Body mass index bias in defining obesity of diverse young adults: the Training Intervention and Genetics of Exercise Response (TIGER) Study

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The BMI cut-score used to define overweight and obesity was derived primarily using data from Caucasian men and women. The present study evaluated the racial/ethnic bias of BMI to estimate the adiposity of young men and women (aged 17–35 years) using dual-energy X-ray absorptiometry (DXA) determination of percentage body fat (DXA-BF%) as the referent standard. The samples were 806 women and 509 men who were tested from one to three times over 9 months providing 1300 observations for women and 820 observations for men. Linear mixed models (LMM) regression showed that with age and BMI controlled, DXA-BF% of African-American (AA) men and women, Asian-Indian men and women, Hispanic women and Asian women significantly differed from non-Hispanic white (NHW) men and women. For the same BMI of NHW women, the DXA-BF% of AA women was 1·76 % lower, but higher for Hispanic (1·65 %), Asian (2·65 %) and Asian-Indian (5·98 %) women. For the same BMI of NHW men, DXA-BF% of AA men was 4·59 % lower and 4·29 % higher for Asian-Indian men. Using the recommended BMI cut-scores to define overweight and obesity systematically overestimated overweight and obesity prevalence for AA men and women, and underestimated prevalence for Asian-Indian men and women, Asian women and Hispanic women. The present study extends the generalisability of research documenting the racial/ethnic bias of the universal overweight and obesity BMI cut-scores.

Percentage body fat: BMI: Overweight: Obesity: Diversity

BMI, the ratio of weight and height, is an accepted public health method to define overweight and obesity[1,2]. In an invited commentary to the *British Journal of Nutrition*, Deurenberg stated his opposition to using a universal BMI cut-score to define obesity[3]. He maintained that the practice of defining obesity with a BMI of 30 kg/m² was based on data from Caucasian men and women from Europe and the USA and represented a percentage body fat (BF%) of about 25 % for young Caucasian men and 35 % for young Caucasian women[4]. Evidence supporting Deurenberg's position comes from research documenting age, sex and race/ethnic group bias in predicting BF% from BMI[5–13]. These studies show that the BF% for BMI systematically varies due to age, sex and race/ethnic group.

Obesity has become a pandemic in the USA and the American population is growing in ethnic and racial diversity. Data from the National Health and Nutrition Examination Survey (NHANES) 2003–4[14] show that the percentage of all Americans over the age of 20 years who exceeded the overweight BMI standard of ≥25 kg/m² was 66·3 %, while 30·5 % were considered obese (BMI ≥ 30 kg/m²). These high prevalence levels are linked to overweight and obesity in young adulthood. The NHANES data documented that 57·1 % of young adults (aged 20–39 years) were overweight, while obesity among this group approaches 30 %[14]. The prevalence of overweight and obesity of African-American (AA) and Mexican American men and women aged 20–39 years is higher than non-Hispanic white (NHW) men and women, linking the prevalence not only to sex, but also racial/ethnic group.

Recent NHANES data[15,16] showed that excess deaths were associated with obesity and underweight, but not overweight. Fontaine *et al.*[17] reported that the association between longevity and BMI of AA and NHW adults differed. The optimal BMI associated with longevity was higher for AA men and women than NHW men and women. Stevens *et al.*[18] reported that BMI was a less potent risk factor in AA women than NHW women when educational status was controlled. Manson & Bassuk[19] report that the ethnic difference in longevity associated with a BMI may in part be due to race bias of BMI to estimate adiposity. The present study was designed to evaluate the fidelity of BMI to estimate adiposity of racially/ethnically diverse young men and women. The goal was to examine the race/ethnic group effect on the BMI prediction of BF% using dual-energy X-ray absorptiometry (DXA) determination of BF% (DXA-BF%) as the referent adiposity standard.

