British Journal of Nutrition (2005), **93**, 101–107 DOI: 10.1079/BJN20041316

BMI and morbidity in relation to body composition: a cross-sectional study of a rural community in North-East India

R. Khongsdier*

Department of Anthropology, North-Eastern Hill University, Permanent Campus, Umshing, Shillong, India

(Received 3 July 2004 – Revised 13 September 2004 – Accepted 1 October 2004)

This paper deals with BMI and morbidity in relation to body-fat mass (BFM) and fat-free mass (FFM). The analysis was based on cross-sectional data concerning the age, household income, anthropometry and morbidity of 575 males aged 18–59 years from a rural community in North-East India. Data on morbidity were based on the self-reported morbidity (SRM) of the subjects during the last 4 weeks before the survey, whereas data on BMI and body composition were estimated from anthropometry. It was found that SRM was significantly associated with age and income. However, the relationship between BMI and SRM was not significant after adjusting for age and income. Separating the BMI into body-fat mass index (BFMI being BFM in kg divided by height squared in metres) and fat-free mass index (FFMI being FFM in kg divided by height squared in metres), it was found that BFMI was significantly associated with SRM after adjusting for age, income and FFMI. The subjects with a low ($<2{\cdot}9\,kg/m^2$) BFMI were about 4·7 times (odds ratio 4·7, 95 % CI 2·6, 8·6) more likely to become sick than those with a normal ($2{\cdot}9–5{\cdot}0\,kg/m^2$) BFMI. In addition, the risk of becoming sick was higher in the subjects with a high ($>5{\cdot}0\,kg/m^2$) BFMI than in those with a normal BFMI (odds ratio 3·9, 95 % CI 1·3, 9·8). However, the relationship between FFMI and morbidity was not clearly perceptible. It is therefore speculated that BMI may not always provide accurate information about the variation in body fat and body composition that is associated with morbidity.

Morbidity: BMI: Body composition: Adult males

Quetelet's index, or BMI, is widely used as a measure of fatness, or the nutritional status of populations in both developed and developing countries. On the basis of data from developed countries, BMI ranges of 25–30 and $>30\,kg/m^2$ are considered to be indicative of overweight and obesity respectively (WHO, 1995). Recent studies have, however, questioned the validity of BMI as an indicator of fatness (Frankenfield *et al.* 2001; Kyle *et al.* 2003) because it lacks specificity in terms of the variation in body composition, and the confounding effects of various factors such as age, sex, body shape and ethnicity (Norgan, 1994; Gurrici *et al.* 1998; Wagner & Heyward, 2000; Prentice & Jebb, 2001). It has been suggested that body fat composition varies considerably between ethnic groups (Norgan, 1990; Gallagher *et al.* 2000). The World Health Organisation (WHO) Regional Office for Western Pacific Region, along with the International Association for the Study of Obesity (IASO) and the International Obesity Task Force (IOTF), has recommended a BMI of $23{\cdot}0\,kg/m^2$ as the cut-off point for defining overweight in Asian populations (WHO, 2000).

A BMI of $<18{\cdot}5\,kg/m^2$ is widely used as a practical measure of chronic energy deficiency (CED), i.e. a 'steady' underweight in which an individual is in energy balance irrespective of a loss in body weight or body energy stores. Such a 'steady' underweight is likely to be associated with morbidity or other physiological and functional impairments (James *et al.* 1988; Shetty & James, 1994; WHO, 1995). It is, however, unclear whether the morbidity or mortality associated with BMI, especially a low BMI in developing countries, also depends upon the variation in body composition. Studies of dietary-induced weight loss revealed that both body fat mass (BFM) and fat-free mass (FFM) decreased, but to different extents (Keys *et al.* 1950). Empirical evidence from Asian populations indicated that a low BMI was associated with a low BFM and FFM, although there were differences in the proportion of BFM and FFM (Ferro-Luzzi *et al.* 1997; Strickland & Tuffrey, 1997). It has also been observed that BFM is higher in Asian than Caucasian subjects at the same BMI (Deurenberg-Yap *et al.* 2000), possibly due to differences in leg length (Norgan, 1994; Deurenberg & Deurenberg-Yap, 2003). Some studies of the relationship between low BMI and morbidity in developing countries have, of course, produced inconsistent results (Garcia & Kennedy, 1994), despite certain evidence of a curvilinear relationship (de Vanconcellos, 1994). Thus, the purpose of the present paper is to understand the relationship between BMI and self-reported morbidity (SRM) in relation to body composition as estimated from the anthropometry of adult males in a rural population from North-East India.

Materials and methods

Subjects

This study was based on a cross-sectional sample of 575 War Khasi males aged 18–59 years as reported elsewhere for a

Abbreviations: BFM, body-fat mass; BFMI, body-fat mass index; CED, chronic energy deficiency; DF, degrees of freedom; FFM, fat-free mass; FFMI, fat-free mass index; IOTF, International Obesity Task Force; ISAO, International Association for the Study of Obesity; SRM, self-reported morbidity.

