British Journal of Nutrition (2001), **86**, 105–112

DOI: 10.1079/BJN2001382

BMI does not accurately predict overweight in Asian Indians in northern India

V. Dudeja[1], A. Misra[1]*, R. M. Pandey[2], G. Devina[1], G. Kumar[2] and N. K. Vikram[1]

[1]*Department of Medicine and* [2]*Department of Biostatistics, All India Institute of Medical Sciences, New Delhi-110029, India*

(Received 30 August 2000 – Revised 20 February 2001 – Accepted 28 February 2001)

Asian Indians are at high risk for the development of atherosclerosis and related complications, possibly initiated by higher body fat (BF). The present study attempted to establish appropriate cut-off levels of the BMI for defining overweight, considering percentage BF in healthy Asian Indians in northern India as the standard. A total of 123 healthy volunteers (eighty-six males aged 18–75 years and thirty-seven females aged 20–69 years) participated in the study. Clinical examination and anthropometric measurements were performed, and percentage BF was calculated. BMI for males was 21·4 (SD 3·7) kg/m^2 and for females was 23·3 (SD 5·5) kg/m^2. Percentage BF was 21·3 (SD 7·6) in males and 35·4 (SD 5·0) in females. A comparison of BF data among Caucasians, Blacks, Polynesians and Asian ethnic groups (e.g. immigrant Chinese) revealed conspicuous differences. Receiver operating characteristic (ROC) curve analysis showed a low sensitivity and negative predictive value of the conventional cut-off value of the BMI (25 kg/m^2) in identifying subjects with overweight as compared to the cut-off value based on percentage BF (males $>$25, females $>$30). This observation is particularly obvious in females, resulting in substantial misclassification. Based on the ROC curve, a lower cut-off value of the BMI (21·5 kg/m^2 for males and 19·0 kg/m^2 for females) displayed the optimal sensitivity and specificity, and less misclassification in identification of subjects with high percentage BF. Furthermore, a novel obesity variable, BF:BMI, was tested and should prove useful for interethnic comparison of body composition. In the northern Indian population, the conventional cut-off level of the BMI underestimates overweight and obesity when percentage BF is used as the standard to define overweight. These preliminary findings, if confirmed in a larger number of subjects and with the use of instruments having a higher accuracy of BF assessment, would be crucial for planning and the prevention and treatment of various obesity-related metabolic diseases in the Asian Indian population.

Body fat: BMI: Asian Indians: Obesity: Skinfolds

Overweight and obesity are a rapidly escalating problem in developing countries. Excess body fat (BF), in particular abdominal fat, is a harbinger of several adverse metabolic consequences, including hyperinsulinaemia, impaired glucose tolerance, hyperlipidaemia and prothrombotic tendency (a conglomeration of features termed insulin resistance syndrome; Reaven, 1988). Insulin resistance is commonly observed in Asian Indians and it precedes the development of CHD (McKeigue *et al.* 1991).

Overweight and obesity are commonly defined by the measurement of BMI. However, this is an imperfect measure, since both fat and fat-free mass (bone, muscles and body water) are estimated. An important limitation of the BMI as a measure of obesity is that it tends to ignore the distinction between fat and fat-free mass. Cut-off levels of the BMI for overweight and obesity are based on the 5th and 95th centiles of body weight and the mortality profile derived from the Caucasian population (World Health Organization, 1995, 1998). A more accurate definition of overweight and obesity, however, should be more appropriately based on the total amount of BF. The upper limits of BF for defining obesity, although still debatable, have been set as 25 % and 30 % for males and females respectively (Pollock & Wilmore, 1990; Hortobagyi *et al.* 1994). In Caucasian men and women, a BMI of 30 kg/m^2 corresponds to 25 % and 30 % BF in males and females respectively (Deurenberg *et al.* 1991). However, body composition is altered with several physiological perturbations: advancing age, hormonal imbalances and menopause. Moreover, due to the differences in height, weight, architecture and proportion of bones, muscles and fat, ethnic differences exist. Several studies have reported that

Abbreviations: BF, body fat; ROC, receiver operating characteristic.

* **Corresponding author:** Professor A. Misra, fax +91 11 6862663/6521041, email anoopmisra@hotmail.com

Blacks have an increased proportion of bone and muscle tissues as compared with Whites (Cohn *et al.* 1977; Gasperino *et al.* 1995). Similarly, for every level of BMI the predicted BF is lower in Polynesians (Swinburn *et al.* 1996). Furthermore, differences in percentage BF were observed even in the same racial lineage residing in different geographical locations. In three different populations of West African heritage from the USA, Jamaica and Nigeria, the relationship between BMI and BF levels differed significantly ($P < 0.001$) (Luke *et al.* 1997).