Methods

Subjects

Subjects were recruited from the Training Intervention and Genetics of Exercise Response (TIGER) study. The TIGER subjects were students enrolled at the University of Houston (Houston, TX, USA). The target subject was a sedentary individual under the age of 35 years who exercised less than 30 min/week for the previous 6 months, and was not actively limiting energy intake by dietary modification. Subjects were excluded from the study if they had a physical or physiological contraindication to aerobic exercise, a known metabolic disorder that may alter body composition, or were pregnant or lactating.

The TIGER study subjects engaged in 30 weeks (two semesters) of exercise training, 3 d/week for 30 min/d at 65–85 % of heart rate-defined VO_{2max}. The data came from five yearly cohorts. The sample consisted of 806 females and 509 males who ranged in age from 17 to 35 years. These data included men and women who had from one to three measurement visits over the 9-month study duration. The measurement visits were at baseline, after 15 weeks, and at the end of the 30-week exercise programme. The total number of observations for the visits was 1300 for women and 820 for men. The race/ethnic group composition of the male and female samples differed slightly. The composition of the 509 men at baseline was: NHW, 37 %; Hispanic, 26 %; AA, 22 %; Asian Indian, 5 %; Asian, 10 %. The composition of the 806 women at baseline was: NHW, 29 %; Hispanic, 25 %; AA, 35 %; Asian-Indian, 3 %; Asian, 8 %.

Measurements

Height was determined with a stadiometer (SECA Road Rod; SECA, Hanover, MD, USA) and weight was measured with a digital scale (SECA 770). Subjects reported their birth date, sex and race/ethnicity using a standard, coded self-report demographic form. DXA was used to measure BF%. The DXA data for the first two cohorts were only measured at baseline and 30-week time points. DXA data were available for all three test visits for cohorts 3 to 5 if the subject completed the exercise programme. All individuals had baseline data. The number of individuals who had repeat tests were: 15 weeks, 311 women and 217 men; 30 weeks, 183 women and ninety-four men.

Whole-body DXA scans were completed on a Hologic Delphi-A unit (adult whole body software v. 11.2; Hologic, Inc., Bedford, MA, USA) and a Hologic Discovery W instrument (adult whole body software QDR v. 12.3). The same trained technicians administered the DXA scans. The instruments were calibrated daily with a spine standard and weekly with a step calibrator, as described by the manufacturer. All female participants completed a standard urine pregnancy test before DXA testing to ensure that they were not pregnant before scanning. Subjects were asked to lie in the supine position and remain still. The entire scan was completed in less than 6 min. Software supplied from the manufacturer was used to calculate whole-body (minus the head) fat mass, lean mass and bone mineral mass. Total DXA weight was computed by summing the DXA parts and used to compute DXA-BF%. As recommended by Lohman & Chen[20], DXA weight and scale-measured body weight were compared with linear regression. The R^2 between measured and DXA weight was >0.99. The slope of the measured–DXA weight regression line of 1.01 (95 % CI 1.00, 1.02) and the intercept of −0.08 (95 % CI −0.37, 0.20) were within chance variation of 1.0 and 0. The standard error of the estimate for scale-measured weight was 1.5 kg.

Statistical methods

Maximum likelihood, linear mixed models (LMM) regression was used to model the data with a random intercept growth model[21]. A major advantage of LMM is that all data can be used with subjects who have a different number of observations over time[21,22]. Stata version 10 (xtmixed program) was used for data analysis[23]. The first LMM examined the linearity of the BMI and DXA-BF% relationship. The second model examined the effect of race/ethnicity group on DXA-BF% with age and BMI statistically controlled. The dependent variable for the LMM analyses was DXA-BF% and the fixed effects variables were BMI and race/ethnic group, which was dummy coded using NHW women and men as the referent groups. The repeat tests were the random part of the model. Each fixed effect LMM regression coefficient was tested with a z-test to determine if it was significantly different from zero[23]. A log-ratio test[21–23] was used to determine if the model that included race/ethnic group provided a better fit of the data than the BMI model. It has been previously documented[13] that for the same BMI, the BF% of women is ≥10.4 % higher than that of men, and that age accounts for BF% independently of BMI and sex. For these reasons, the men and women's data were analysed separately and age was used as a covariate.

