Association between Body Composition

and

Body Mass Index in Young Japanese Women

日本人若年女性における身体組成と体格指数の関係

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I. INTRODUCTION

Obesity has increased at an alarming rate in recent years and is currently a worldwide public health problem (*1*). For the obese person, the overweight state denotes an increased risk of chronic disabling conditions, poor quality, presently accounting for approximately 4-8% of total health care expenditure. In view of the high and still-rising prevalence of obesity, the aging populations of affluent countries face an increasing burden of chronic diseases with high social and economic cost (*2*). For these reasons, obesity is a well-recognized health hazard associated with up to one-half of all cases of chronic disabling diseases such as hypertension (*3*), dyslipidemia (*4*), type 2 diabetes (*5-8*), coronary artery disease (*9*), stroke (*10*), gallbladder disease (*11*), osteoarthrosis (*12*), sleep apnea and respiratory problems (*13*), and cancers of the endometrium, breast, prostate and colon (*14*). Higher body weights are also correlated with increased mortality from all causes (*5*).

1. Evaluation of Obesity

The prevalence of obesity in populations actually refers to that proportion of individuals exhibiting excess storage of body fat. Differences in weight between individuals are only partly due to variations in body fat; consequently, many researchers object to the use of weight or indices based on height and weight to discriminate between overweight and normal-weight persons.

1.1. Body Composition

Wang et al. (*15*) collated all data with respect to body composition and presented it as a comprehensive five-level model of body composition. This five-level model has become the standard for body composition research. The five levels of the model are as follows: elemental, molecular, cellular, tissue systems and total body (*15*). A survey of the literature of the past 50 years depicts an evolutionary process from the basic two-component (2-C) models to the currently popular four-component (4-C) models of body composition. Owing to its early development and widespread utility, the measurement of body density is often referred to as a 'gold standard' for body composition measurements, despite the fact that it is a 2-C model, consisting of both body fat mass (BFM) and fat free mass (FFM).

The ideal method for the assessment of human body composition should be relatively inexpensive at initial purchase and maintenance of operation should require little inconvenience for the subjects; additionally, operation should be manageable by unskilled technicians and yield highly reproducible and accurate results (*16*). Unfortunately, no such technique is available that meets these criteria. A number of factors should be considered when selecting one or more indirect methods for the assessment of human body composition for a specific study. Method selection might depend upon which compositional variable(s) requires quantitation. Overweight and fat distribution might be useful predictors of health risks associated with obesity; therefore, a clear definition of these terms is essential. The most commonly employed technique for determination of body density is underwater weighing, which requires the subject to be completely submerged in water. The volume of water displaced and/or the subject's weight underwater, combined with the subject's laboratory weight, are applied to calculate the density of the entire body. Little difficulty exists with respect to obtaining an accurate measure of body weight; limitations and restrictions are associated with the estimates of body volume and the residual lung volume.

1.2. Body Mass Index

Body weight and height are employed in combination as simple and reliable measurements for evaluation of nutritional and overall health status and overweight screening (*17*). Overweight is generally defined as weight that exceeds the threshold of a criterion standard or reference value (*17*). Reference values are generally based on observed population distributions of measured weight, whereas criterion standards are based on the relation of weight to morbidity or mortality outcomes (*17*). The distinction between references and standards is important as it indicates whether the source of the weight criteria is based on descriptive statistical distribution or on health outcomes (*17*). The derivation, comparison and limitations of various weight-for-height indices have been described in the scientific literature (*17-25*). The most widely used weight-for-height index is the body mass index (BMI), also referred to as the Quetelet index (*22,26*). Numerous reports have shown that BMI is a reasonable indicator of fatness (*27-32*) as overweight (high-BMI) subjects are also defined as obese (high-BFM). This situation indicates that changes in body weight are a suitable reflection of alterations in BFM rather than in FFM. However, BMI generally correlates strongly with fatness, although it can occasionally misclassify total BFM. In fact, Allison et al. suggested that the U-shaped relation frequently observed between BMI and mortality may result, at least in part, from the fact that BMI is composed of separate components, mainly BFM and FFM, which exert opposite effects on health and longevity (*30*).

In observational studies, BMI is a simple, easy measure for obesity; however, Heitmann et al. argue that this method may be inappropriate for measurement of body fatness (*31*). They concluded that the apparent U-shaped association between BMI and total mortality might be the result of compound risk functions from BFM and FFM. BMI is independent of age and reference population; therefore, it can be utilized for comparison across studies internationally (*17*). According to the Expert Panel, overweight is defined as a body mass index (BMI) of 25-29.9 kg/m^2, whereas obesity is defined as a BMI ≥ 30 kg/m^2. However, overweight and obesity are not mutually exclusive as obese persons are also overweight. Recently, classification of body weight based on BMI in adult Asians for prevention of chronic diseases was proposed by the International Obesity Task Force (*29*). An "at risk of overweight" category, BMI of 23.0-24.9 kg/m^2, was added to the "in Japanese" classification.