Short stature, stunting of growth and malnutrition may alter the appropriateness of assessing the relationship between height, weight and body composition, facts of critical importance for the Asian populations (Shetty, 2000). Chinese subjects who were born in Asia and settled in New York had increased subcutaneous fat, particularly in the upper body distribution (Wang *et al.* 1994). This difference was sex dependent, being larger in females. Similarly, a recent study of Singaporean Chinese also questioned the cut-off points for BMI and waist:hip ratio based on the WHO guidelines (Yap *et al.* 1999, 2000). Further, the risk (as assessed by odds ratio) for co-morbidities such as diabetes, dyslipidaemia and hypertension in Chinese residing in Hong Kong started to increase from a BMI of 22 kg/m^2 onwards (Ko *et al.* 1999). Notably, a similar situation may exist in Asian Indians, since they do not have a high BMI, but abdominal obesity and excess fat is more frequently observed (Banerji *et al.* 1999). This particular habitus of Asian Indians, i.e. decrease in lean body mass and excess BF, is an interesting observation; however, its detailed phenotypic, biochemical and metabolic characteristics remain to be investigated.

In the present study we have attempted to assess the relationship between percentage BF and BMI with other anthropometric measurements. Further, using the receiver operating characteristic (ROC) curve, we have attempted to establish the appropriate cut-off points of the BMI for males and females, considering percentage BF as standard.

Methodology

The present study was carried out from January 1999 to December 1999 at the All India Institute of Medical Sciences, New Delhi (one of the largest tertiary referral hospitals in northern India). Healthy non-diabetic subjects were recruited by local advertisement and posters. Informed consent was obtained from all the volunteers after full explanation of the procedure. All the participating subjects were ambulatory. A preliminary assessment was carried out in the clinic to rule out any systemic disease. Subjects were then admitted briefly to the General Clinical Research Center for detailed evaluation. The same observer performed the clinical examinations, including the anthropometric measurements.

Anthropometric measurements

Body weight (to the nearest 0·1 kg) and height (to the nearest 0·001 m) were recorded in subjects without shoes and wearing only light indoor clothes. The waist circumference was measured midway between the iliac crest and the lower-most margin of the ribs. The hip circumference was measured at the maximum circumference of the buttocks, the subject standing with feet placed together. The mean of three readings of each circumference was taken for the calculation of the waist:hip ratio. Biceps, triceps, subscapular and suprailiac skinfold thicknesses were measured using Lange skinfold calipers (Beta Technology Inc., Santa Cruz, CA, USA). For the biceps skinfold thickness, with the right arm pendant the biceps fat pad was measured at the level of the nipple line. For the triceps skinfold thickness, the triceps fat pad was measured midway between the acromion process of the scapula and the olecranon process. For the subscapular and suprailiac skinfold thicknesses, the fat pads at the inferior angle of the scapula and superiorly on the iliac crest directly in the mid-axillary line respectively were measured. All skinfold thicknesses were measured to the nearest 1 mm. The mean of three readings was recorded at each site. Subscapular: triceps skinfold thicknesses, and central (sum of subscapular and suprailiac):peripheral skinfold thicknesses (sum of biceps and triceps) were also calculated. The sum of all skinfold thicknesses was used for the calculation of percentage BF using the standard equation (Durnin & Womersely, 1974). The equation for the calculation of BF from skinfold thicknesses has been validated in Asian Indians (Kuriyan *et al.* 1998).

Statistical analysis

Data were recorded on a predesigned proforma and managed in a Microsoft Excel spreadsheet. All the entries were double-checked for any possible keyboard error. Descriptive statistics for anthropometric variables were computed by mean and standard deviation. Since the difference in the mean age of male and female subjects was statistically significant ($P = 0.019$), and the anthropometric variables that needed to be compared between males and females are a function of age, the anthropometric profiles in males and females were compared by adjusting for age. Adjustment was made for the age factor alone. Since the results of analysis of covariance is sensitive to two assumptions (homogeneity of residual variance and equality of regression coefficients), these assumptions were verified before applying analysis of covariance to compute the mean and standard deviation of the anthropometric profile adjusted for age. Since ROC analysis was performed for males and females separately and no comparison was made between them, unadjusted values of BMI and percentage BF were used to draw the ROC curve. The χ^2 test was applied to assess the statistical association between gender and the various anthropometric measurements in categorical form. For males and females, ROC curves were drawn to determine an appropriate cut-off point of the BMI, considering the percentage BF derived from skinfold measurements as standard. Analysis was performed using STATA 6·0 intercooled version (STATA Corporation, Houston, TX, USA) statistical software. All the statistical tests were two-tailed; $P < 0.05$ was considered as statistically significant.