Results

Table 1 gives the descriptive statistics for the women and men and the number of observations for the total sample and for race/ethnicity group. The women and men were similar in age and the data exhibited the well-documented sex differences in physical characteristics for height, weight and body composition. The NHW women were significantly taller than Hispanic, Asian-Indian and Asian women and heavier than Asian-Indian and Asian women, while AA women were heavier than NHW women. Compared with NHW women, the BMI of Hispanic ($P=0.057$) and AA women was higher and the BMI for Asian women was lower. The DXA bone mineral mass and lean mass of all race/ethnic groups were significantly different from NHW women. The DXA-BF% of Hispanic and Asian-Indian women was significantly higher than that of NHW women, while DXA-BF% did not differ between NHW, AA and Asian women. The NHW men were significantly taller than Hispanic, Asian-Indian and Asian men. There were no significant race/ethnic group differences for weight or BMI in males. The DXA bone mineral and lean mass of all groups were significantly different from those of the NHW men. The mean DXA fat mass of AA men was significantly ($P=0.023$) lower than that of NHW men. The mean DXA-BF% of AA men was 3.5 % lower than that for NHW men.

The LMM analyses are provided in Table 2 (women) and Table 3 (men). Provided are the LMM regression coefficients (estimates), the standard errors of the coefficient (SE) and the

Table 1. Characteristics of the Training Intervention and Genetics of Exercise Response (TIGER) women (*n* 806) and men (*n* 509) for the total sample and contrasted by race/ethnic groups

(Mean values and standard deviations)

Variable	White Mean	SD	Hispanic Mean	SD	African-American Mean	SD	Asian-Indian Mean	SD	Asian Mean	SD	Total Mean	SD
TIGER women												
Observations	379		325		449		43		104		1300	
Age (years)	21·7	3·1	21·6	2·9	21·1	3·2	21·3	1·7	21·1	2·2	21·4	3·0
Height (cm)	164·4	6·5	159·2*	5·8	164·2	6·6	155·7*	6·3	156·5*	5·6	162·1	7·0
Weight (kg)	68·1	16·6	67·3	15·8	73·2*	19·6	57·8*	12·0	55·4*	11·5	68·3	17·8
BMI (kg/m^2)	25·3	5·9	26·6	6·0	27·1*	6·7	23·9	4·5	22·6*	3·9	26·0	6·2
BMC (kg)	2·2	0·3	2·0*	0·3	2·4*	0·3	1·9*	0·2	1·9*	0·2	2·2	0·4
Lean mass (kg)	43·4	6·9	40·9*	6·5	46·2*	8·2	34·5*	5·8	35·8*	5·6	42·8	7·9
Fat mass (kg)	21·9	10·8	23·7	10·0	23·9	12·0	20·8	6·8	17·1*	6·8	22·6	10·8
DXA-BF%	31·0	7·4	34·3*	6·6	31·3	7·9	35·7*	5·1	30·3	6·1	32·0	7·4
TIGER men												
Observations	305		217		183		37		78		820	
Age (years)	22·3	3·4	21·6	2·5	21·1*	2·9	22·7	3·8	21·7	2·2	21·8	3·0
Height (cm)	177·1	6·0	173·3*	6·6	177·6	6·5	172·3*	5·9	172·2*	7·2	175·5	6·7
Weight (kg)	83·6	18·1	82·0	18·8	85·8	20·7	76·4	19·2	82·9	25·6	83·3	19·8
BMI (kg/m^2)	26·6	5·2	27·3	5·6	27·2	5·8	25·8	5·8	27·8	7·1	27·0	5·7
BMC (kg)	2·8	0·4	2·7*	0·4	3·1*	0·5	2·5*	0·4	2·6*	0·4	2·8	0·5
Lean mass (kg)	62·0	9·3	59·9*	10·2	65·6*	9·5	53·3*	8·8	59·6*	12·4	61·6	10·3
Fat mass (kg)	17·8	10·2	18·1	9·8	15·6*	12·4	19·2	11·2	19·4	13·6	17·6	11·1
DXA-BF%	20·3	7·5	21·4	6·9	16·8*	8·3	24·1*	8·8	21·7	8·2	20·1	7·9

