

## Original Article

# Defining obesity by body mass index in the Thai population: an epidemiologic study

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The objective of this study was to develop cut-off values and evaluate the accuracy of body mass index (BMI) in the definition of obesity in the Thai population. A cross-sectional, epidemiologic study in 340 men and 507 women aged  $50 \pm 16$  yr (mean  $\pm$  SD; range: 20-84 yr), were sampled by stratified clustering sampling method. Body composition, including percentage body fat (%BF), was measured by dual energy X-ray absorptiometry (GE Lunar Corp, Madison, WI). BMI was obtained by dividing weight (in kg) by height (in m<sup>2</sup>). The "golden standard" for defining obesity was %BF  $\geq$  25% in men and %BF  $\geq$  35% in women. The %BF-based prevalence of obesity in men and women was 18.8% and 39.5%, respectively. However, using the BMI cut-off of  $\geq$  30, only 2.9% of men and 8.9% of women were classified as obese. In the cubic regression model, BMI was a significant predictor of %BF, such that in men a BMI of 27 kg/m<sup>2</sup> would predict a %BF of 25%, and in women a BMI of 25 kg/m<sup>2</sup> would correspond to a %BF of 35%. The area under the receiver operating characteristic curve for BMI was approximately 0.87 (95% CI: 0.82-0.92) and 0.86 (95% CI: 0.83-0.90) in men and women, respectively. In conclusion, for the Thai population, BMI is a reasonably useful indicator of obesity; however, the cut-off values of BMI for diagnosing obesity should be lowered to 27 kg/m<sup>2</sup> in men and 25 kg/m<sup>2</sup> in women.

**Key Words:** BMI, percentage body fat, epidemiology, Thailand, Asian

## Introduction

Obesity is a complex disorder characterized by an excessively high amount of fat or adipose tissue in the body to the degree that health and well-being are adversely affected.<sup>1-5</sup> The disorder is considered one of the most important global threats to human health, because its prevalence is rapidly increasing in developed as well as in developing countries,<sup>6-9</sup> and because it is associated with a range of medical, psychosocial and economic consequences.<sup>9-11</sup> While anthropometry-based diagnostic criteria of obesity have been developed for Caucasian populations, there is currently a lack of accepted and validated diagnostic criteria for the Thai population.

Because an excess of body fat is the main characteristic of obesity, the "golden standard" for defining the disorder is based on percentage body fat (%BF). In Caucasian populations, the cut-off value of body mass index (BMI) for defining obesity is 30 kg/m<sup>2</sup> which corresponds with a percentage body fat (%BF) of over 25% in men and 35% in women.<sup>12-14</sup> These criteria were defined on the basis of consideration that higher %BF

increased the risk of mortality, cardiovascular diseases, increased blood pressure, and unfavourable lipoprotein profile. However, it seems that the Caucasian-based cut-off value is not necessarily applicable to Asian populations, because the relationships between BMI and %BF in Caucasian and Asian populations are not necessarily identical. For example, Asians are known to have lower BMI but higher %BF than Caucasians.<sup>15</sup> Furthermore, measurement of %BF is expensive, requiring sophisticated instruments such as dual-energy X-ray absorptiometry (DXA) densitometer, which is scarcely available in developing countries, particularly in primary care setting.

Therefore, the development of alternative non-invasive and inexpensive measures of obesity in developing

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**Table 1.** Demographic, anthropometric and body composition data according to gender

Variable	Men (N=340)	Women (N=507)	Difference (95% CI)
Age (y)	49.3 ± 17.2	50.5 ± 15.5	1.2 (-1.0, 3.4)
Body Weight (kg)	61.1 ± 10.4	55.7 ± 9.8	-5.4 (-6.7, -4.0) <sup>†</sup>
Height (cm)	163.2 ± 6.4	153.4 ± 5.4	-9.8 (-10.6, -9.0) <sup>*</sup>
BMI (kg/m <sup>2</sup> )	22.9 ± 3.3	23.7 ± 3.9	0.8 (0.3, 1.3) <sup>*</sup>
Fat mass (kg)	10.8 ± 6.1	18.6 ± 7.0	7.8 (6.9, 8.7) <sup>*</sup>
Lean mass (kg)	46.6 ± 6.0	33.8 ± 4.1	-12.8 (-13.5, -12.1) <sup>*</sup>
Percentage Body Fat	17.0 ± 7.5	32.5 ± 8.0	15.5 (14.5, 16.7) <sup>*</sup>

Statistical significant at <sup>\*</sup>*P* < 0.001 and <sup>†</sup>*P* < 0.05

countries is an important research endeavour. Indeed, a recent WHO Expert Consultation could not arrive at a specific cut-off value for defining obesity in Asian populations, primarily because of lack of empirical data, and they call for “[F]urther body composition studies are needed”.<sup>16</sup> The present study was designed to address this question by (i) first validating the WHO recommended criteria; and (ii) developing new optimal anthropometric criteria for defining obesity in Thai men and women.