* **Corresponding author:** Dr R. Khongsdier, fax +91 364 2550076, email rkhongsdier@hotmail.com

different purpose (Khongsdier, 2002). The study was conducted among the rural War Khasis in the East Khasi Hills district of the state of Meghalaya in North-East India. The War Khasis are one of the sub-groups of the Khasi tribe, who speak the Mon-khmer language of the Austro-Asiatic group. They have been following the matrilineal system of society. Their main occupation is agriculture, and rice is their staple food. Data were collected from 366 households (95 %) in five villages (3 %) selected by means of a systematic random sampling of the listed villages in the study area. No statistical sampling of individuals was applied for the collection of anthropometric data due to operational difficulties in the field. However, all adult males (aged 18–59 years) who were willing to cooperate in the study were included in our sample.

Measurements

Data on anthropometric measurements included body weight and height as well as biceps, triceps, sub-scapular and supra-iliac skinfold thicknesses. A beam-balance scale (100 g precision; Galaxy Informatics Ltd, New Delhi, India) was used to weigh the subject barefoot, wearing light apparel. The balance was checked against a standard weight after weighing each subject. The height was measured with a Harpenden anthropometer (1 mm precision; Galaxy Informatics Ltd) and the skinfold thickness with Holtain skinfold calipers (0·1 mm precision; Holtain, Crymych, UK), following the methods described by Weiner & Lourie (1981).

Data on morbidity were based on the 'self-reported illness experience' of a subject as generally adopted in surveys, which did not involve a clinician (Strickland & Ulijaszek, 1993; Garcia & Kennedy, 1994; Strickland & Tuffrey, 1997). SRM is also more preferable from the point of view that a clinical diagnosis involves much time, cost and technical expertise, which are not always possible when carrying out community-based studies in developing countries, including India. Despite its limitations (Sadana, 2000), SRM might be considered to be the second alternative proxy for assessing the morbidity status of populations in developing countries. Nevertheless, the term 'morbidity' in this study was defined simply in terms of the number of 'days ill' and/or 'days unable to work' in the last 4 weeks before the survey. Each subject included in the study was asked whether or not he had been ill at any time in the past 4 weeks. If the answer was yes, he was asked how many days had he been in bed or unable to work due to illness. A subject who reported at least 2 d ill was classified as being 'ill'. No attempt was made to determine the prevalence of a specific disease or symptom. Of 575 subjects included in the study, 137 (23·8 %) reported that they had experienced illness for at least 2 d in the 4 weeks before the survey. This proportion included those who were still unable to go for work at the time of survey because of illness for the previous 4 weeks.

Data on household income were also collected directly from the heads of households after developing a rapport through a prolonged stay in the field; these were cross-checked, taking into consideration some aspects of socio-economic conditions such as housing conditions, types of occupation, land-holding and monthly expenditure. Three economic groups were arbitrarily classified following the interval estimation based on the standard deviation of the average monthly per capita income of households, as described elsewhere (Khongsdier, 2002).

With a view to understanding the relationship between body composition and SRM, the BMI was separated into two components: body fat mass index (BFMI = BFM in kg divided by height squared in metres) and fat-free mass index (FFMI = FFM in kg divided by height squared in metres). BFM and FFM were estimated using the predicted equations of Durnin & Womersley (1974) and Siri (1961). On the basis of data on 2986 Caucasian men aged 18–98 years, Schutz *et al.* (2002) and Kyle *et al.* (2003) have proposed a normal range of 16·7–19·8 kg/m^2 for FFMI and 1·8–5·2 kg/m^2 for BFMI for a normal range of BMI of 18·5–25·0 kg/m^2. These Caucasian subjects had a mean height of about 175 cm and weight of 74 kg compared with a mean height of 158 cm and weight of 49 kg for the subjects in the current study. Considering these massive differences in weight and height between the two ethnic groups, as well as the negative relationship between FFMI and longer hospital stay (Pichard *et al.* 2004), the cut-off for the lower range of FFMI was adjusted as follows:

$$16{\cdot}7/175\,\text{cm} \times 158\,\text{cm} = 15{\cdot}1.$$

Therefore, the subjects with FFMI $<15{\cdot}1$, 15·1–18·0 and $>18{\cdot}0$ kg/m^2 were arbitrarily categorised as having low, normal and high FFMI, respectively. On the other hand, the normal range for BMI was adjusted to 18·0–23·0 kg/m^2, taking into consideration the recommended cut-off point of 23·0 kg/m^2 for the upper range of normal BMI in Asian populations (WHO, 2000). Thus, the subjects with BFMI $<2{\cdot}9$, 2·9–5·0 and $>5{\cdot}0$ kg/m^2 were arbitrarily grouped into low, normal and high BFMI categories, respectively.