BMC, bone mineral content; DXA-BF%, body fat percentage determined by dual-energy X-ray absorptiometry.
* Mean value was significantly different from that of white men or women ($P < 0.01$).

probability (*P*) that the coefficient was significantly different from 0. LMM I showed that, with age controlled, the BMI relationship with DXA-BF% for men was linear, but quadratic for women. Fig. 1 gives the bivariate relationship for all observations contrasted by sex. Also provided in Fig. 1 are the quadratic and linear lines of best fit for the women and men's bivariate distributions. These graphs show that the DXA-BF% of women was higher than that of men for the same BMI through the range studied.

LMM II in Tables 2 and 3 included race/ethnic group with BMI. The log-ratio test confirmed that LMM II provided a better fit for both women and men ($P < 0.001$). The women's LMM regression weights for all race/ethnic groups were significantly different from the referent group, NHW women.

For the same age and BMI, the DXA-BF% of AA women was 1·76 % lower than that of NHW women and the DXA-BF% of Hispanic, Asian-Indian and Asian women were significantly higher. The race/ethnic group bias for the same age and BMI ranged from 1·65 % for Hispanic women to nearly 6 % for Asian-Indian Women. The analysis of the men's data showed that the LMM II regression weights of Hispanic and Asian men were within random variation of NHW men. The LMM regression weights for AA and Asian-Indian men were significantly different from that of NHW men and the effects were substantial. For the same age and BMI, the DXA-BF% of AA men was 4·57 % lower than that of NHW men while the DXA-BF% of Asian-Indian men was 4·29 % higher. A final LMM analyses examined the race/ethnic

Table 2. Maximum likelihood linear mixed models (LMM) analyses of the Training Intervention and Genetics of Exercise Response (TIGER) women (1300 total observations)

(Estimates with their standard errors)

Term	LMM I Estimate	SE	P	LMM II Estimate	SE	P
Fixed part						
Constant (β)	13·0535	2·2726	<0·001	−14·4900	2·1190	<0·001
Age (β)	0·0219	0·0479	0·647	0·0080	0·0438	0·855
BMI (β)	2·3527	0·1396	<0·001	2·4274	0·1302	<0·001
BMI^2 (β)	−0·0230	0·0023	<0·001	−0·0236	0·0021	<0·001
Hispanic (β)				1·6520	0·3740	<0·001
African-American (β)				−1·7619	0·3437	<0·001
Asian-Indian (β)				5·9779	0·7415	<0·001
Asian (β)				2·6480	0·5590	<0·001
Random part						
Intercept (SD)	4·18	0·11		3·75	0·10	
Error (SD)	1·13	0·04		1·13	0·04	

Table 3. Maximum likelihood linear mixed models (LMM) analyses of the Training Intervention and Genetics of Exercise Response (TIGER) men (820 total observations)

(Estimates with their standard errors)

	LMM I			LMM II		
Term	Estimate	SE	P	Estimate	SE	P
Fixed part						
Constant (β)	−11·8441	1·6975	<0·001	−9·4839	1·5855	<0·001
Age (β)	0·0647	0·0698	0·353	−0·0173	0·0641	0·787
BMI (β)	1·1338	0·0337	<0·001	1·1427	0·0310	<0·001
Hispanic (β)				−0·0707	0·5047	0·889
African-American (β)				−4·5940	0·5287	<0·001
Asian-Indian (β)				4·2932	0·9330	<0·001
Asian (β)				0·3004	0·7243	0·678
Random part						
Intercept (SD)	4·85	0·16		4·33	0·14	
Error (SD)	1·19	0·05		1·18	0·05	

group and BMI interaction. A log likelihood-ratio test confirmed that adding the BMI × race/ethnic group interaction term for both men ($P=0.093$) and women ($P=0.384$) did not improve the fit over LMM II. This confirmed that the systematic race/ethnic bias was constant over the entire BMI range.