### Subjects and Methods

The study was designed as a cross-sectional community-based investigation. The settings were Bangkok city and Khon Kaen province. Bangkok is predominantly an urban centre of Thailand with a population of 5.7 million and lifestyle similar to that in Western cities. Khon Kaen is a rural province with a population of 1.8 million, located 445 km northeast of Bangkok.

The sampling technique has been described previously.<sup>17</sup> Briefly, subjects were recruited from 14 hamlets within 2 villages in Muang district of the Khon Kaen province. In each hamlet, a full list of subjects was obtained, from which 10 subjects were randomly selected by the village’s administrator. We excluded participants with a history of recent acute illness (e.g. myocardial infarction or pneumonia), chronic conditions (e.g. cancer, chronic infection, collagen vascular disease, hepatic or renal impairment, diabetes), history taking of medication affecting body weight (e.g. thyroid hormone, prednisolone, diuretics) or involvement in weight training. In Bangkok, subjects were recruited via a media campaign, and the sampling technique was similar to the scheme used in Khon Kaen, where subjects were randomly selected from 5 districts within the City of Bangkok. The study was formally approved by the Ethics Committee of Khon Kaen University, and written informed consent was obtained from each subject. The study was performed in accordance with the Helsinki Declaration of 1975 as revised in Edinburgh 2000.

### Anthropometric measurements

Body weight (including light indoor clothing) was measured using an electronic balance (accuracy 0.1 kg) and standing height (without shoes) with a stadiometer (nearest 0.1 cm). Body mass index (BMI) was calculated as the ratio of weight (in kg) over height (in m<sup>2</sup>).

### Measures of body composition

Body composition, including lean tissue mass and fat mass, was measured by DXA scanner (model DPX-IQ, Lunar Radiation Corp, Madison, WI, USA). The onboard software estimated fat mass, lean tissue mass and %BF based on an extrapolation of fatness from the ratio of soft tissue attenuation of two x-ray energies in pixels not containing bone. Fat mass and lean tissue mass were expressed in kg. Percentage body fat (%BF) was calculated as the percent of fat mass relative to body weight. The coefficient of variation for DXA measures of body composition was between 3 and 4%.<sup>18,19</sup>

### Statistical analyses

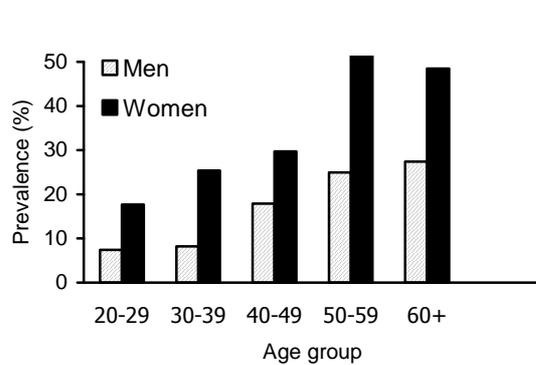
Data analysis was performed separately for men and women. By using the WHO recommended criteria, a man was classified as obese if his %BF was equal to or more than 25, while the criterion for women was 35. The prevalence of obesity was then estimated for each sex. In order to derive an optimal cut-off value of BMI for the diagnosis of obesity in the absence of %BF, a series of regression analyses were carried out. In this analysis, %BF was considered the primary outcome variable, while BMI was treated as predictor variable. In each sex, a polynomial regression equation for predicting %BF as a linear function of BMI was developed, e.g.,  $\%BF = \beta_0 + \beta_1 BMI + \beta_2 BMI^2 + \beta_3 BMI^3 + \dots + e$ , where  $\beta_0, \beta_1, \beta_2, \beta_3, \dots$  are unknown parameters, the random error *e* is assumed to be normally distributed with mean 0 and a constant variance. The unknown parameters of the polynomial regression equation were estimated by the method of least squares. Because there are several possible polynomial equations, the selection of a “final” equation was based on measures of goodness-of-fit of the equation, such as coefficient of determination (which reflects the amount of variation in %BF that could be explained by BMI), residual mean square error, and residual analyses (to make sure the assumptions of normality, homogeneity and independence were satisfied). Based on the parameter estimates of the final polynomial equation, a BMI value was derived so that the predicted value of %BF is 25% for men and 35% for women.