Statistical analyses

Statistical analyses were carried out using the Statistical Package for Social Sciences (Version 10.0; SPSS Inc., Chicago, USA) for Windows, in which the level of significance was set at 5 %. The characteristics of the subjects taken in this study are given in Table 1 according to the different categories used for statistical analyses. The analysis was first carried out to present the age–income-adjusted means of anthropometric measurements and

Table 1. Characteristics of study sample (*n* 575)

Characteristics	Frequency (%)
Age group (years)	
18–31 (*n* 179)	31·13
32–45 (*n* 202)	35·13
46–59 (*n* 194)	33·74
Income group	
Low (*n* 224)	38·96
Middle (*n* 193)	33·57
High (*n* 158)	27·48
BMI category	
< 18·0 (*n* 150)	26·09
18·0–23·0 (*n* 358)	62·26
> 23·0 (*n* 67)	11·65
BFMI category	
< 2·9 (*n* 329)	57·22
2·9–5·0 (*n* 221)	38·43
> 5·0 (*n* 25)	4·35
FFMI category	
< 15·1 (*n* 58)	10·09
15·1–18·0 (*n* 391)	68·00
> 18·0 (*n* 126)	21·91
Reporting and not reporting illness	
Yes (*n* 137)	23·83
No (*n* 438)	76·17

indices using the one-way analysis of co-variance for both the subjects reporting and not reporting illness. The risk estimates with 95 % CI for morbidity relative to age, income, BMI, BFMI and FFMI categories were computed using odds ratios and regression coefficients from logistic regression models. The morbidity dummy was 1 for the subjects reporting illness and 0 for those subjects not reporting illness. The income variable was expressed in terms of individual score, according to whether a given subject belonged to the low-income, middle-income or high-income group, which were graded as 1, 2 and 3, respectively. The low, high and normal categories of BMI, BFMI and FFMI were coded as 1, 2 and 3, respectively. The curve of the relationship between BFMI and percentage SRM was also fitted using the second-degree polynomial model, and the significance of departure from linearity was tested following the method suggested by Snedecor & Cochran (1967).

Results

Prevalence of chronic energy deficiency and self-reported morbidity

Table 1 shows the percentage distribution of the study subjects according to age, income and body composition. About 26 %, 62 % and 12 % of the subjects were in the BMI categories of $<18{\cdot}0$, 18·0–23·0 and $>23{\cdot}0\,kg/m^2$, respectively. The prevalence of CED, as defined by a BMI $<18{\cdot}0\,kg/m^2$ (26 %), was about 54 % less than that measured by a BFMI $<2{\cdot}9\,kg/m^2$ (57 %). Nevertheless, it indicates that CED was still a major nutritional problem in the study population. In addition, about 24 % of men reported having experienced illness for at least 2d during the 4 weeks before the survey, and about 39 % of them belonged to the low-income group. It may thus be theoretically expected that SRM in this population should be associated with low body composition and poor socio-economic conditions, besides other factors including individual age.

Subjects of reporting and non-reporting illness

Table 2 gives the means of anthropometric measurements and indices for the subjects reporting and not reporting illness after adjusting for individual age and household income. According to the analysis of co-variance test, the subjects reporting illness were taller than were the subjects not reporting illness (F-ratio 5·69; degrees of freedom DF 1, 571; $P=0{\cdot}017$), despite the absence of a significant difference between them with respect to body weight. Overall, anthropometric measurements and indices relative to body fat composition, for example skinfold thickness, BFM, percentage BFM and BFMI, were significantly lower in the subjects reporting illness than in those not reporting illness. There was, however, no significant difference between the two groups with respect to BMI. In this regard, it may be noted that BMI is simply a composite measure of body mass in terms of BFMI and FFMI relative to height. The significant difference between the subjects reporting and not reporting illness with respect to BFMI (F-ratio 7·73; (DF) 1, 571; $P=0{\cdot}006$) was indicative of the same trend that anthropometric measurements and indices relative to body fat composition were significantly lower in the former than in the latter (Table 2).

Self-reported morbidity in relation to age, income and body composition

Table 3 shows the prevalence of SRM by age, income and body composition. The risk estimates of getting sick, with 95 % CI, were computed using odds ratios and regression coefficients ($\beta \pm$ SE) from logistic regression models. Allowing for income level in the first model, the risk of getting sick was higher in elderly subjects than in younger ones. The subjects aged 46–59 years were about 2·4 times (95 % CI 1·4, 3·9; β 0·858 (SE 0·259); $P<0{\cdot}001$) more likely to get sick than those who were aged 18–31 years. The relationship between SRM and income level was determined by using the second logistic regression model, in which the individual age was adjusted. It indicated that the subjects in the low- and middle-income groups had approximately twice the risk ($P<0{\cdot}02$) of becoming sick of those in the high-income group. Thus, age and household income are likely to play a significant role in patterning body composition and morbidity in the present population.

The relationship between BMI and SRM was tested using the third logistic regression model by adjusting age and household income. The results suggested that the subjects with low ($<18{\cdot}0\,kg/m^2$) and high ($>23{\cdot}0\,kg/m^2$) BMI were not significantly different in terms of their risk of getting sick compared with those subjects who had a normal BMI ($18{\cdot}0–23{\cdot}0\,kg/m^2$). Separating the BMI into BFMI and FFMI, the fourth model of logistic regression analysis was used for testing the relationship between FFMI and SRM after allowing for age, income level

Table 2. Actual and adjusted means of anthropometric measurements and indices for subjects reporting and not reporting illness