2. Factors Influencing Obesity

Obesity is not a single disorder, but a heterogeneous group of conditions with multiple causes. Body weight is determined by an interaction between genetic, environmental and psychosocial factors acting through the physiological mediators of energy intake and expenditure. Although genetic differences are undoubtedly importance, the marked rise in the prevalence of obesity is best explained by behavioral and environmental changes resulting from technological advances (*33*).

Implicit within the susceptible-gene hypothesis is the role of environmental factors that unmask latent tendencies with respect to development of obesity. Predictions regarding possible interactions between genes and the environment are difficult due to the potential for delay in an individual's exposure to an 'obesogenic' environment, and/or alteration in lifestyle related to living circumstances and uncertainly about the precise timing of the onset of weight gain (*33*). Evidence supporting the critical role of environmental factors in the development of obesity derives from migrant studies and the 'Westernization' of diet and lifestyle in developing countries (*33*). The effect of high-fat diet, which plays a role in the development of obesity, is embroiled in controversy (*34-36*). However, this controversy clearly indicates that to reduce the prevalence of obesity, an increase in energy expenditure, a reduction in total energy intake, or both, must occur. Popkin found that problems of under- and over-nutrition often co-exist, reflecting the trend in which an increasing proportion of people consume the types of diets associated with a number of chronic diseases (*37*).

3. Lifestyle Transition in Japan

Following World War II, Japan experienced an extended period of socioeconomic development, which evoked many changes within the culture. Changes in eating habits have persisted since that time and have greatly affected the physical size and health of Japanese children. Since 1945, the Ministry of Health and Welfare has reported annual changes occurring in the intake of fat, protein, carbohydrates and total energy in the Japanese population in the form of the National Nutrition Survey. These annual reports indicate that general nutritional improvements among the Japanese population are regarded as the major contributory factor to the recent achievement of the top-ranked position for longevity in the world (*38*).

Based on the perspective of food supply or nutritional conditions, these 57 years may by divided into four periods (*39*). The first period constitutes shortages of the food supply from 1945-1950. The second period comprises recovery of the food supply from 1950-1955. The third period is characterized by rapid socioeconomic development in a 'Westernized' and 'Industrialized' manner from 1955-1970. The fourth period is representative of the sufficient or excess food supply in effect since 1970. This last period can be further divided into two portions. The first sub-period occurred from 1970 to 1980, during which time the Japanese people enjoyed 'Westernized' and 'Industrialized' affluent living, along with "delicious food." In the second sub-period, from 1980 to the present, people have actually felt that this affluent living has advantageous health effects.

4. Emerging the Study Purpose

In Japan, current prevalence of obesity (BMI $\geq$ 30 kg/m^2) is relatively low (1.9% of men and 2.9% of women) (*40*), with little increase over the last 30 years. In addition, a decreasing BMI trend is evident among young Japanese women (*41-44*). However, our previous studies (*45,46*) suggest that the ratio of young women with high-body fat percentage (BF%), who are not screened by BMI cutoff in Japanese (≥ 25.0 kg/m^2) (*41,42*), is increasing. This phenomenon is commonly observed in young Japanese (*47-49*) and is referred to as "masked obesity". This observation indicates that some individuals who are classified within not screened by BMI (“normal range” and “underweight”) often do not correlate with negative BF%. Comparative epidemiologic investigations suggest that a 'Westernized lifestyle' induces chronic diseases, especially diabetes mellitus (*50-55*).

Sugano et al. (*56*) found that lifestyle among Japanese has been 'Westernized', particularly among the younger generation based on the results of the National Nutrition Survey. On the other hand, young Japanese women desire thinness (*57,58*). Their dieting behaviors appear to consist of undesirable methods (ex., skipping meals). Kaneko et al. (*57*) and Kiriike et al. (*43*) suggest that significant concerns regarding weight and shape dieting behaviors are present in Japanese girls and increase progressively with age. Again, it is assumed that an excess BF% defines obesity (*25-27,32,53-61*). Literature documenting the association between body composition and BMI is relatively sparse. In addition, screening performance of "at risk of overweight" and classification of BMI of excess BF% individuals in young Japanese women are not found. Therefore, this investigation evaluated the association between body composition and BMI in young Japanese women.

II. SUBJECTS AND METHODS

1. Study Subjects

The present investigation was conducted from 1994 to 1999. Subjects were recruited only after being informed of the study protocol and methods. The subject population consisted of 605 female college students in Saitama prefecture aged 19-21 years; moreover, these individuals were free from chronic disease and endocrine disorders.

