurate than those of BAI. However, the sensitivity in which WC predicted central fat distribution (Tfat%) was similar to that of BMI and was even more accurate than BMI among females older than 11 years. Overall, these findings indicate that a good surrogate for whole body fat in a Chinese population is still BMI rather than BAI; however, WC represents a reliable surrogate for central adiposity in relatively adipose populations (Figure 4).

As the worldwide prevalence of obesity has continued to escalate in recent decades, the accuracy of the methods by which body fat is evaluated has gained tremendous significance. While there are many accurate methods for measuring body fat, including underwater weighing, DXA, magnetic resonance imaging (MRI), X-ray computed tomography (CT), and so on, these methods are costly, time-consuming, and inconvenient, hampering widespread use. As such, scientists have committed time to finding a simple, accurate, and handy anthropometric index for evaluating body fat, including whole body fat and central fat. Surrogate methods include impedance analysis and skin-fold thickness for whole body fat, as well as waist circumference and ratio of waist-to-hip circumference for central fat. However, these surrogates, although more practical, have not proved to be very accurate.[12] BMI has long been accepted as a good index of body fat, due to its high correlation with body fat, and to date has been a widely used diagnostic measure of overweight and obesity in human adult and child populations. With that said, BMI has limitations in estimating body fat. First, BMI cannot accurately reflect body fat mass

Table 4. Parameters for Sex- and Age-Specific Equations Relating Bfat% and Tfat% to BMI or BAI Among Chinese Children and Adults (Only 1 Twin).[a]

	Males							Females						
		BMI		BAI		WC			BMI		BAI		WC	
Variable	n	β	R^2	β	R^2	β	R^2	n	β	R^2	β	R^2	β	R^2
Twin children aged 6–7 y														
Bfat%	72	0.42	0.07	0.36	0.09	0.38	0.21	62	1.05	0.24	0.21	0.05	0.11	0.03
Tfat %	72	−0.33	0.01	0.05	−0.01	−0.005	−0.01	62	−0.11	−0.02	−0.17	−0.002	0.21	0.03
Children aged 8–9 y														
Bfat%	216	0.72	0.11	0.01	−0.004	0.17	0.05	163	0.56	0.08	0.19	0.03	0.27	0.09
Tfat %	216	−0.24	−0.0004	0.12	0.003	0.17	0.01	163	0.16	−0.002	−0.02	−0.006	0.21	0.03
Children aged 10–11 y														
Bfat%	159	1.09	0.21	0.37	0.10	0.29	0.12	140	1.44	0.25	0.32	0.04	0.22	0.09
Tfat %	159	−0.26	−0.002	–0.13	−0.002	0.22	0.02	140	1.60	0.14	0.28	0.01	0.28	0.06
Children aged 12–13 y														
Bfat%	132	1.14	0.28	0.63	0.17	0.43	0.25	135	2.18	0.57	0.87	0.20	0.50	0.27
Tfat %	132	0.60	0.05	−0.13	−0.002	0.23	0.04	135	1.79	0.30	0.56	0.06	0.56	0.26
Children aged 14–15 y														
Bfat%	89	0.14	0.001	0.40	0.07	0.25	0.12	63	1.37	0.33	1.16	0.33	0.82	0.35
Tfat %	89	0.82	0.11	−0.04	−0.01	0.42	0.11	63	0.96	0.30	0.71	0.23	0.59	0.35
Children aged 16–17 y														
Bfat%	46	0.98	0.35	0.51	0.09	0.40	0.38	38	1.64	0.39	1.23	0.26	0.77	0.39
Tfat %	46	1.30	0.18	−0.27	−0.01	0.47	0.15	38	1.06	0.32	1.05	0.39	0.44	0.25
Adults aged 18–65 y														
Bfat%	464	1.56	0.45	0.80	0.18	0.51	0.41	2492	1.74	0.61	1.28	0.42	0.56	0.49
Tfat %	464	0.92	0.19	0.46	0.07	0.31	0.17	2492	0.78	0.23	0.51	0.13	0.31	0.28

BAI, body adiposity index; Bfat, body fat; Bfat%, percent body fat; BMI, body mass index; Tfat, trunk fat; Tfat%, percent trunk fat; WC, waist circumference. β and R^2 respectively represent the slope and adjusted R^2 of the regression line.
[a]Modeled using linear regression model.

when an individual has higher lean body mass. Second, BMI correlates more highly with whole-body fat mass, but correlations tend to be lower with central-body fat mass, which was confirmed by our data.[24]