	Reporting illness (n 137)				Not reporting illness (n 438)				Analysis of co-variance tests	
	Actual		Adjusted		Actual		Adjusted			
Variables	Mean	SD	Mean	SE	Mean	SD	Mean	SE	F-ratio	P-value
Height (cm)	158·81	4·93	158·8	0·42	157·66	4·71	157·66	0·23	5·69	0·017
Weight (kg)	48·24	6·65	49·00	0·56	49·66	6·74	49·43	0·31	0·46	0·498
Log 4 ST	1·43	0·13	1·44	0·01	1·49	0·12	1·48	0·01	14·86	0·000
BMI (kg/m^2)	19·21	2·66	19·50	0·22	20·05	2·65	19·96	0·12	3·20	0·074
Body fat mass (kg)	6·29	3·24	6·57	0·24	7·34	2·82	7·25	0·13	6·14	0·013
Body fat mass (%)	12·57	4·16	12·89	0·32	14·41	3·90	14·31	0·18	14·49	0·000
Fat-free mass (kg)	41·95	3·98	42·42	0·37	42·32	4·54	42·22	0·21	0·33	0·565
Fat-free mass index (kg/m^2)	16·64	1·49	16·83	0·14	17·03	1·74	16·97	0·08	0·76	0·383
Body fat mass index (kg/m^2)	2·50	1·31	2·61	0·10	2·96	1·13	2·92	0·05	7·73	0·006

ST, skinfold thicknesses (biceps + triceps + sub-scapular + supra-iliac).

Table 3. Prevalence of self-reported morbidity (SRM) by age, income, BMI and its components

Categories	*n*	Prevalence of SRM (%)	Odds ratio (95 % CI)	β	SE β	*P*-value
Age groups (years)						
18–31	179	15·64	1·00	–	–	–
32–45	202	24·26	1·74 (1·04–2·93)*	0·555	0·265	0·036
46–59	194	30·93	2·36 (1·42–3·92)*	0·858	0·259	0·001
Income groups						
High	158	15·19	1·00	–	–	–
Middle	193	25·91	1·91 (1·10–3·30)†	0·645	0·280	0·021
Low	224	28·13	2·06 (1·21–3·51)†	0·725	0·271	0·007
BMI categories						
18·0–23·0	358	22·07	1·00	–	–	–
<18·0	150	33·33	1·39 (0·89–2·15)‡	0·326	0·225	0·147
>23·0	67	11·94	0·58 (0·26–1·29)‡	−0·542	0·405	0·181
Fat-free mass index categories						
15·1–18·0	391	24·55	1·00	–	–	–
<15·1	58	32·76	0·90 (0·47–1·71)§	−0·108	0·328	0·743
>18·0	126	17·46	1·54 (0·79–3·01)§	0·430	0·343	0·210
Body-fat mass index categories						
2·9–5·0	221	9·50	1·00	–	–	–
<2·9	329	32·83	4·71 (2·57–8·58)‖	1·547	0·307	0·000
>5·0	25	32·00	3·94 (1·32–9·75)‖	1·372	0·557	0·014

* Adjusted for income.
† Adjusted for age.
‡ Adjusted for age and income.
§ Adjusted for age, income and BFMI.
‖ Adjusted for age, income and fat-free mass index.

and BFMI. As with BMI, there was no significant relationship between FFMI and SRM. Age, income level and FFMI were adjusted in the fifth model. The subjects with a low BFMI (<2·9 kg/m^2) were about 4·7 times (95 % CI 2·6, 8·6; β 1·547 (SE 0·307); P<0·0001) more likely to become sick than those with a normal BFMI (2·3–5·0 kg/m^2). Also, the risk of getting sick was about four times higher in the subjects with a high BFMI (>5·0 kg/m^2) than those with a normal BFMI (95 % CI 1·3, 9·8; β 1·372 (SE 0·557); P<0·02).

Figure 1 shows the prevalence of SRM (%) according to BFMI categories of ≤1·5, 1·6–2·0, 2·1–2·5, 2·6–3·0, 3·1–3·5, 3·6–4·0, 4·1–5·0 and >5 kg/m^2. The means of these BFMI groups were 1·44, 1·78, 2·30, 2·79, 3·27, 3·76, 4·43 and 6·2 kg/m^2, respectively, as indicated in the figure by the eight data points with 95 % CI error bars. The curve was fitted using the second-degree polynomial model. It was found that the nature of relationship between BFMI and SRM was U-shaped. The significance of a departure from linearity was tested as described by Snedecor & Cochran (1967), this being found to be significant (F-ratio = curvilinearity of regression divided by mean squares of deviations from quadratic regression=583·39/62·46=9·34; DF 1, 5; P<0·05). The polynomial equation was derived as follows:

$$\text{SRM (\%)} = 89{\cdot}199 + (-37{\cdot}057)(\text{BFMI}) + 4{\cdot}432(\text{BFMI})^2$$

The summary of logistic regression of SRM on BFMI in relation to age, income level and FFMI is given in Table 4. Overall, the results showed that there was a negatively significant relationship between BFMI and SRM (β=−0·456 (SE 0·149); P<0·002). This therefore indicates that BMI in terms of BFMI is actually associated with morbidity in the present study.