2. Body Composition Measurement

Following a two-hour fast, body weight and height were measured with the subjects barefoot and wearing swimsuits. An underwater weighing approach was employed in order to measure body density (see APPENDIX). Body density was calculated from simultaneous measurements of underwater weight and residual lung volumes as per the approach of Abe et al. (*62*). Subjects were weighed in an acrylic resin tank utilizing strain gauges (MFG-250: Shinko Denshi Co.). The water temperature was maintained at 37 ± 1 °C. Residual lung volumes were measured with an oxygen dilution technique described by Rahn et al. (*63*). Gastrointestinal gas volumes were not measured (*64*). BF% was calculated from body density based on the method of Brozok et al. (*65*) related to underwater weighing:

Body fat percentage (BF%, %) = (4.570 / body density (kg/L) - 4.142) x 100

3. Calculation of Body Mass Index

A common obesity index as BMI was calculated as follows:

Body mass index (BMI, kg/m^2) = body weight (kg) / square of body height (m)

4. Classification of Study Subjects

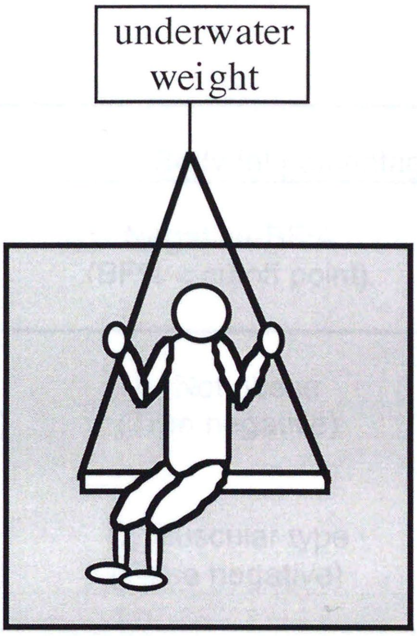
The 85^{th} percentile value of BF% was employed for classification in the present investigation; negative-BF% as less than the cutoff point (BF% < 85^{th} percentile) and positive-BF% as equal to or greater than cutoff point (BF% ≥ 85^{th} percentile), respectively (*66*). In contrast, "BMI classes in adult Asians" (*29*) consisted of "underweight", "normal range", "at risk", "obese I" and "obese II"; furthermore, these categories were also used for cross-classification. However, "obese I" and "obese II" categories were combined into a single ("obese") group in this investigation. Consequently, subjects were classified by BMI at 18.5, 23.0 and 25.0 kg/m^2, respectively.

5. Statistical Analyses

Statistical analyses were performed with the JMP 4.0.2 (Academic Edition) software package (SAS Institute). P values <

0.05 were defined as statistically significant. Shapiro-Wilk's W test was employed in order to establish normal distribution. The correlation between BMI and BF% was analyzed by Pearson's correlation coefficient. Sensitivity, specificity and Cohen's Kappa coefficient level were utilized for degree of agreement (See APPENDIX 2).

This study was conducted in accordance with the DECLARATION OF HELSINKI: Subjects were recruited only after being informed of and agree to the protocol and the methods.



$$\text{Body Density (kg/L)} = \frac{\text{Body Weight (kg)}}{\dfrac{\text{Body weight (kg) - Underwater weight (kg)}}{\text{Water Density (kg/L)}} - \text{Residual Lung Volume (L)}}$$

$$\text{Residual Lung Volume (L)} = O_2\text{(L)} \times \frac{N_2(\%)}{79.04 - N_2(\%)} \times \frac{273+37}{273+GT(^\circ C)} \times \frac{AP(mmHg) - SVP(mmHg)}{AP(mmHg) - 47.08} - DS$$

APPENDIX 1. Measurements of body density by underwater weighing.

O_2, volume of oxigen gas (1.5L); $N_2 = 100 - (O_2 - CO_2)$; GT, gas temp; AP, atmospheric pressure; SVP, saturated vapor pressure; DS, dead space of snorkel (0.17L).

	Body fat percentage (BF%) status	
	Negative-BF% (BF% < cutoff point)	Positive-BF% (BF% ≥ cutoff point)
Not-Screened (BMI < cutoff point)	A, Not obese (True negative)	B, Masked obese (False negative)
Screened (BMI ≥ cutoff point)	C, Muscular type (False negative)	D, Obese (True positive)

APPENDIX 2. Contingency table analysis

Body fat percentage (BF%) was measured by underwater weighing method. Cutoff points of BF% and BMI were reffered to 85th percentile of total study subjects and cutoff points in adult Asians (29), respectively. Calculations were as follows: sensitiviy = D / (B + D); specificity = A / (A + C); Kappa = agree of (observation - chance alone) / (1 - agree of chance alone).

III. RESULTS

1. Subjects

Anthropometric variables and BF% of total study subjects and of classified subjects (negative-BF% as less than cutoff point and positive-BF% as equal to or greater than cutoff point, respectively) are presented in Table 1. Figure 1 shows histograms of both BMI (A) and BF% (B), respectively. Distribution of BMI was not normal; however, BF% exhibited normal distribution. The BF% cutoff point (85^{th} percentile) was indicated at 29.8% (Table 1).