Figs. 2 and 3 show the significant ethnic group bias for women and men. The graphs include solid and dashed lines representing the NHW women and men DXA-BF% for the BMI overweight and obesity cut-scores. These DXA-BF% NHW cut-scores for overweight and obesity were: women, 31·2 and 36·9%; men, 18·7 and 24·6%. The overweight and obese lines in the figures show that the BMI for Hispanic, Asian and Asian-Indian women is lower than the NHW women values of 25 and 30 kg/m² while the BMI for AA women is higher. Figure 3 shows that the BMI of AA men is about 4 kg/m² lower than NHW men and the BMI cut-score for Asian-Indian men is nearly 4 kg/m² higher. Table 4 gives these race/ethnic group BMI specific cut-scores (95 % CI) equated to the NHW DXA-BF% values.
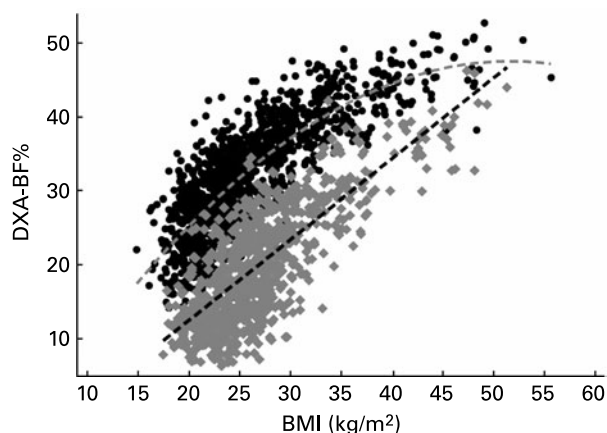
The LMM III random model residuals were examined graphically two ways: normal curves superimposed on the histogram of residuals; standardised normal quartile probability plots of the residuals[21,23,24]. These graphs showed that the residuals were normally distributed (graphics not shown) with no serious outliers. The excellent fit of the LMM II data is further documented by the model error estimates provided in Tables 2 and 3. The error estimates were <1·2 %, which is close to the measurement error that would be expected when measuring BF% with DXA technology.

Discussion

These TIGER results documented that the relationship between BMI and BF% differs for men and women. Similar to results reported by other investigators[7,10,11,13], these TIGER data found that, for a given BMI, the BF% of women was higher than of men. These results with young adults documented that the relationship between BMI and BF% of men was linear, but quadratic for women. For a BMI <40 kg/m² the sex difference in BF% was ≥10 %.

Fig. 1. The bivariate relationship between BMI and body fat percentage determined by dual-energy X-ray absorptiometry (DXA-BF%) using 1300 total observations for women and 820 observations for men. (●), Women's data; (◆), men's data. The relationship (regression line) for women was quadratic (------); for men it was linear (---).
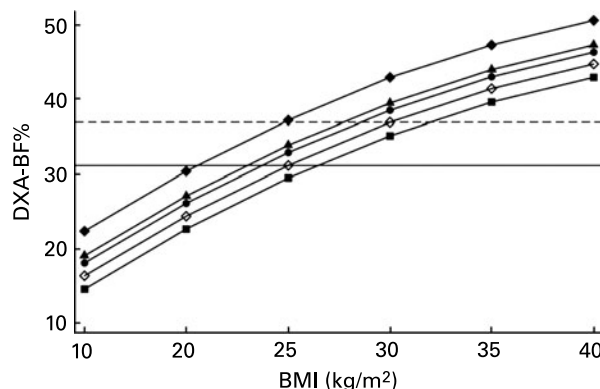