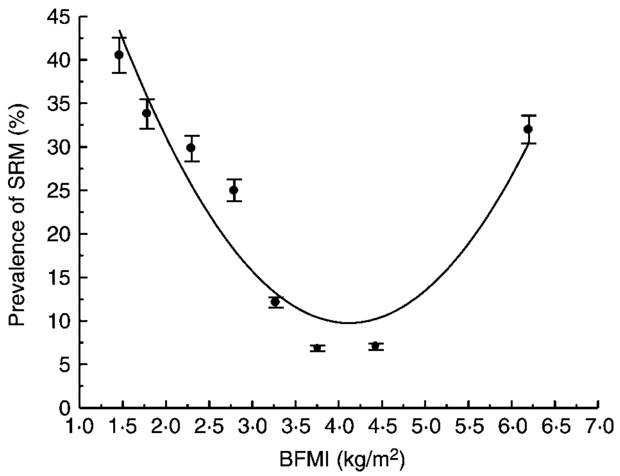

Fig. 1. Prevalence of self-reported morbidity (SRM) by body-fat mass index (BFMI) categories (Error bars represent 95 % CI for the means of eight BFMI groups).

Discussion

Chronic energy deficiency and self-reported morbidity in relation to age and economic condition

In view of the present findings and those reported for some populations in North-East India (Khongsdier, 2001), the prevalence of CED (26 %) in the study population is still a major concern when compared with that of overweight (12 %). Moreover, the subjects

Table 4. Coefficients of logistic regression of self-reported morbidity on body-fat mass index (BFMI) and fat-free mass index (FFMI)

Variables	β	SE β	Wald test	*P*-value
Age	0·039	0·009	18·07	0·000
Income	−0·169	0·136	1·54	0·215
FFMI	0·158	0·096	2·73	0·099
BFMI	−0·456	0·149	9·36	0·002

belonging to the low-income group had about twice the risk of getting sick when compared with those belonging to the high-income group. In addition, the prevalence of SRM in the age group aged 46–59 years was more than twice that of the lower age group of 18–31 years. This indicates the significant role of age and socio-economic status in patterning BMI and morbidity. However, the relationship between BMI and SRM was not significant after adjusting for age and income level. Considering BMI alone, it looks as though SRM in the present population was not associated with low or high BMI, but that it occurred mainly because of poor economic condition compounded by age and other socio-environmental factors (Khongsdier, 2002). Therefore, although BMI is widely considered to be a variable indicating the socio-economic and health status of the population, its relationship with morbidity in the present sample of adult males was not statistically perceptible.

BMI and its components

It is obvious from the current analysis that the absence of a significant relationship between BMI and SRM was due not only to the confounding effects of age and income level, but also to the effects of body composition. After separating the BMI into BFMI and FFMI, the results indicated that BFMI was significantly associated with SRM, the relationship being U-shaped after fitting according to the second-degree polynomial model. Thus, the present findings indicate that BMI is actually associated with morbidity in terms of BFMI, but not in terms of both BFMI and FFMI.

The present findings are therefore inconsistent with the general observation that BMI is a good indicator of fatness and associated morbidity and/or mortality, especially in developed countries (Garrow, 1988; Allison *et al.* 1999; Must *et al.* 1999; Himes, 2000; Barbagallo *et al.* 2001; Farrell *et al.* 2002; Krueger *et al.* 2004). It may be noted that BMI is highly correlated with both BFM and FFM (Garn *et al.* 1986; Norgan, 1994). Accordingly, it is likely that the respective relationship of these two components of body composition and morbidity is not accounted for by BMI alone. It has been suggested that BMI alone is not a good indicator of the respective contribution of BFM and FFM to the body mass of an individual (Garn *et al.* 1986; Frankenfield *et al.* 2001; Prentice & Jebb, 2001; Kyle *et al.* 2003). In their study of rural men and women in Guatemala, Immink *et al.* (1992) also observed that BMI explained little of the variation in BFM and FFM, especially at a low level of BMI. Thus, although BMI is widely used as an indicator of fatness, it does not always provide accurate information about BFM relative to FFM and other components of body composition. This may have certain implications for the variation in the responses of BFM and FFM to ageing, physical activity, genetic/ethnic factors, etc. (Forbes, 1987, 1999; Guo *et al.* 1999; Mott *et al.* 1999; Wagner & Heyward, 2000; Hughes *et al.* 2002).

Low body-fat mass index and self-reported morbidity

The present findings are also inconsistent with the recent findings that low FFMI, but not low BFMI, in Caucasian patients is associated with a longer length of hospital stay (Pichard *et al.* 2004). This study was, however, primarily concerned with the risk of becoming sick in the individuals with a low BMI relative to a low BFMI or FFMI at population level. It had little to do with the severity of illness or prolonged hospital stay due to CED or low BMI. Moreover, this study might have missed information on chronic illness that did not cause the subject to report the days of being ill in the 4-week reporting period. Therefore, the relationship between low BMI and morbidity in relation to low BFMI and FFMI warrants more future studies, especially in developing countries where such data are still limited. The present findings, nevertheless, seem to support the hypothesis that low fatness or energy fat stores may have functional and health consequences (James *et al.* 1988; Shetty & James, 1994; WHO, 1995).

In this study, the adjusted mean of percentage BFM in the subjects of reporting illness was 12·9 %, which was similar to the cut-off point (13 %) predicted for the healthy Asian men aged 20–59 years (Gallagher *et al.* 2000). Whether the percentage BFM of 13 % should be used as the cut-off point for screening the individuals who are likely to become sick with a low BMI is subject to further studies in other Asian populations. It has, however, been suggested that fatness relative to height, rather than fatness relative to body weight, is more appropriate for assessing overweight and obesity (Garrow & Webster, 1985; Frankenfield *et al.* 2001). In other words, BFMI may be considered more appropriate than percentage BFM for measuring fatness at both individual and population levels.