2. Relationship between BMI and BF%

Figure 2 presents the fit line (solid line) and 95% confidence interval (CI) area (dot area) of total subjects between BF% and BMI. In addition, Figure 2 includes the 95% mahalanobis distance ellipses and fit lines (broken lines) for both negative- and positive-BF% groups, respectively. Intercepts and slopes of these fit lines appear distinct. Furthermore, the ranges of both 95% CI for prediction of BF% employing BMI and for BMI utilizing BF% were very broad (approximately 20 kg/m^2 and 15%, respectively). On the other hand, it is clear that nearly the entire ellipse of negative-BF% group was located at BF% < 85^{th} percentile and BMI < 25.0 kg/m^2. In contrast, the ellipse of positive-BF% group covered a wide BMI range between < 18.5 and ≥ 30.0 kg/m^2.

Relationships among each BMI class were significantly correlated, with the exception of BMI < 18.5 kg/m^2, presented in Table 2. The strongest relationship (r = 0.573) was found in BMI ≥ 25.0 kg/m^2. Correlations of BMI 23.0-24.9 kg/m^2 and BMI 18.5-22.9 kg/m^2 were low (r = 0.331 and 0.385, respectively).

3. Distribution of Cross-Classified Individuals

Appearance and distribution of positive-BF% individuals and categorized number of individuals within each BMI class are presented in Figure 3. Reasonable results were obtained in the case of appearances; positive-BF% individuals appearances increased with increased BMI class. False positive (negative-BF% and higher-BMI, i.e., “muscular type”) individuals within BMI ≥ 25.0 and 23.0-24.9 kg/m^2 classes were 37.8% and 73.4%, respectively. In distribution categories, false negative (positive-BF% but BMI < 23.0 kg/m^2, i.e., “masked obesity”) readings were observed in 47.9% of positive-BF% individuals. In particular, approximately 10% of “normal range” (BMI 18.5-22.9 kg/m^2) individuals displayed false negative readings.

4. Screening Performance with BMI Cutoff Points

Screening performances of BMI cutoff points as BMI ≥ 23.0 and ≥ 25.0 kg/m^2 for positive-BF% individuals are shown in Tables 3 and 4, respectively. Specificity (not-screened by BMI and negative-BF% individuals ratio in total negative-BF% individuals) of BMI ≥ 23.0 kg/m^2 was indicated as high (0.853) and Cohen's Kappa coefficient levels (0.331) were nearly identical to BMI ≥ 25.0 kg/m^2 (0.976 and 0.336, respectively). These findings are significant with respect to sensitivity (screened by BMI and positive-BF% individuals ratio in total positive-BF% individuals) of BMI ≥ 23.0 kg/m^2 indicating a 1.7-fold greater reading than that of BMI ≥ 25.0 kg/m^2 (0.521 and 0.298, respectively).

Table 1

Anthropometric valiables and body fat percentage of Study Subjects

	Total (n = 605)		Body fat percentage (BF%) status[1]			
			Negative-BF% (n = 511) (BF% < 85^{th} percentile)		Positive-BF% (n = 94) (BF% ≥ 85^{th} percentile)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Age (y)	19.6 ± 0.5	19.0 ~ 21.8	19.5 ± 0.5	19.0 ~ 21.2	19.6 ± 0.4	19.0 ~ 21.8
Height (cm)	158.7 ± 5.6	142.0 ~ 178.0	158.6 ± 5.6	144.0 ~ 178	159.6 ± 5.5	142.0 ~ 172.4
Weight (kg)	53.8 ± 7.2	37.9 ~ 82.6	52.6 ± 6.2	37.9 ~ 75.2	60.8 ± 8.2	44.3 ~ 82.6
BMI[2] (kg/m^2)	21.3 ± 2.4	15.9 ~ 31.7	20.9 ± 2.0	15.9 ~ 27.2	23.8 ± 2.8	18.4 ~ 31.7
Body Fat (%)[3]	24.9 ± 4.9	7.9 ~ 39.5	23.5 ± 3.8	7.9 ~ 29.7	32.4 ± 2.3	29.8 ~ 39.5
85^{th} percentile (%)		29.8				

1, Subjects were classified by each BF% status; negative-BF% as less than BF% at 85^{th} percentile and positive-BF% as equal to or greater than BF% at 85^{th} percentile of total study subjects.

2, BMI, body mass index

3, Body fat percentage was measured by underwater weighing method.

Table 2

Relationships of body mass index (BMI) with body fat percentage (BF%) by BMI classes[1]

Class	Range (kg/m^2)	n	r	p	95% Confidence Interval		
Obese	25≤	45	0.573	<0.01	0.335	-	0.741
At Risk	23-24.9	79	0.331	<0.01	0.118	-	0.514
Normal Range	18.5-22.9	421	0.385	<0.01	0.301	-	0.464
Underweight	< 18.5	60	0.179	0.1708	-0.078	-	0.415

1, According to BMI cutoff points in adult Asians (29).