Table 1. Anthropometric profile and percentage body fat (BF) of healthy Asian Indian subjects adjusted for age*
(Mean values and standard deviations)

Anthropometric measurements	Males (*n* 86) Mean	Males SD	Females (*n* 37) Mean	Females SD	Statistical significance of difference: *P*	95 % CI
Height (m)	1·644	0·230	1·586	0·232	0·19	−3·13, 14·85
Weight (kg)	62·4	11·53	56·9	11·6	0·01	1·01, 10·00
BMI (kg/m^2)	21·4	3·7	23·3	5·5	0·029	0·19, 3·56
Waist circumference (cm)	79·6†	11·4	77·4	12·6	0·367	−2·52, 6·77
Waist:hip ratio	0·86†	0·08	0·82	0·09	<0·001	0·05, 0·11
Biceps skinfold thickness (mm)	8·3	5·8	14·0	6·6	<0·001	3·29, 8·02
Triceps (T) skinfold thickness (mm)	14·6	7·8	22·1	6·7	<0·001	4·59, 10·39
Subscapular (S) skinfold thickness (mm)	18·8	8·8	23·4	8·5	0·008	1·18, 7·95
Suprailiac skinfold thickness (mm)	21·3	10·6	24·6	7·0	0·086	−0·40, 7·05
S:T	1·35	0·41	1·07	0·37	0·001	0·12, 0·43
Σ 4SF (mm)	63·1	30·2	84·0	24·4	0·001	9·77, 32·11
Peripheral (P) skinfold thickness (mm)	23·0	13·2	36·0	12·2	<0·001	8·02, 18·09
Central (C) skinfold thickness (mm)	40·2	18·5	48·0	14·1	0·048	0·06, 13·53
C:P	1·91	0·54	1·37	0·31	<0·001	0·35, 0·73
Percentage BF	21·3	7·6	35·4	5·0	<0·001	11·32, 15·7
Percentage BF:BMI	1·01	0·02	1·52	0·03	<0·001	0·47, 0·61

Σ 4SF, sum of four skinfold thicknesses.
* For details of subjects and procedures, see pp. 105–106.
† *n* 80.

Definitions

Two definitions of overweight were used. BMI >25 kg/m^2 and BF >25 % in males and >30 % in females (Pollock & Wilmore, 1990; Hortobagyi *et al.* 1994) were used as twin criteria. A high waist:hip ratio was defined as >0·95 in males and >0·80 in females (Willett *et al.* 1999). The sum of skinfold thicknesses was defined as high when the value exceeded 50 mm. A high waist circumference was defined as >102 cm in males and >88 cm in females (Han *et al.* 1995).

Results

The present study included eighty-six males and thirty-seven females. Males were comparatively younger than females (males 28·2 (SD 11·9) years, females 33·9 (SD 12·9) years; $P = 0·019$, 95 % CI 0·96, 10·49).

Anthropometry and body fat analysis

The anthropometric and BF profile of the study population is shown in Table 1. The mean BMI of females was higher than that of males ($P < 0·029$). The waist circumference was similar in males and females ($P = 0·367$), but the waist:hip ratio was significantly higher in males ($P < 0·001$). The sum of skinfold thicknesses was higher in females than in males ($P = 0·001$). Similarly, peripheral and central skinfold thicknesses were higher in females ($P < 0·001$ and $P = 0·048$ respectively). The subscapular: triceps skinfold thickness was higher in males than in females ($P = 0·001$).

The percentage BF was 21·3 (SD 7·6) in males and 35·4 (SD 5·0) in females. Forty-nine (56·9 %) males and thirty-four (91·9 %) females had a high sum of skinfold thicknesses (Fig. 1). When a BMI of >25 kg/m^2 was applied as the cut-off level, thirteen (15·1 %) males and ten (27·0 %) females were overweight and obese. This situation was substantially different when percentage BF was taken as the measurement of overweight. Based on this criterion thirty (34·8 %) males and thirty-three (89·2 %) females were overweight. Significantly higher numbers of females had high waist circumference and high waist:hip ratio than males ($P = 0·002$ and $P < 0·001$ respectively; Fig. 1).

A ROC curve was drawn to determine the appropriate cut-off value of the BMI while taking percentage BF as the standard (Table 2 and Fig. 2). While the specificity of a BMI of 25 kg/m^2 in defining overweight was high, the sensitivity was low (males 36·7 %, females 30·3 %). When a BMI of 21·5 kg/m^2 was used as the cut-off point for overweight in males, the specificity decreased marginally by 7·1 %; however, the sensitivity increased substantially by 50·0 %. Notably, in females, even a lower BMI cut-off level (19·0 kg/m^2) improved the sensitivity to 93·9 %, while maintaining the same degree of specificity (100 %).