In considering the use of BMI as a surrogate measure of obesity, a number of receiver operating characteristic (ROC) curves were constructed. ROC curve is a graphical representation of the trade-off between true positive rate (e.g., sensitivity) and false positive rate (e.g., 1

**Table 2.** Mean and standard deviation of percentage body fat in men and women stratified by BMI-based categories

BMI category	Men*	Women*	Difference and 95% CI†
BMI < 25 kg/m <sup>2</sup>	14.4 ± 6.3 (N = 255)	29.2 ± 7.2 (N = 320)	14.9 (14.0 – 15.8)
BMI = 25-29 kg/m <sup>2</sup>	24.2 ± 5.1 (N = 75)	37.2 ± 4.9 (N = 142)	13.1 (11.7 – 14.4)
BMI ≥ 30 kg/m <sup>2</sup>	27.8 ± 3.3 (N = 10)	41.7 ± 7.0 (N = 45)	14.7 (10.6 – 18.8)
All groups	17.0 ± 7.5 (N = 340)	32.5 ± 8.0 (N = 507)	14.3 (13.5 – 15.1)

Note: \*, mean and standard deviation were calculated based on raw (unadjusted) data; †, differences and 95% confidence intervals were calculated from the analysis of covariance model in which age and BMI were covariates, sex was a factor, and %BF was the dependent variable.



**Figure 1.** Prevalence of obesity in Thai according to the percentage body fat cut-off criteria (%BF ≥ 25% for men and %BF ≥ 35% for women)

minus specificity) of a prediction model. The area under the ROC curve (denoted by AUC) is a measure of accuracy of a diagnostic test which is, in this case, BMI. Practically, AUC is the probability that a randomly drawn individual from the obese group (defined by %BF) has a greater BMI value than a randomly drawn individual from the non-obese group. This probability is not affected by the prevalence of obesity in the population.

## Results

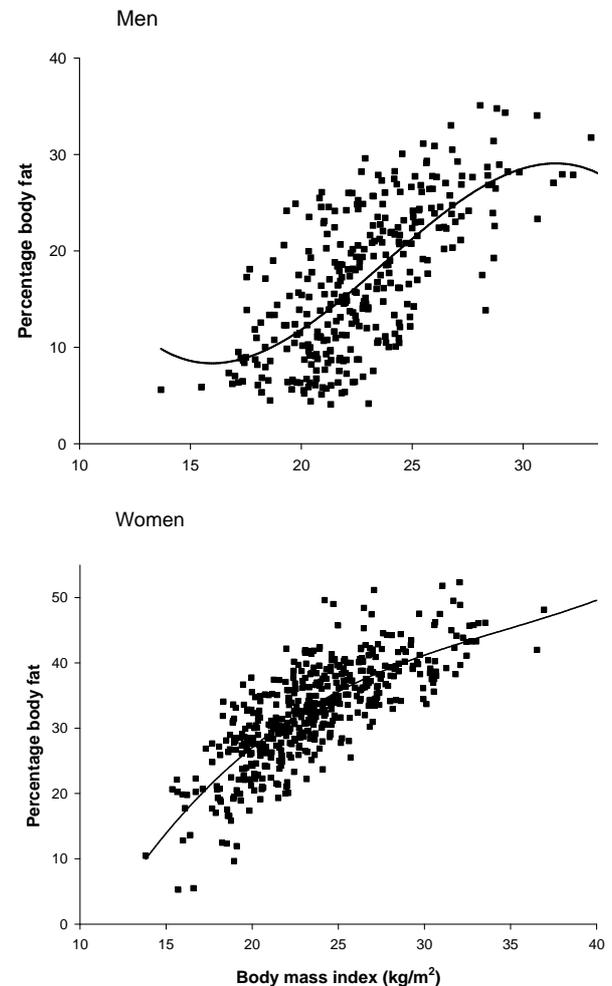
### Characteristics of study sample

A total of 340 men and 507 women aged  $50 \pm 16$  yr (mean ± SD; range: 20-84 yr) were included in this study. While the two sexes were comparable in terms of age, men had significantly greater stature, heavier weight, higher percentage of lean mass tissue, but lower BMI, lower %BF, than women (Table 1). There was no evidence of skewness in the distribution of %BF or anthropometric variables.