Fig. 2. Body fat percentage estimates determined by dual-energy X-ray absorptiometry (DXA-BF%) for selected BMI values of women contrasted by race/ethnic groups. (—), DXA-BF% value of 31·2%, which equates to the BMI cut-score for overweight; (---), DXA-BF% value of 36·9%, which equates to the BMI cut-score for obese; (◇), non-Hispanic whites; (●), Hispanic whites; (■), African-Americans; (◆), Asian-Indians; (▲), Asians. The graphs were constructed using linear mixed model (LMM) II to model the data (see Table 2).
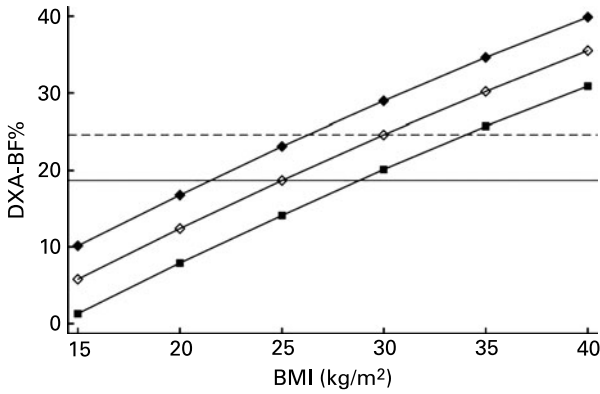
Fig. 3. Body fat percentage estimates determined by dual-energy X-ray absorptiometry (DXA-BF%) for selected BMI values of men contrasted by non-Hispanic white (◇), African-American (■) and Asian-Indian (◆) groups. (—), DXA-BF% value of 18·7 %, which equates to the BMI cut-score for overweight; (- - -), DXA-BF% value of 24·6 %, which equates to the BMI cut-score for obese. The graphs were constructed using linear mixed model (LMM) II to model the data (see Table 3).

The non-linear relationship between BMI and BF% has been documented with men and women from the Heritage Family Study[13]. The major difference between samples was that the Heritage study subjects ranged in age from 17 to 65 years, compared with the TIGER age range of 17 to 35 years, and the Heritage study BF% was measured with a two-component method, not DXA.

An important finding of the present study was that BMI overestimated the DXA-BF% of AA men and women. These TIGER results are consistent with the meta-analysis results reported by Deurenberg et al.[7] and Jackson et al.[13] but differed from the results reported by Gallagher et al.[11]. Deurenberg et al. found that using a BMI prediction equation derived with Caucasians overestimated the measured BF% of AA men and women by nearly 2 %. The Heritage Family Study included 665 AA and NHW men and women who ranged in age from 17 to 65 years. In a second Heritage study[25] a race effect for abdominal visceral fat was found for both men and women. Controlling for age, BMI and waist circumference, the abdominal visceral fat measured by computed tomography of AA men and women was significantly lower than that of NHW men and women.

Other investigators have reported a race/ethnic group bias when estimating BF% from BMI with equations derived

from Caucasian men and women. Using samples of older Hispanic Americans and controlling for age, Fernandez et al.[9] reported that for BMI values below 30 kg/m², Hispanic American women had a higher BF% than either Caucasian or AA women, but, like these results, did not find a significant race/ethnic group effect for men. Several investigators[5-8] reported that BMI systematically underestimated the BF% of Asian subjects. Deurenberg-Yap et al.[8] recommended that, for the same Caucasian BF%, the obesity BMI cut-score for Chinese and Malays was 27 kg/m². These TIGER data showed that the obesity BMI cut-score for Asian women was 27·6 (95 % CI 26·6, 28·9) kg/m², within random variation of the Deurenberg-Yap et al. recommendation. Deurenberg-Yap et al.[8] also reported a race bias for Singaporean Indians. Their data showed that, for the same BF% of Caucasians, the BMI cut-score for obesity was 26 kg/m², which is within chance variation of the values we found with these young Asian-Indian men (26·5 (95 % CI 24·9, 28·1) kg/m²) and slightly higher than what we found for Asian-Indian women (24·8 (95 % CI 23·6, 25·9) kg/m²).