Table 2. Test characteristics (%) of using BMI as a measure of obesity in Asian Indian subjects*†
(Mean values and 95 % CI)

	Conventional Mean	Conventional 95 % CI	Proposed Mean	Proposed 95 % CI
Males	BMI >25 kg/m^2		BMI >21·5 kg/m^2	
Sensitivity	36·7	19·4, 54·0	86·7	74·6, 98·8
Specificity	96·4	91·5, 100·0	89·3	81·2, 97·4
Overall misclassification	24·4	15·4, 33·4	11·6	4·9, 18·3
Positive predictive value	84·6	65·0, 100·0	81·3	67·8, 94·8
Negative predictive value	78·0	68·5, 87·5	92·6	85·6, 99·6
Females	BMI >25 kg/m^2		BMI >19·0 kg/m^2	
Sensitivity	30·3	14·6, 56·0	93·9	85·7, 100·0
Specificity	100·0		100·0	
Overall misclassification	69·6	54·0, 85·2	6·1	0, 14·3
Positive predictive value	100·0		100·0	
Negative predictive value	14·8	1·4, 28·2	66·6	28·9, 100·0

* For details of subjects and procedures, see pp. 105–106.
† Standard for males and females: obese, >25 and >30 % body fat; non-obese, ≤25 and ≤30 % body fat respectively.

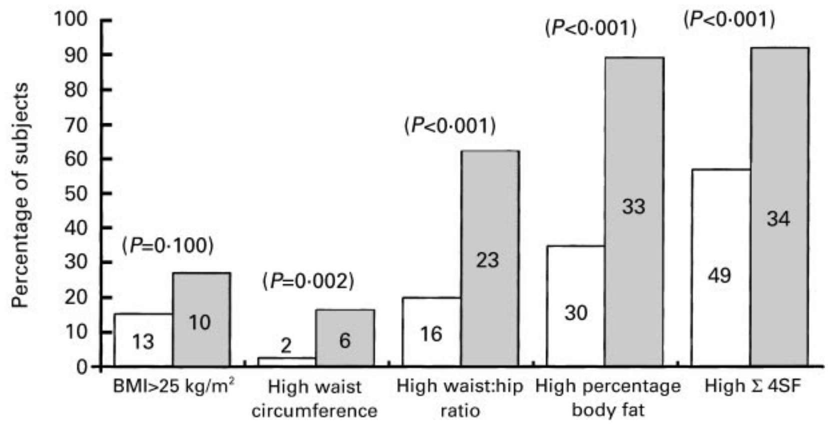

Fig. 1. Measures of obesity in healthy Asian Indians in northern India. (□), Males (*n* 86); (▩), females (*n* 37). Numbers shown for each variable indicate the no. of subjects. For males and females cut-off values used were: high waist circumference 102 and 88 cm respectively; high waist:hip ratio >0·95 and >0·80 respectively; high percentage body fat >25 and >30 respectively; high sum of four skinfold thicknesses (∑ 4SF) >50 mm. For details of subjects and procedures, see pp. 105–106.

Thus, derived lower BMI cut-off values decreased overall misclassification (males 11·6 %, females 6·1 %) of individuals into category of overweight. Further, a BMI cut-off level of 21·5 kg/m^2 in males markedly improved the negative predictive value with only a marginal decrease in positive predictive value (Table 2). Similarly, in females defining overweight by a BMI level of 19·0 kg/m^2 markedly improved the negative predictive value, while maintaining the positive predictive value at 100 %.

Most of these calculated anthropometric measurements have been reported by various workers earlier. We analysed a novel variable, percentage BF:BMI. From the observations on Asian Indians, there is a suggestion that they have a higher BF per unit BMI. This phenomenon, although noticeable in males (percentage BF:BMI 1·01 (SD 0·02)), was particularly remarkable in females (percentage BF:BMI 1·52 (SD 0·03); Table 1).