There was no statistically significant correlation between age and BMI in either men ( $r = 0.08$ ;  $P = 0.12$ ) or women ( $r = 0.07$ ;  $P = 0.08$ ). However, age was positively correlated with %BF in men ( $r = 0.30$ ;  $P < 0.001$ ) and in women ( $r = 0.14$ ;  $P = 0.001$ ). As expected, for the same BMI category, women had consistently higher %BF than men. For example, among those with BMI ≥ 25 kg/m<sup>2</sup>, %BF in women was approximately 16% higher than that in men. The difference was somewhat lower among those with BMI ≥ 30 kg/m<sup>2</sup> (Table 2).

### Prevalence of obesity

Using the “golden criteria” (e.g. %BF ≥ 25% for men and %BF ≥ 35% for women), 18.8% of men and 39.5% of



**Figure 2.** Scatter plot between percentage body fat and body mass index in men and women.

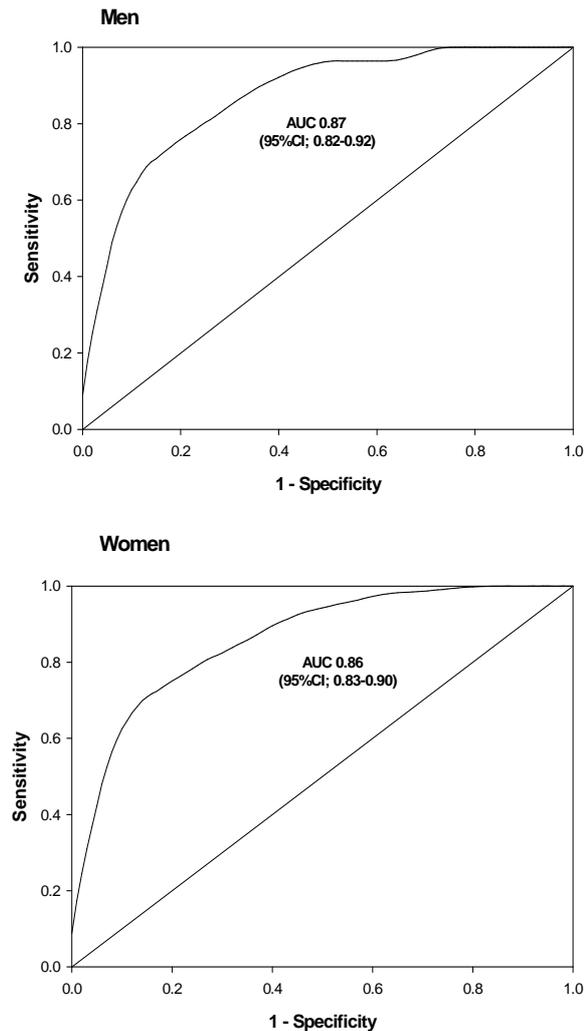
women were classified as “obese”. However, in either gender, the prevalence of obesity increased with advancing age such that by the age of 50<sup>+</sup>, 27% of men and almost 50% of women were obese (Fig. 1). In each age group, the prevalence of obesity in women was consistently higher than men.

### Relationships between %BF and BMI

In men, the relationship between %BF and BMI was significant at the third degree polynomial (cubic equation; Fig. 2). It was estimated that 49% of variation in %BF was explained by BMI. Using the estimated regression parameters (Table 3) a BMI of 27 kg/m<sup>2</sup> would predict a %BF of 25%. In women, the relationship between %BF and BMI also followed a cubic function (Fig. 2), in which 51% of variation in %BF was attributed to BMI. On

**Table 3.** Prediction of percentage body fat by body mass index: estimates of regression parameters and associated statistics. Predictor: Body mass index

Parameter	Men	Women
Intercept	122.23 ± 42.05	-79.54 ± 19.75
BMI	-17.11 ± 5.31	9.59 ± 2.27
BMI <sup>2</sup>	0.81 ± 0.22	-0.26 ± 0.08
BMI <sup>3</sup>	-0.011 ± 0.003	0.003 ± 0.001
R-square	0.49	0.51
Residual mean square	28.53	31.51
Estimated BMI so that %BF is 25 for men and 35 for women	27.0	25.0

**Figure 3.** ROC curve of percentage body fat and body mass index in men and women.

solving the cubic equation, it was estimated that a BMI of 25 kg/m<sup>2</sup> would predict a %BF of 35% in women (Table 3).