Table 3

Screening performance of body mass index (BMI) ≥ 23.0 kg/m^2 for positive-body fat percentage individuals

	Body fat percentage (BF%) status[1]				
	Negative-BF%	Positive-BF%	Total	Screening performance	
Not-Screened	436	45	481	Sensitivity[2]	0.521
Screened	75	49	124	Specificity[3]	0.853
Total	511	94	605	Kappa[4]	0.331

1, BF% status was classified by BF% at 85th percentile (See Table 1).

2, Positive-BF% and BMI ≥ 23.0 individuals (n = 49) ratio in total positive-BF% individuals (n = 94).

3, Negative-BF% and BMI < 23.0 individuals (n = 436) ratio in total negative-BF% individuals (n = 511).

4, Kappa measures the degree of agreement (See APPENDIX 2).

Table 4

Screening performance of body mass index (BMI) ≥ 25.0 kg/m^2 for positive-body fat percentage individuals

	Body fat percentage (BF%) status[1]			Screening performance	
	Negative-BF%	Positive-BF%	Total		
Not-Screened	494	66	560	Sensitivity[1]	0.298
Screened	17	28	45	Specificity[2]	0.967
Total	511	94	605	Kappa[3]	0.336

1, BF% status was classified by BF% at 85th percentile (See Table 1).

2, Positive-BF% and BMI ≥ 25.0 individuals (n = 28) ratio in total positive-BF% individuals (n = 94).

3, negative-BF% and BMI < 25.0 individuals (n = 494) ratio in total negative-BF% individuals (n = 511).

4, Kappa measures the degree of agreement (See APPENDIX 2).

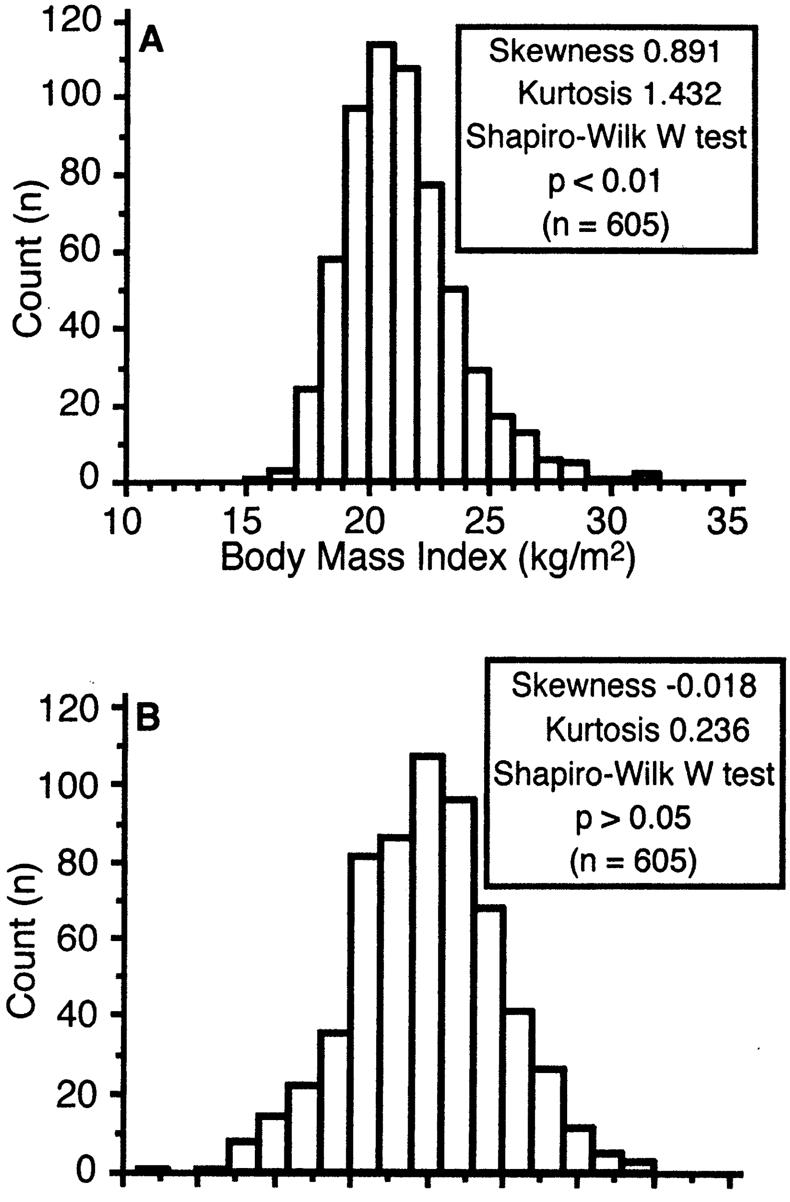


Figure 1. Histograms of body mass index (A) and body fat percentage (B). Subjects were classified per each 1 kg/m^2 of body mass index and each 2% of body fat.