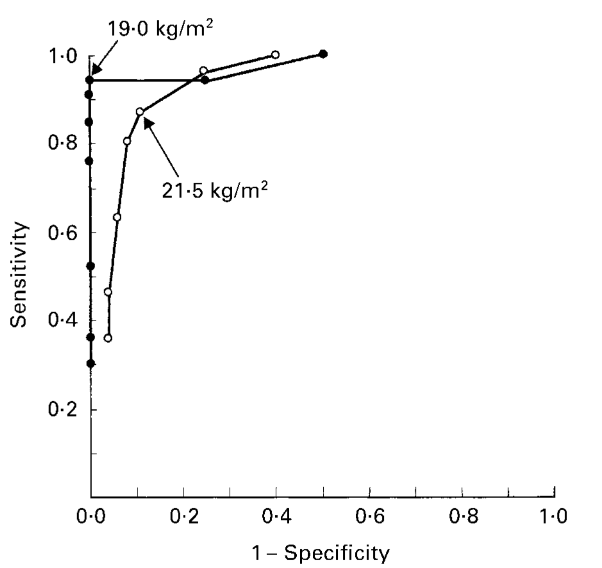

Fig. 2. Receiver operating characteristic curve to determine the appropriate cut-off value of the BMI (kg/m^2), while taking the percentage body fat as standard. Subjects were healhy male (○) and female (●) Asian Indians in northern India. For details of subjects and procedures, see pp. 105–106.

Discussion

The mean values of BMI recorded in the present study are consistent with observations on the urban Indian population (Gopinath *et al.* 1994). Data derived from migrant Indians, however, showed higher values for both males (25·7 kg/m^2) and females (27·0 kg/m^2) ($P < 0·001$; McKeigue *et al.* 1991; Tables 3 and 4). However, the mean value of the waist:hip ratio, in both males and females, was lower than that reported by McKeigue *et al.* (1991). In general, values for skinfold thickness, both central and peripheral, are also higher in migrant Indians of both genders except for that of the triceps skinfold, which was higher in native Asian Indians in the present study. These data indicate that migrant Indians were more overweight as estimated by BMI, and also had higher percentage BF as estimated by skinfold thicknesses, when compared with the sample of northern Indians in the current study.

For males, the distribution of BMI (21·4 (SD 3·7) kg/m^2) and percentage BF (21·3 (SD 7·6)) were similar, while for females, the distribution of percentage BF (35·4 (SD 5·0)) was shifted towards higher BMI values (23·3 (SD 5·5) kg/m^2). It is of note that thirty-three (89·2 %) females had excess percentage BF. The prevalence of overweight in females according to percentage BF estimation was more than twice that estimated by BMI.

Other workers have also observed a higher percentage BF in Asian Indians at a comparatively low BMI. In a study carried out on migrant Indian male volunteers in the USA, a mean BMI of 24·5 (SD 2·5) kg/m^2 was associated with 33 (SD 7) % BF (Banerji *et al.* 1999). Further, the majority of the fat was localized in the subcutaneous tissues. This finding becomes particularly relevant since, according to a few studies it is the subcutaneous fat in the abdominal region that has the major impact on the metabolic variables

Table 3. Comparison of BMI and percentage body fat (BF) in males Asian Indians of the present study with different ethnic groups
(Mean values and standard deviations, with 95 % CI)

		BMI (kg/m^2)					Percentage BF			
Reference	*n*	Mean	95 % CI	SD	*P*‡	95 % CI	Mean	SD	*P*‡	95 % CI
McKeigue *et al.* (1991)										
Europeans	1515	25·9	25·7, 26·1		<0·001	3·61, 5·31	Not available			
South Asians	1421	25·7	25·2, 25·8		<0·001	2·26, 6·26	Not available			
Afro-Caribbeans	209	26·3	25·8, 26·8		<0·001	3·94, 5·78	Not available			
Wang *et al.* (1994)										
Whites	187	25·1		3·0	<0·001	2·83, 4·49	19·3	6·4	0·009	0·53, 3·77
Asians	110	23·4		3·0	<0·001	1·01, 2·91	21·4	6·3	0·956	−1·72, 1·82
Swinburn *et al.* (1996)										
Polynesians	48	29·6		0·7	<0·001	7·09, 9·23	Not available			
Caucasians	243	26·4		0·2	<0·001	4·49, 5·43	Not available			
Gallagher *et al.* (1996)										
Blacks	98	25·8		3·3	<0·001	3·34, 5·38	21·7	7·9	0·813	−1·83, 2·33
Whites	214	25·2		3·1	<0·001	2·93, 4·59	21·2	7·8	0·791	−1·60, 2·10
Luke *et al.* (1997)										
Nigerians	137	21·7		3·9	0·622	−0·78, 1·3	11·4	7·5	<0·001	8·15, 11·94
Jamaicans	94	23·6		4·4	0·001	0·95, 3·36	19·2	7·6	0·031	0·21, 4·29
US*	189	27·0		5·7	<0·001	4·24, 6·88	27·1	7·8	<0·001	3·78, 7·52
Yap *et al.* (1999)										
Singaporean Chinese	1108	22·8		3·4	0·004	0·61, 2·11	Not available			
Yap *et al.* (2000)†										
Chinese	108	22·8		3·5			24·4	6·3		
Malays	76	25·0		3·7			26·2	7·6		
Indians	107	24·2		3·6			27·3	6·0		
Present study										
Asian Indians	86	21·4		3·7			21·3	7·6		

* Black immigrants to the USA.
† Data not sufficient to calculate *P* values. Separate numbers for males and females not given.
‡ Statistical significance of difference from the present study.