#### Sensitivity and specificity of BMI

In men, using the %BF-based criteria of  $\geq 25\%$  the prevalence of obesity was estimated to be 18.8% (64/340). On the other hand, if BMI levels of  $\geq 30$  kg/m<sup>2</sup> were used, the prevalence of obesity was only 2.9% (or 10/340). Therefore, the sensitivity of the BMI criteria was low (12.5%), even with a high specificity of 99.3%.

However, using the present study proposed cut-off criteria (BMI  $\geq 27$  kg/m<sup>2</sup>), the prevalence of obesity in men was 12.6%, and the sensitivity of the proposed criteria increased to 44%, while the specificity remained high (95%) and the positive predictive value was 69% (Table 4). The AUC estimate for BMI was 0.87 (95% CI: 0.82-0.92), (Fig. 3).

In women, the prevalence of obesity, using the criteria of %BF  $\geq 35\%$ , was 39.5% (307/507). In the same sample, 8.9% (45/507) of women were found to have BMI  $\geq 30$  kg/m<sup>2</sup>. The sensitivity and specificity for BMI were 20.5% and 98.7%, respectively. However, using the present study proposed cut-off criteria (BMI  $\geq 25$  kg/m<sup>2</sup>) the prevalence of obesity in women was 37%. The diagnostic sensitivity of the new criteria increased to 69%, while the specificity was 84%, with the positive predictive value being 74% (Table 4). The AUC estimate for BMI was 0.86 (95% CI: 0.83-0.90), (Fig. 3).

#### Discussion

Despite the recognition that obesity is a public health threat in Asian countries, the definition of obesity is still controversial. It has been recognized that the current Caucasian-based BMI criteria for classifying obesity may not be appropriated in Asian populations, because the relationships between BMI and the degree of fatness varied significantly among ethnic populations.<sup>16,20-22</sup> However, the recent WHO Expert Consultation could not come up with a definite cut-off BMI values for defining obesity in Asians, because "The consultation did not have enough data to adequately describe either the association of BMI with body fat, or the association of BMI or fatness with morbidity".<sup>16</sup> The present study represents a contribution toward that research endeavour. By using the DXA methodology, this study shows that the use of the WHO criteria of BMI ( $\geq 30$  kg/m<sup>2</sup>) is likely to under-estimate the prevalence of obesity in the Thai population. Results of this study suggest that a minimal BMI of 27 kg/m<sup>2</sup> (in men) and 25 kg/m<sup>2</sup> (in women) should be considered obese in the Thai population. These proposed BMI cut-off values are lower than the WHO's 30 kg/m<sup>2</sup> but fall well within the BMI range of 26 to 31 kg/m<sup>2</sup> which was considered at risk of having health complications.<sup>16,23</sup>

Ideally, optimal cut-off values should be derived based on health-related criteria, and this has been the basis of the WHO's BMI-based classification of obesity.<sup>23</sup> However, there have been no long-term prospective studies

**Table 4.** Cut-off values for body mass index for the diagnosis of obesity (%BF  $\geq$  25% for men and  $\geq$  35% for women) and associated diagnostic indices

	Men	Women
WHO cut-off	30 kg/m <sup>2</sup>	30 kg/m <sup>2</sup>
Prevalence (%)	2.9	8.9
Sensitivity (%)	12.5	20.5
Specificity (%)	99.3	98.7
PPV (%)	80.0	91.1
Proposed cut-off	27 kg/m <sup>2</sup>	25 kg/m <sup>2</sup>
Prevalence (%)	12.6	36.9
Sensitivity (%)	43.7	69.5
Specificity (%)	94.6	84.4
PPV (%)	69.1	74.3

PPV: Positive predictive value

examining the relationship between body fat or BMI and health complications in Asian populations; therefore, an indirect derivation is the only choice. Nevertheless, a recent study of association between body fat and cardiovascular risks in Singaporean Chinese, Malays and Indians has presented a case for lowering the BMI cut-off values for obesity in these populations from 30 to 27 kg/m<sup>2</sup> which are reasonably consistent with our proposed cut-off values.<sup>24</sup> Furthermore, our proposed cut-off values were built on the fact that BMI was a reasonable indicator of obesity in this population. Indeed, the area under the ROC curve for BMI (as a predictor of %BF obesity) was around 0.9, which represents a very good trade-off between true positive and false positive rates.