Cut-off points

It has been proposed that the normal range for BFMI is 1·8–5·2 kg/m^2 for the normal range of BMI 18·5–25·0 kg/m^2 (Schutz *et al.* 2002; Kyle *et al.* 2003). In this study, the mean BFMI values in the subjects reporting and not reporting illness for the BMI range of 18·5–23·0 kg/m^2 were 2·68 and 3·19 kg/m^2, respectively, after allowing for age and income level (F-ratio 31·88; DF 1, 302; $P<0·0001$). This indicates that the mean BFMI values are in the normal category for both the subjects reporting and not reporting illness. The significant differences between them may, however, be related to the observation that BFM is higher in Asian than in Caucasian populations (Norgan, 1990; Gallagher *et al.* 2000). Indeed, many studies have suggested lower cut-off points for screening the prevalence of overweight and obesity in Asian populations (Deurenberg-Yap *et al.* 2000; Ko *et al.* 2001; Lin *et al.* 2002; Shiwaku *et al.* 2004). In addition, the WHO Regional Office for Western Pacific Region, in collaboration with the IASO and IOTF, has recommended a BMI of 23·0 kg/m^2 as the cut-off point for defining overweight in Asian populations (WHO, 2000).

In the present study, the cut-off point for the lower range of normal BMI was also reduced to 18·0 kg/m^2 for screening the individuals with underweight or CED. Thus, the normal range for BMI was set at 18·0–23·0 kg/m^2, bearing in mind the recommended cut-off for the upper range (WHO, 2000). It has recently been reported that low FFMI in Caucasian patients is associated with longer hospital stays (Pichard *et al.* 2004). Considering the lower range for normal FFMI in Caucasian subjects (Schutz *et al.* 2002; Kyle *et al.* 2003), the cut-off point of 15·1 kg/m^2 for low FFMI was obtained after allowing for height. Thus, the normal range for FFMI was adjusted to 15·1–18·0 kg/m^2. In addition, the corresponding range for normal BFMI was arbitrarily adjusted to 2·9–5·0 kg/m^2. There are still limited data from Asian populations on the relationship between low BMI (especially low BFMI or FFMI) and morbidity or mortality (Garcia & Kennedy, 1994; Yuan *et al.* 1998; Khongsdier, 2002). In the current analysis, this point is not certain by looking at BMI alone. It is, however, likely that men with a BFMI of $<2{\cdot}9$ or $>5{\cdot}0\,kg/m^2$ would have a higher risk of becoming sick than those with a normal BFMI ($2{\cdot}9$–$5{\cdot}0\,kg/m^2$).

Study limitations

Anthropometric measurements, including skinfold thickness, are the classical techniques used by anthropologists for comparative studies of human forms at a population level. Although they are useful in the field because they are simple and easy to perform, their lack of precision and specificity is a drawback in estimating the body composition at an individual level (Johnston, 1982). Thus, prediction equations of total body fatness from skinfold measurements are primarily population-specific, thereby lacking a general validity (Norgan & Ferro-Luzzi, 1985). Moreover, such equations assume that the proportion of internal and external fat stores is constant at any level of fatness. Thus, individual and/or population variation, besides age and sex variation, in the distribution of internal and external fat stores may affect the general validity of prediction equations based on skinfold thickness (Davies, 1994). This holds true with the Durnin and Womersley equation, which was derived from skinfold measurements of Caucasian subjects. Using a four-compartment model as a reference, it has been recently shown that the Durnin and Womersley equation also underestimates the percentage of body fat (Peterson *et al.* 2003). Nonetheless, it is crucial to realise that methods used for assessing the body composition of populations are subject to approximation and are not entirely free from limitations or different types of error. Although it is always necessary to develop more accurate methods, it is also crucial to realise that human biological variation and its associated morbidity/mortality might be best measured with a consistency of the use of methods or techniques of measurements and analyses. As for skinfold equations, the Durnin and Womersley equation is commonly used, and it appears to be 'the best of a poor bunch' (Norgan, 1995), especially among Indians (Jones *et al.* 1976).

The other limitation of the present study is concerned with the data on morbidity, which were based on self-reported illness during the 4 weeks before the survey. The SRM was simply a sweeping generalisation about ill health, regardless of specific diseases or impairments that the subjects had suffered. Moreover, the present study might have failed to ascertain information about chronic illness that did not cause the subject to report the days of being ill in the last 4 weeks before the survey. Longitudinal studies should thus be also carried out in order to have a better understanding of the relationship between BMI, or body composition, and morbidity in developing countries.

Conclusions

Despite certain limitations of this study, it is possible that BMI alone may provide misleading information about the relationship between morbidity and body fat or body energy stores. Subject to further studies, breaking up BMI into BFMI and FFMI is likely to provide more information about the nature and degree of such relationship. This does not, however, mean that BMI is not at all suitable for assessing the nutritional and health status of a population. BMI as an indicator variable continues to serve well for different purposes, including the assessment of standards of living in developing countries (Nubé *et al.* 1998). BMI may be useful in screening those individuals who are likely to be malnourished. As a composite measure of the total body mass relative to height, BMI needs to be supplemented by other quantitative and qualitative measures of the health and nutritional status of an individual or a population.