These TIGER results identified a significant Asian group effect for women, but not men, whereas Chang et al.[5] and Deurenberg-Yap et al.[8] reported a significant effect for both men and women. A likely reason for this difference was research design. Chang et al. and Deurenberg-Yap et al. combined the data of men and women and controlled for sex by including it as an independent variable of their multiple regression model. To examine this methodological issue, we combined the TIGER men and women's data and used sex as an independent variable (male = 0, female = 1). This LMM analysis (results not shown) revealed that, with age and sex statistically controlled, the Asian group effect was 1·72 ($P < 0.001$). This demonstrated that for the same BMI, the DXA-BF% of Asian men and women would be 1·7 % higher than that of NHW men and women. This suggested that the difference between studies was linked to combining men and women into the same statistical model. A strength of the present study was the large number of observations for men and women. This not only provided our sex-specific models with sufficient statistical power, but also controlled the effect of sex, which has been shown to be substantial. For the same BMI, the BF% of women has consistently been found to be ≥ 10·4 % higher than that of men[13].

The recommended obesity cut-score of 30 kg/m²[1,2] was determined from the general trends in the relationship between

Table 4. Overweight and obese BMI cut-scores for race/ethnic groups equivalent to body fat percentage determined by dual-energy X-ray absorptiometry for 25 and 30 kg/m² of non-Hispanic white women and men

(Mean values and 95 % confidence intervals)

| | Women | | | | Men | | | |
| | Overweight | | Obese | | Overweight | | Obese | |
Group	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
African-American	26·4	25·9, 27·0	31·9	31·2, 32·5	29·0	28·2, 29·9	34·2	33·3, 35·2
Asian-Indian	20·6	19·6, 21·6	24·8	23·6, 25·9	21·3	19·7, 22·9	26·5	24·9, 28·1
Asian	22·9	22·2, 23·9	27·6	26·6, 28·9	25·0		30·0	
Hispanic	23·7	23·2, 24·3	28·5	27·8, 29·3	25·0		30·0	
White	25·0		30·0		25·0		30·0	

BMI and morbidity and mortality rates, not on the accuracy of BMI to estimate BF%. Recent NHANES results[15,16] found that, compared with the normal-weight category (BMI 18·5 to <25 kg/m²), obesity (BMI ≥ 30 kg/m²) was associated with excess mortality or CVD, whereas overweight (BMI 25 to <30 kg/m²) was not. Fontaine et al.[17] reported that the BMI of young adults was related to longevity and the effect on AA men and women differed from that on NHW men and women. They reported that NHW men and women had a reduced longevity if their BMI was ≥ 30 kg/m² at age 20 to 30 years. The pattern for AA men and women differed. A consistent reduction in longevity did not take place with AA women until the BMI reached ≥ 37 kg/m² and ≥ 33 kg/m² for AA men. Stevens et al.[18] reported that the reference BMI for a 40 % higher risk of all-cause mortality was 35·9 kg/m² in AA women compared with 27·3 kg/m² for NHW women. These TIGER results are consistent with the observation made by Manson & Bassuk[19] who stated that the ethnic variation in the relationship between BMI and total adiposity or visceral adiposity might partly account for the observed racial discrepancies reported by Fontaine et al.[17]

A limitation of the present study is that the TIGER subjects are not a random sample of the US population, but the TIGER men and women are representative of the overweight and obesity prevalence of the national population of young adults[14]. The self-reported definition of racial/ethnic group membership was another limitation in the present study. The genetic technique of admixture analysis provides an objective method of defining racial heritage. Research has shown that admixture mapping cannot only localise, but also fine map, a phenotypically important variant[26]. The genetic examination of these TIGER data with admixture analysis is planned and will provide a clearer understanding of the source of the race/ethnic group bias found with these diverse young men and women.

These TIGER results support the findings of others[5–9,13,25] that standardised obesity cut-points based on BMI do not represent equivalent levels of body fat across different race/ethnic groups. Our data indicate that, based on DXA-BF%, overweight and obesity cut-points should be higher in AA men and women and lower in Asian-Indian, Asian and Hispanic women and Asian-Indian men. These findings document the inherent bias of using BMI as an indicator of obesity in diverse men and women. These results extend the generalisability of race/ethnic group bias of BMI to young adults. The large number of observations and separate models for women and men support the fidelity of these findings.

Acknowledgements

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