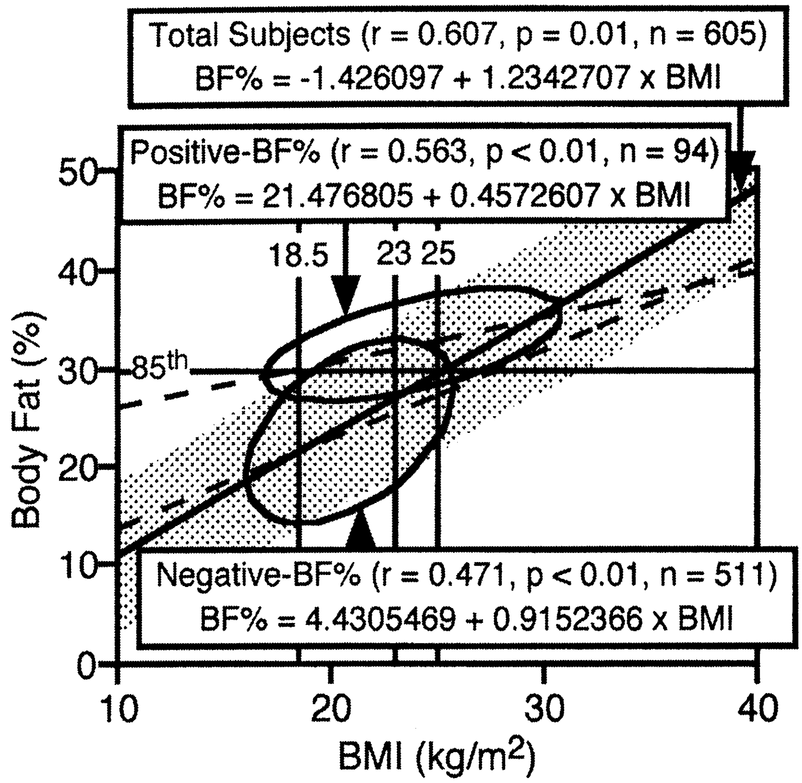
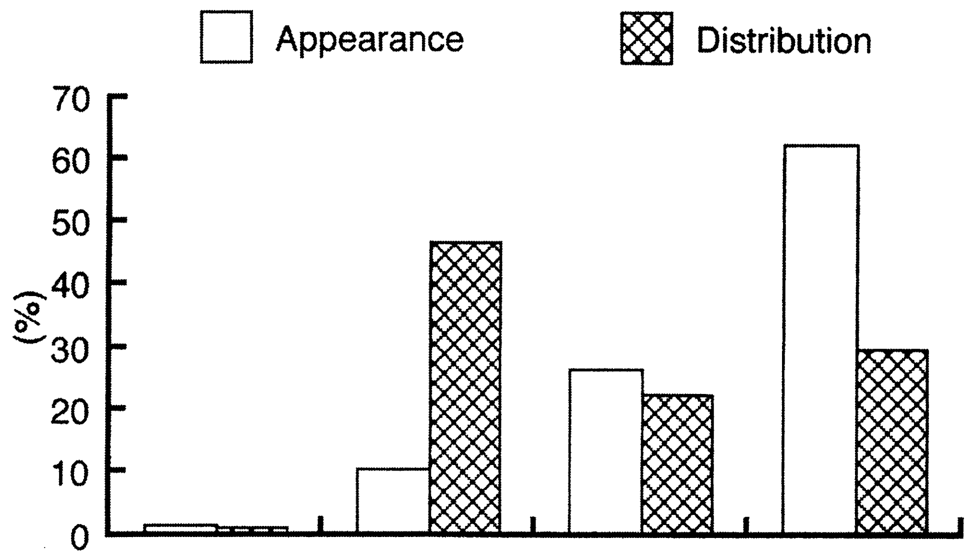


Figure 2. Relationships between body mass index (BMI) and body fat percentage (BF%). Fit lines indicate total subjects (solid line) and classified subjects (broken lines). Dot area indicates 95% confidence interval of total subjects. Ellipses indicate 95% mahalanobis distance of classified subjects (See Table 1).



BMI (kg/m2)	< 18.5	18.5-22.9	23.0-24.9	25 ≤
BMI Class	Underweight	Normal range	At risk	Obese
Positive-BF% subjects (n)	1	44	21	28
Total classified subjects (n)	60	421	79	45

Figure 3. Appearances and distribution of positive-body fat percentage (High-BF%) subjects of each body mass index (BMI) class. Appearance = positive-BF% subjects (n) / total subjects (n) in each BMI class. Distributions = positive-BF% subjects in each BMI class (n) / total positive-BF% subjects (n = 94).