Acknowledgements

The author wishes to acknowledge the anonymous reviewers for their valuable comments. Thanks are also due to the Department of Anthropology, North-Eastern Hill University, for providing necessary facilities to carry out the study.

References

Allison DB, Fontaine KR, Manson JE, Stevens J & Vanltallie TB (1999) Annual deaths attributable to obesity in the United States. *JAMA* **282**, 1530–1538.

Barbagallo CM, Cavera G, Sapienza M, Noto D, Cefalú AB, Pagano M, Montalto G, Notarbartolo A & Averna MR (2001) Prevalence of overweight and obesity in a rural Southern Italy population and relationships with total and cardiovascular mortality: the Ventimiglia di Sicilia project. *Int J Obes Relat Metab Disord* **25**, 185–190.

Davies PSW (1994) Anthropometry and body composition. In *Anthropometry: The Individual and the Population*, pp. 130–140 [SJ Ulijaszek and CGN Mascie-Taylor, editors]. Cambridge: Cambridge University Press.

Deurenberg P & Deurenberg-Yap M (2003) Validity of body composition methods across ethnic population groups. *Acta Diabetol* **40**, S246–S249.

Deurenberg-Yap M, Schmidt G, Van Staveren WA & Deurenberg P (2000) The paradox of low body mass index and high body fat percentage among Chinese, Malays and Indians in Singapore. *Int J Obes Relat Metab Disord* **24**, 1011–1017.

de Vanconcellos MTL (1994) Body mass index: its relationship with food consumption and socio-economic variables in Brazil. *Eur J Clin Nutr* **48**, S115–S123.

Durnin JVGA & Womersley J (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. *Br J Nutr* **32**, 77–97.

Farrell SW, Braun LA, Barlow CE, Cheng YJ & Blair SN (2002) The relation of body mass index, cardiorespiratory fitness, and all-cause mortality in women. *Obes Res* **10**, 417–423.

Ferro-Luzzi A, Petracchi C, Kuriyan R & Kurpad AB (1997) Basal metabolism of weight-stable chronically undernourished men and women: lack of metabolic adaptation and ethnic differences. *Eur J Clin Nutr* **66**, 1086–1093.

Forbes GB (1987) *Human Body Composition: Growth, Aging, Nutrition, and Activity*. London: Springer-Verlag.

Forbes GB (1999) Longitudinal changes in adult fat-free mass: influence of body weight. *Am J Clin Nutr* **70**, 1025–1031.

Frankenfield DC, Rowe WA, Cooney RN, Smith JS & Becker D (2001) Limits of body mass index to detect obesity and predict body composition. *Nutrition* **17**, 26–30.

Gallagher D, Heymsfield SB, Heo M, Jebb SA, Murgatroyd PR & Sakamoto Y (2000) Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. *Am J Clin Nutr* **72**, 694–701.

Garcia M & Kennedy E (1994) Assessing linkages between body mass index and morbidity in adults: evidence from four developing countries. *Eur J Clin Nutr* **48**, S90–S97.

Garn SM, Leonard WR & Hawthorne WM (1986) Three limitations of the body mass index. *Am J Clin Nutr* **44**, 996–997.

Garrow JS (1988) *Obesity and Related Diseases*. Edinburgh: Churchill Livingstone.

Garrow JS & Webster J (1985) Quetelet's index (W/H^2) as a measure of fatness. *Int J Obes Relat Metab Disord* **9**, 147–153.

Guo SS, Zeller C, Chumlea WC & Siervogel RM (1999) Aging, body composition, and lifestyle: the Fels longitudinal study. *Am J Clin Nutr* **70**, 405–411.

Gurrici S, Hartriyanti Y, Hautvast JG & Deurenberg P (1998) Relationship between body fat and body mass index: differences between Indonesians and Dutch Caucasians. *Eur J Clin Nutr* **52**, 779–783.

Himes CL (2000) Obesity, disease, and functional limitation in later life. *Demography* **37**, 73–82.

Hughes VA, Frontera W, Roubenoff R, Evans WJ & Singh MAF (2002) Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. *Am J Clin Nutr* **76**, 473–481.

Immink MD, Flores R & Diaz EO (1992) Body mass index, body composition and the chronic energy deficiency classification of rural adult populations in Guatemala. *Eur J Clin Nutr* **46**, 419–427.

James WPT, Ferro-Luzzi A & Waterlow JC (1988) Definition of chronic energy deficiency in adults. *Eur J Clin Nutr* **42**, 969–981.

Johnston FE (1982) Relationship between body composition and anthropometry. *Hum Biol* **54**, 221–245.

Jones PRMJ, Bharadwaj H, Bhatia MR & Malhotra MS (1976) Differences between ethnic groups in the relationship of skinfold thickness to body density. In *Selected Topics in Environmental Biology*, pp. 373–376 [B Bhatia, GS Chhina and B Singh, editors]. New Delhi: Interprint Publications.

Keys A, Brozek J, Henschel A, Mickelson O & Taylor JL (1950) *The Biology of Human Starvation*. Minneapolis: University of Minnesota Press.

Khongsdier R (2001) Body mass index in twelve populations in Northeast India. *Ann Hum Biol* **28**, 374–383.