In 2011, Bergman and colleagues[18] generated a new index of body fat mass: BAI. They validated BAI as better parameter of body fat mass than BMI in Mexican American and African American populations. Subsequently, some studies have focused on evaluating the potential of BAI and BMI as surrogates for body fat mass measures among adults.[25–27] However, results were inconsistent across these studies. On closer evaluation, the conclusion by Bergman et al that BAI is a better surrogate for body fat mass[18] was confirmed or partially supported by data from nondialyzed patients with chronic kidney disease,[28] women and American European adults with familial partial lipodystrophy,[29,30] and data from white and African American adults.[19] However, other studies conducted in African American and white adults suggested that BMI is a better proxy of body fat mass than BAI.[27,31–36] Suchanek and colleagues[32] reported that BMI is a better surrogate for body fat mass than BAI in a white population. Furthermore, a prospective investigation found that BAI was less accurate than BMI in tracking adiposity change in 159 African American and 206 white midlife women and would not be a suitable replacement for BMI in most research applications involving adiposity change.[37] BAI was also not a good index for %Bfat in athletic women[33] and has limitations for use in clinical settings for overweight/obese postmenopausal white women,[27] as well as morbidly obese patients.[34] Our data also strongly indicate that BMI is a better proxy of body fat mass, including whole-body fat mass and central-body fat mass, in a large child and adult Chinese population. Overall, our data showed that both BMI and WC, as surrogates of body fat mass (whole-body fat mass and central-body fat mass), were better able to accurately assess adults than children. Similarly, Lam et al[21] found that BMI was a better index for general body fat than BAI in a small sample of Singapore Chinese adults. Most important, BAI is not as strongly related to cardiovascular health risk[38] and diabetes incidence as is BMI.[39] This provides even more evidence supporting the use of BMI and WC as a proxy of body fat mass in human populations.

The body composition of Asian populations, who have a lower BMI but a relatively higher body fat mass, typically differs from that in non-Asian populations.[20] To our knowledge, this is the only study focused on evaluating the predictive effect of BMI and BAI on body fat mass in an Asian population. Therefore, it partly explains why BMI is a better proxy of body fat in an Asian population.

Since the same cutoff points for BMI are used as diagnostic criteria for overweight/obesity in adults despite age and sex, we included both male and female adults in our analyses. However, because cutoff points for BMI in children vary by sex and age, our analyses were performed in sex- and age- specific groups. Our findings show that the correlation between BMI and %Bfat increased with age, except for those in the 14- to 15-year-old age group. Another population-based, cross-sectional study found that for any BMI in the normal range, percent body fat was greater for women than for men.[40] Our study found that the correlation coefficient of Bfat% with BMI in adults was 0.88 for women and 0.74 for men, respectively. As our study population was relatively thin, BMI may not be as accurate of a surrogate for body adiposity in a Chinese population given their low body adiposity, especially in males, whose percent body fat was only as high as 10.4%. However, it may explain a portion of the sex-specific differences documented in the relationship between BMI and percent body fat.

In addition, WC is accepted as one of the International Diabetes Foundation's criteria for metabolic syndrome, as WC is highly correlated with adverse health outcomes. In our study, we also evaluated WC's predictive value for assessing whole body fat and central body fat. In general, WC is a better index for central body fat than whole body fat, especially among a population with relatively more body fat. WC and BMI had similar sensitivities with respect to higher central body fat in males, but WC had more sensitivity relative to higher central body fat than did BMI in females with more body adiposity. Both BMI and WC were better surrogates for central body fat than BAI in either males or females. Overall, correlation coefficients, R^2 coefficients of linear regression models for associations between the 3 indexes and body fat, and their sensitivities to higher body fat all increased from male to female sex and with age. These findings may be explained primarily by percent body fat. As age increased, percent body fat rose from 7.6% to 10.4% in males and from 9.1% to 25.4% in females. As such, our data suggest that WC and BMI are much better indexes for central body fat and whole body fat, respectively, among more highly adipose populations.

This study has several strengths and weaknesses. First, because this was a population-based, cross-sectional study, the sample was random and representative. The method used to estimate percent body fat has been compared with the gold standard measured by DXA. Although the respondents were twins, raising the possibility that the sample was not fully independent, the results were highly consistent before and after excluding 1 member of the twin pair. Moreover, given the variation in percent body fat and BMI by ethnicity, this study provides important body composition data regarding children and adults of Han Chinese nationality.[41] In addition, although the data were collected almost 15 years ago and the prevalence of obesity in the Chinese population has increased contemporarily, this study mainly focuses on estimating BAI and BMI predicts whole body fat and central body fat in a Chinese population. However, body composition should not have changed in a given population with the changes of the times, so we think those data can be used for achieving the study aims.

In conclusion, this study indicated that BMI and WC are better tools for estimating whole body fat and central body fat, respectively, in a Chinese population. In conjunction, BAI does not appear to be a good surrogate for either whole body fat or central body fat in a Chinese population.

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