Table 4. Comparison of BMI and percentage body fat (BF) in female Asian Indians of the present study with different ethnic groups
(Mean values and standard deviations, with 95 % CI)

		BMI (kg/m^2)					Percentage BF			
Reference	*n*	Mean	95 % CI	SD	*P*‡	95 % CI	Mean	SD	*P*‡	95 % CI
McKeigue *et al.* (1991)										
Europeans	246	25·2	24·7, 25·7		0·010	0·45, 3·33	Not available			
South Asians	291	27·0	26·5, 27·5		<0·001	2·16, 5·20	Not available			
Wang *et al.* (1994)										
Whites	258	23·9		3·4	0·376	−1·87, 0·7	30·1	8·7	0·001	2·00, 7·74
Asians	132	22·5		3·3	0·257	−0·60, 2·24	31·6	6·5	0·003	1·13, 5·61
Swinburn *et al.* (1996)										
Polynesians	80	29·7		0·7	<0·001	5·15, 7·61	Not available			
Caucasians	250	25·2		0·3	<0·001	1·20, 2·56	Not available			
Gallagher *et al.* (1996)										
Blacks	104	27·0		4·3	<0·001	1·92, 5·44	35·6	8·5	0·667	−3·52, 2·26
Whites	290	23·3		3·7	0·977	−1·33, 1·37	30·3	8·6	0·001	1·84, 7·50
Luke *et al.* (1997)										
Nigerians	161	23·6		5·0	0·763	−2·11, 1·55	25·1	10·4	<0·001	6·43, 13·31
Jamaicans	146	27·0		6·0	0·001	1·54, 5·82	35·3	8·4	0·817	−3·15, 2·49
US*	327	30·9		7·9	<0·001	4·96, 10·2	42·2	7·9	<0·001	4·63, 9·83
Yap *et al.* (1999)										
Singaporean Chinese	1211	22·1		3·8	0·058	−0·05, 2·48	Not available			
Yap *et al.* (2000)†										
Chinese	108	22·1		4·8			33·3	6·3		
Malays	76	24·5		4·8			35·8	6·4		
Indians	107	24·9		5·2			35·8	5·6		
Present study										
Asian Indians	37	23·3		5·5			35·4	5·0		

* Black immigrants to the USA.
† Data not sufficient to calculate *P* values. Separate numbers for males and females not given.
‡ Statistical significance of difference from the present study.

(Abate *et al.* 1995; Misra *et al.* 1997). An increased amount of subcutaneous fat leads to resistance to insulin-mediated glucose uptake, via an increased release of non-esterified fatty acids. Banerji *et al.* (1999) have further observed that 66 % of these 'non-obese' men were insulin resistant. Moreover, increased visceral fat in these volunteers was associated with generalized obesity. The comparatively higher BMI in migrant Indians compared with the subjects in the current study ($P < 0{\cdot}001$; McKeigue *et al.* 1991) has been mentioned earlier (Tables 3 and 4). However, no BF data were available for these individuals. These observations, if corroborated by other studies, would indicate that the migrant Indians, as compared with native Indians, may be at an even greater risk for atherosclerosis on account of the proportionally higher BF. A recent study on Chinese, Malays and Asian Indians in Singapore corroborates these observations (Yap *et al.* 2000). In this study, the authors used multiple methods of BF measurement including skinfold thickness, total body water by ^2H_2O dilution, densitometry with Bodpod® and bone mineral content dual-energy X-ray absorptiometric scan. The BMI was a poor predictor of BF with the mean prediction error ranging from 2·7 to 5·6 %. The relationship between BMI and BF was different among the three ethnic groups, with Asian Indians having the highest percentage BF for the same BMI, age and sex (Yap *et al.* 2000).

Similarly, high percentage BF was also observed in other Asian ethnic groups (Tables 3 and 4). Wang *et al.* (1994) studied a Chinese population residing in New York City, and observed that both males and females of Asian origin had lower BMI values than Whites, but had a higher percentage BF. However, although the percentage BF in males was similar, it was comparatively higher in female subjects in the present study ($P = 0{\cdot}003$). Chinese males had a higher BMI ($P < 0{\cdot}001$) for a similar BF when compared with males in the present study (Wang *et al.* 1994). Furthermore, the skinfolds of Chinese subjects were thinner (Wang *et al.* 1994). These comparative observations are of considerable interest, denoting that all Asians may not be similar in body composition, and that Asian Indians may have higher percentage BF per unit BMI than the other Asian ethnic groups.