Khongsdier R (2002) Body mass index and morbidity in adult males of the War Khasi in Northeast India. *Eur J Clin Nutr* **56**, 484–489.

Ko GTC, Tang J, Chan JCN, Sung R, Wu MMF, Wai HPS, Chen R, (2001) Lower BMI cut-off value to define obesity in Hong Kong Chinese: an analysis based on body fat assessment by bioelectrical impedance. *Br J Nutr* **85**, 239–242.

Krueger PM, Rogers RG, Hummer RA & Boardman JD (2004) Body mass, smoking, and overall and cause-specific mortality among older US adults. *Res Aging* **26**, 82–107.

Kyle UG, Schutz Y, Dupertuis YM & Pichard C (2003) Body composition interpretation: contributions of the fat-free mass index and the body fat mass index. *Nutrition* **19**, 597–604.

Lin WY, Lee LT, Chen CY, Lo H, Hsia HH, Liu IL, Lin RS, Shau WY & Huang KC (2002) Optimal cut-off values for obesity: using simple anthropometric indices to predict cardiovascular risk factors in Taiwan. *Int J Obes Relat Metab Disord* **26**, 1232–1238.

Mott JW, Wang J, Thornton JC, Allison DB, Heymsfield SB & Pierson RN (1999) Relation between body fat and age in 4 ethnic groups. *Am J Clin Nutr* **69**, 1007–1013.

Must A, Spadano J, Coakley EH, Field AE, Colditz G & Dietz WH (1999) The disease burden associated with overweight and obesity. *JAMA* **282**, 1523–1529.

Norgan NG (1990) Body mass index and body energy stores in developing countries. *Eur J Clin Nutr* **44**, S79–S84.

Norgan NG (1994) Population differences in body composition in relation to the body mass index. *Eur J Clin Nutr* **48**, S10–S27.

Norgan NG (1995) The assessment of the body composition of populations. In *Body Composition Techniques in Health and Disease*, pp. 195–221 [PSW Davies and TJ Cole, editors]. Cambridge: Cambridge University Press.

Norgan NG & Ferro-Luzzi A (1985) The estimation of body density in men: are general equations general? *Ann Hum Biol* **12**, 1–15.

Nubé M, Asenso-Okyere WK & van den Boom GJM (1998) Body mass index as indicator of standard of living in developing countries. *Eur J Clin Nutr* **52**, 136–144.

Peterson MJ, Czerwinski SA & Siervogel RM (2003) Development and validation of skinfold-thickness prediction equations with a 4-compartment model. *Am J Clin Nutr* **77**, 1186–1191.

Pichard C, Kyle UG, Morabia A, Perrier A, Vermeulen B & Unger P (2004) Nutritional assessment: lean body mass depletion at hospital admission is associated with an increased length of stay. *Am J Clin Nutr* **74**, 613–618.

Prentice AM & Jebb SA (2001) Beyond body mass index. *Obes Rev* **2**, 141–147.

Sadana R (2000) Measuring reproductive health: review of community based approaches to assessing morbidity. *Bull WHO* **78**, 640–654.

Schutz Y, Kyle UUG & Pichard C (2002) Fat-free mass index and fat mass index percentiles in Caucasians aged 18–98 y. *Int J Obes Relat Metab Disord* **26**, 953–960.

Shetty PS & James WPT (1994) *Body Mass Index: A Measure of Chronic Energy Deficiency in Adults*. Food and Nutrition Paper No. 56. Rome: FAO.

Shiwaku K, Anuurad E, Enkhmaa B, Nogi A, Kitajima K, Shimono K, Yamane Y & Oyunsuren T (2004) Overweight Japanese with body mass indexes of 23·0–24·9 have higher risks for obesity-associated disorders: a comparison of Japanese and Mongolians. *Int J Obes Relat Metab Disord* **28**, 152–158.

Siri WE (1961) *Body Composition from Fluid Spaces and Density: Analyses of Methods*. Washington, DC: National Academy of Sciences.

Snedecor GW & Cochran WG (1967) *Statistical Methods*. Iowa: Iowa State University Press.

Strickland SS & Tuffrey VR (1997) *Form and Function: A Study of Nutrition, Adaptation and Social Inequality in Three Gurung Villages of the Nepal Himalayas*. London: Smith-Gordon.

Strickland SS & Ulijaszek SJ (1993) Body mass index, ageing and differential reported morbidity in rural Sawarak. *Eur J Clin Nutr* **47**, 9–19.

Wagner DR & Heyward VH (2000) Measures of body composition in blacks and whites: a comparative review. *Am J Clin Nutr* **71**, 1392–1402.

Weiner JS & Lourie JA (1981) *Practical Human Biology*. London: Academic Press.

World Health Organization (1995) *Physical Status: The Use and Interpretation of Anthropometry. Report of a WHO Expert Committee*. Technical Report Series No. 854. Geneva: World Health Organization.

World Health Organization (2000) *The Asia–Pacific Perspective: Redefining Obesity and its Treatment*. Geneva: World Health Organization.

Yuan JM, Ross RK, Gao YT & Yu MC (1998) Body weight and mortality: a prospective evaluation in a cohort of middle-aged men in Shanghai, China. *Int J Epidemiol* **27**, 824–832.