IV. DISCUSSION

Obesity is defined as excess BF% (*25-27,32,53-61*). It is possible to measure BFM by various means; however, most of these approaches require sophisticated apparatus and techniques beyond the scope of most clinical practices. In contrast, height and weight are the most simple and commonly used measures. A number of weight-for-height indices have been developed, of which the BMI is the most widely applied. However, the principal limitation of the BMI as a measure of fatness involves its inability to distinguish BFM from FFM (*60*). For example, muscular athletes exhibit high BMIs, as muscle weighs more than fat; moreover, their BMIs will occur within the overweight range despite the fact that these individuals are not fat. Furthermore, it appears that these individuals are not exposed to health risks as their overweight status occurs due to increased FFM (*26*). The shortest and tallest subjects also tend to be misclassified as obese (*67,68*). However, for the general population, it is usually assumed that individuals above certain weight-for-height thresholds are over-fat as well as overweight (*17,69*). This situation is further complicated by the frequent confusion associated with the terms overweight and obesity (*70*).

Obesity refers to excess BFM; furthermore, this term should be applied when evidence exists that the amount of BFM exceeds an expected value. The information necessary to directly correlate BF% with morbidity and mortality is, unfortunately, currently unavailable despite increasing interest in body fat ranges associated with optimum health (*71*). Recently, Gallagher et al. demonstrated a working approach to developing body fat ranges by linking current BMI guidelines with predicted BF% employing a variable as 1 / BMI although the objective of their study was not to provide population ranges for body fatness as might be a goal of epidemiologic studies (*71*). They found BF% levels, based on the relation between BMI and BF% from dual-energy X-ray absorptiometry (DXA), corresponding to BMI thresholds for underweight (< 18.5 kg/m^2), overweight (≥ 25.0 kg/m^2) and obesity (≥ 30.0 kg/m^2), respectively. Estimated BF% (based on 633 Japanese women aged 20 - 39 years) were 25.0, 35.0 and 40.0%, respectively (*71*). Their assumption was that BF% is an improved phenotype characteristic relative to BMI when functionality and mortality risk are considered.

Conventionally, BMI is used to define BF% with respect to degree of obesity in the Japanese population as 20% in men and 30% in women (*45*). This conventional cutoff point in women is supported by the study of Imamura et al. (*72*). They demonstrated that the medical parameter values were poorer when BF% exceeded 30% among 250 women, aged 17 to 68 years, who never drank or smoked (*72*). It is suggested that the BF% cutoff point in this investigation (29.8%) appears reasonable in terms of degree of obesity and with respect to consideration of health risks later in life.

1. Mass-Evaluation with BMI

Numerous reports have shown that BMI is a reasonable indicator of fatness (*27-29*). The relationship between BF% and BMI differs among different ethnic groups (*73-75*). The International

Obesity Task Force recommends "BMI classes in adult Asians" (*29*). In the case of young Japanese women, this investigation also demonstrated that high-BMI (BMI ≥ 25.0 kg/m^2) is a suitable reflection of positive-BF% and supports the concept of the “at risk of overweight” (BMI 23.0-24.9 kg/m^2) category focused on preventive medicine; “at risk of overweight” appears to be the threshold of increasingly positive-BF% individuals appearance ratio within classified individuals (Figure 3).

Sensitivity in this context refers to the ratio of true positives (BF% ≥ 85th percentile) correctly classified by BMI; specificity refers to the ratio of true negatives (BF% < 85th percentile) correctly classified. The selection of a cutoff point on a continuum involves the balancing of sensitivity and specificity. In this investigation, Cohen's kappa coefficient level of each cutoff point (BMI ≥ 23.0 and 25.0 kg/m^2) was also compared to evaluate the degree of agreement. These indicators (sensitivity, specificity and kappa) suggest that the newly determined BMI cutoff "in Asians" (BMI ≥ 23.0 kg/m^2) is valuable and acceptable for mass-evaluation as a fatness indicator in comparison to previous cutoff points "in Japanese" (BMI ≥ 25.0 kg/m^2), at least among young women.

2. Individual-Evaluation with BMI

It is well known that extremely athletic persons may be heavy due to excess body fat (*76*), but not quantity of total body fatness. The results of this investigation clearly demonstrated that BMI is a poor representation of individual body composition in young Japanese women; naturally, no very athletic persons were included. Numerous investigations (*35,77,78*) also revealed that BMI was a poor surrogate for body fatness for individual-evaluation. In the case of individuals with BMI ≥ 25 kg/m^2, it may appear that body composition measurement is not necessitated by individual evaluation of fatness as BMI ≥ 25 kg/m^2 displayed the strongest relationship (Table 2); moreover, specificity was quite high (Table 3). In contrast, it is clear that the BMI ≥ 25.0 kg/m^2 category included 27.8% of false positive ("muscular type") individuals.

Additionally, we found that approximately 70% of "at risk of overweight" (BMI as 23.0-24.9 kg/m^2) individuals were defined as false positive ("muscular type"). Although the sensitivity of BMI ≥ 23.0 kg/m^2 was improved relative to that of BMI ≥ 25.0 kg/m^2, positive-BF% individuals were in the minority in the category of "at risk of overweight". Norgan (*74*) suggested that the range of BMI 20.0-25.0 kg/m^2 is more important than those values in excess of 25.0 kg/m^2. However, to our knowledge, in comparison with research on higher BF% with overweight subjects, little attention has been focused on higher BF% with low body weight, relative body weight or BMI, or FFM (*30*).