A comparison of BMI and percentage BF with other non-Asian ethnic groups reveals interesting observations (Table 3). For example, while the BMI values in Black men and White men residing in or near New York City were higher than in the native Asian Indians in the current study, the percentage BF was comparable ($P = 0{\cdot}813$ and 0·791 respectively; Gallagher *et al.* 1996), again indicating higher BF per unit BMI in Asian Indian subjects. Similarly, the observed BMI values of Nigerian males by Luke *et al.* (1997) were similar ($P = 0{\cdot}622$) to those of the current study, while their percentage BF was significantly lower than that of the male subjects in the present study ($P < 0{\cdot}001$).

Similarly, while Asian Indian females in the current study had BMI values similar to those of White women in New York ($P = 0{\cdot}97$), their percentage BF was higher ($P = 0{\cdot}001$; Table 4; Gallagher *et al.* 1996). A striking observation was the markedly high BMI and percentage BF in Black immigrants in the USA in a study of Luke *et al.* (1997). Nigerian women in the same study showed a lower percentage BF ($P < 0{\cdot}001$), with BMI ($P = 0{\cdot}76$) similar to that of Asian females in the present study. All these studies substantiate the observation of higher BF in native and migrant Asian Indians at similar or lower BMI as compared with other non-Asian ethnic groups.

The BF:BMI, a novel ratio for assessing obesity, is introduced in the present study for the first time. Derivation of this ratio is based on the observation that different ethnic groups have widely different BF for a similar level of BMI. The BF:BMI would, thus, theoretically be a better variable for comparisons between different races if data for both BMI and BF were available. Moreover, a higher percentage BF per unit BMI, giving a high BF:BMI, would be metabolically detrimental. Augmented generation of free fatty acid per unit liver and muscle mass, facilitating dyslipidaemia and insulin resistance, may result. However, we present no anthropometric–metabolic correlation backing this hypothesis in the present study, and it remains to be tested in further studies.

Ruderman *et al.* (1981) initially hypothesized and recently updated (Ruderman *et al.* 1998) their description of individuals with normal weight but who were 'metabolically obese'. These are distinct subsets of individuals in the general population who display insulin resistance, hyperinsulinaemia and dyslipidaemia, but have weight within normal limits. The common denominator for the metabolic abnormalities in this subset of subjects is increased percentage BF and abdominal fat. This finding has become clearer with the improved methods of BF estimation. Detailed studies have recently been performed by Dvorack *et al.* (1999) in women of normal weight. While their mean BMI was 22·5 (SD 2·0) kg/m², they had a high percentage BF (31·8 (SD 5·9), and additionally had higher truncal fat and L4–5 subcutaneous and visceral fat. These women had a lower glucose disposal rate, higher fasting and post-glucose-load plasma insulin levels, and dyslipidaemia. Even a small increase in BF by 2–3 kg within the normal range of BMI affected insulin sensitivity. These findings assume immediate relevance in Asian Indian women, where high percentage BF is noted within lower ranges of BMI.

ROC curve analysis of the data from the current study showed that the sensitivity and specificity of BMI at the current cut-off level of overweight is rather low. However, if the cut-off level of BMI in males was taken as 21·5 kg/m² and in females as 19·0 kg/m², the sensitivity and negative predictive value improved considerably and misclassification was reduced. In a study in Dayton, OH, USA, the BMI (28 kg/m² for males and 26 kg/m² for females) correctly identified 44 % of the obese men and 52 % of obese women when obesity was determined by percentage BF (25 for males and 33 for females). ROC curve analyses by the authors showed that a BMI of 25 kg/m² for males and 23 kg/m² for females should be used as the diagnostic criteria of obesity (Wellens *et al.* 1996). Whereas ROC curve data of the current study is of considerable interest, there is a paucity of comparative studies on Asian Indians.