It has been reported that for a given BMI level, Asians have a higher percentage body fat than Caucasians.<sup>15,25</sup> However, the present study does not confirm that observation. For example, in this sample, among women whose BMI  $\geq$  30 kg/m<sup>2</sup>, the mean %BF was  $41.7 \pm 7.0\%$  (mean  $\pm$  SD), which is not much different from the figure of 41% for White Caucasian women.<sup>26</sup> The mean %BF of men with BMI  $\geq$  30 kg/m<sup>2</sup> in this sample ( $27.8 \pm 3.3\%$ ) although based on only 10 observations is also very comparable to that observed in Caucasian men.<sup>26</sup>

The lowering of BMI cut-off will result in an increase in the prevalence of obesity in the Thai population. Indeed, in this study, the prevalence of obesity as defined by WHO's recommended criteria (BMI  $\geq$  30 kg/m<sup>2</sup>) was only 3% in men and 9% in women; this prevalence would increase to 19% in men and 39% in women by using the study's suggested cut-offs. It is difficult to know whether this prevalence is clinically sensible, because there is currently no data to assess the cardiovascular manifestations in the Thai population with this range of BMI; however, the prevalence in women as estimated by the proposed cut-off is highly consistent with the %BF-based prevalence (viz %BF  $>$  25%).

The present findings must be interpreted within the context of a number of potential strengths and weaknesses. A major strength of this study lies in its validity and sampling scheme. The measurement of body fat and fat-free mass in this study was based on the DXA instrument, which is considered to be one of the most accurate and valid methods of measurement. The sample size was

reasonably large to allow for a stable estimation of relations between body fat and BMI. Despite the subjects in this study were randomly selected, well characterized, the study subjects were Thai, among whom, body size, lifestyles, cultural backgrounds and environmental living conditions are different from other populations. Thus care should be taken when extrapolating these results to other populations. The measurement error of body fat could result in misclassification of obesity and body weight was measured at a single time point which may not reflect a true long-term weight of a subject. These two sources of measurement errors albeit inevitable, could have affected the result. However such a limitation is present in any study of this type. Furthermore, we do not have morbidity and mortality data to validate our proposed cut-off, and this needs to be validated in another Thai or Asian sample.

In summary, the prevalence of obesity based on BMI that corresponds to a percentage body fat previously defined in Caucasian populations was lower in the Thai population. In this study, adult Thai men and women did not have higher percentage body fat for a given BMI than Caucasian populations. However, results of this study suggest that optimal cut-off values using BMI to define obesity should be lower in Thailand than in Western countries. The present study's results suggest that the optimal cut-off values for BMI were 27 kg/m<sup>2</sup> in men and 25 kg/m<sup>2</sup> in women.

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## 在泰国用身体质量指数定义肥胖：一项流行病学研究

这项研究的目的是在泰国研究身体质量指数(BMI)的分割点和评估用身体质量指数(BMI)定义肥胖的精确性。一项代表性的流行病学研究，对象是 340 名男性和 507 名女性，年龄为  $50 \pm 16$  岁（平均值 $\pm$ 标准差，极差：20-84 岁），取样采用分层聚类取样方法。体质组成，包括体脂比例（%BF），用双能 X-射线吸收测定法（GE Lunar Corp, Madison, WI）来测定。身体质量指数是用体重（千克）除身高的平方（平方米）得来。对于男性，定义肥胖的“金牌标准”是体脂比例  $\geq 25\%$ ，对于女性是体脂比例  $\geq 35\%$ 。这种用体脂比例来判断肥胖得出的肥胖率，男性和女性分别为 18.8% 和 39.5%。但是，如果用身体质量指数  $\geq 30$  来判断，仅有 2.9% 男性和 8.9% 女性可以归为肥胖。在三次回归模型中，身体质量指数是体脂比例的一个很好的预报器，例如一个身体质量指数为  $27 \text{ kg/m}^2$  的男性，可以预测出其体脂比例为 25%，相应地，一个身体质量指数为  $25 \text{ kg/m}^2$  的女性，预测其体脂比例为 35%。接受测试者的身体质量指数特征曲线下方面区域大约是男性 0.87 (95% 置信区间: 0.82-0.92)，女性 0.86 (95% 置信区间: 0.83-0.90)。总的来说，在泰国，身体质量指数是肥胖的一个合理、有用的指示器。尽管如此，判断肥胖的身体质量指数的分割点必须降到男性  $27 \text{ kg/m}^2$ ，女性  $25 \text{ kg/m}^2$ 。

**关键词：** 身体质量指数、体脂比例、流行病学研究、泰国、亚洲人。