A recent study by Yap *et al.* (2000) reached similar observations. Using the reference point of BF of

Caucasians having a BMI of 30 kg/m^2 as the cut-off level for obesity, they predicted a BMI cut-off level of 27 kg/m^2 for Chinese and Malays, and 26 kg/m^2 for Asian Indians for defining obesity. They emphasized further that the cut-off level of BMI for obesity would have to be lowered according to age and ethnic group. It must be noted, however, that compared with the subjects in the present study the immigrant Indians studied by Yap *et al.* (2000) were heavier, but their mean height was comparable. Further, the mean BMI of immigrant Indians in Singapore studied by Yap *et al.* (2000) was considerably higher than that of the subjects of the current study (males 24·2 *v.* 21·4 kg/m^2 and females 24·9 *v.* 23·3 kg/m^2 in immigrant Indians in Singapore *v.* Asian Indians in the current study respectively). The recent World Health Organization (2000) monograph on obesity in South Asians supports these observations. The working group has redefined the criteria of obesity in an Asian population acknowledging the 'need for different standards that are culturally specific' and taking cognizance of the fact that co-morbidities occur at a lower BMI in Asian Indians. The proposed reclassification of overweight for adult Asians is >23 kg/m^2 and for obesity it is >25 kg/m^2. Similarly, the cut-off level for waist circumference for Asian Indians has been lowered in the proposed criteria (World Health Organization, 2000).

However, findings of the current study and those of Yap *et al.* (2000) for immigrant Indians cannot be generalized to all adult Asian Indians. Asian Indians in rural and semi-urban locations and different geographical regions (Sikhs, Assamese, Tamils, etc.) may have different body composition and BF. Potential inaccuracy of BMI as a diagnostic tool for the measurement of obesity may even be higher in growing children and adolescents, as indicated by Sardinha *et al.* (1999), and in other physiological conditions (lactating mothers, the elderly) where there is a disproportionate growth or regression of some tissues as compared with others. The relationship between BMI and BF in each of these situations will be different.

The preliminary data from the current study on a small sample of subjects therefore suggests that the native northern Indians have higher BF while their BMI may not be high, and this finding is particularly noteworthy in women. This observation is of particular concern, since the incidence of impaired insulin sensitivity reaches about 40 % among those women with percentage BF of >30 (Dvorak *et al.* 1999), and more than two-thirds of women in the current study belonged to this subgroup. While a larger study is required to test these interesting observations further, there is a suggestion that the cut-off levels of BMI for defining overweight and obesity in Asian Indians are lower, and that in this subgroup the estimation of BF may reflect present and future metabolic status more correctly. It must, however, be mentioned that accuracy of skinfold thickness measurement for calculating BF is subject to observer-derived errors, and currently other methods such as hydrodensitometry and dual-energy X-ray absorptiometry are used as the reference methods. Although preliminary evidence is provided by the current study, no firm conclusions can be drawn.

Several mechanisms for development of such a phenotype can be hypothesized. In Asian Indians childhood malnutrition may be an important and prevalent factor. It predisposes to excess deposition of fat tissue, particularly leading to abdominal obesity at the expense of muscle mass (Law *et al.* 1992; Shetty, 2000). The possible mechanisms are changes in the hypothalamic, autonomic nervous system and hormonal profiles during the period of malnutrition. Perturbation of the hypothalamic–pituitary axis (Bjorntorp, 1993) secondary to stress is deemed to be an important factor. Further, while linear growth may slow down during malnutrition, adipocyte development may continue to take place, resulting in the inordinate adipocyte numbers. Genetic predisposition may provide a background on which some of these factors may easily proliferate. Increasing urbanization, changing lifestyle and increased intake of saturated fat and energy further aggravate the problem. Alteration in the body composition would further result in a reduced BMR and energy cost of physical activity, thus establishing a vicious cycle.

With the increase in obesity and changes in the related lifestyle it is of paramount importance to define exact cut-off levels for obesity for each ethnic group. Exact quantification, however, is possible only on the basis of a large amount of epidemiological data. Although phenotypic characteristics of Asian Indians are known with regards to BMI, waist:hip ratio and skinfold thickness only a few studies have analysed BF in this ethnic group. Moreover, sensitivity, specificity, predictive value and misclassification of BMI for defining overweight and obesity have been rarely tested when percentage BF is taken as a criterion for defining overweight and obesity. The working group on the Asia–Pacific perspective on redefining obesity and its treatment (World Health Organization, 2000), realizing the need for such investigations, has proposed that 'body composition studies need to be performed to determine whether Asian population have equivalent levels of fatness for body size and BMI and whether Asians preferentially deposit abdominal fat'. The clinical practice guidelines for various diseases, particularly diabetes mellitus, are based on the universal cut-off levels of BMI. Clinical practice, including lifestyle measures and pharmacological therapy, for most of the non-communicable diseases would substantially change with the modification of the definition of overweight.

Acknowledgements

The authors express their appreciation to the staff of the SRB Center of Clinical Pharmacology including Mr Inder Taneja, Mr Ramesh Giri, Mr Gian Chand and Mrs Alice Jacob for performing various investigations, and Miss Jyoti for typing the manuscript.

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