Prediction of BF% employing BMI in young Japanese women appears difficult due to the extremely wide range associated with the 95% CI of predicted BF% derived (Figure 2). This finding is consistent with the results of many studies (*25,77*). The results obtained for BMI readings ≥ 23.0 kg/m^2 overlooked approximately 50% of positive-BF% individuals (Figure 3 and Table 3). These false negative individuals are commonly observed and referred to as "masked obesity" in contemporary young Japanese (*47-49*). On the basis of the data presented here, it appears that BMI alone would not accurately diagnose obesity, at least for an individual.

3. Lifestyle-Related Health Risks

Tanaka and Nakanishi emphasized that the successful management of obesity often requires comprehensive lifestyle restructuring with attention to increased physical activity, healthy eating habits, behavioral modification and/or psychological coping strategies (*79*). Certain lifestyle choices, such as consumption of a typical 'Western diet', lack of adequate physical activity and smoking, greatly contribute to Syndrome X. Diet appears to play a pivotal role; the typical 'Western diet', high in refined carbohydrates and saturated fat and low in fiber, is associated with increased risk of obesity leading to insulin resistance and Syndrome X (*53*). Obesity is a complex, multifactorial disease that develops from the interaction between genotype and the environment. Our understanding of how and why obesity occurs is incomplete; however, it involves the integration of social, behavioral, cultural, physiological, metabolic and genetic factors (*73*).

The lifestyle among Japanese has been 'Westernized', especially in the younger generation (*56*). From the perspective of genetic backgrounds among Japanese, Kawamura et al. (*54*) found the association between the Trp64Arg variant of the β_3-adrenargic receptor gene and insulin resistance when combined with a 'Westernized lifestyle'. Additionally, epidemiological data also suggest that a 'Westernized lifestyle' induces peripheral insulin resistance and promotes the development of diabetes in Japanese Americans (*52,55*).

In Japan, current prevalence of obesity (BMI $\geq$ 30 kg/m^2) is relatively low (1.9% of men and 2.9% of women) (*40*), with little increase over the last 30 years. In addition, a decreasing BMI trend is evident among young Japanese women (*41-44*). In fact, over the last 35 years adolescent and young adult women have become thinner. These results suggest that young Japanese women have decreased their BMI by dieting in order to become slim. In adolescents, weight control by exercise rather than diet restriction appears to carry less risk with respect to development of eating disorders (*80*). However, dieting behaviors in young Japanese women appear to consist of undesirable methods (*57,58*). If this tendency persists, with regard to a close relationship between restrained eating or dieting and eating disorders, young Japanese women are exposed to a much greater risk of developing eating disorders (*43*). In the case of improved anorexia nervosa, a typical eating disorder, BF% in the weight regained in reference female anorectic patients was directly related to the extent of body mass increase (*81*). It appears that "masked obesity" as a consequence of several dieting histories cannot be excluded.

Physical activity appears to attenuate the health risks associated with overweight and obesity; moreover, active obese individuals actually show lower morbidity and mortality in comparison with sedentary normal weight individuals (*82*). Inactivity and low cardiorespiratory fitness are as important as overweight and obesity as mortality predictors (*82*). Although physical inactivity is believed to contribute to the rising prevalence of obesity, the role and magnitude of its contribution to weight gain are unknown. Weinsier et al. compared total free-living activity energy expenditure and physical activity level in women successful and unsuccessful with respect to maintaining normal body weight (*83*). They showed that the maintainers exhibited greater muscle strength and engaged in more physical activity than did the gainers (*83*). Interestingly, the type of physical activity practiced by the maintainers appeared to be of relatively low intensity (*83*). This finding is important as this type of physical activity would be enhanced by an effort to increase activities associated with daily living such as walking or taking the stairs rather than by planned exercise. They conclude that the general U.S. population should increase its daily physical activity levels to decrease the rising prevalence of obesity (*83*). In addition, Poehlman et al. (*84*) demonstrated that both endurance and resistance training improve glucose disposal, albeit by different mechanisms, in young women. They concluded that enhanced glucose uptake following physical training in young women occurs with and without changes in FFM and body composition (*84*). These findings suggest that physical activity energy expenditure should be enhanced to decrease the rising prevalence of obesity and to avoid metabolic dysfunctions.

4. Hazards of "Masked Obesity" Later in Life

Manson et al. found that body weight and mortality from all causes were directly related among middle-aged women. They concluded that the lowest mortality rate was observed among women weighing at least 15% less than the U.S. average for women of similar age and among those whose weight had been stable since adulthood (*85*). According to Manson et al. (*85*), it appears that "masked obesity" has little or no health risks as a result of categorization as "normal range" body weight. However, it is significant that higher levels of body weight within the normal range, as well as modest weight gains (> 5 kg) after 18 years of age, appear to increase risk of coronary heart disease in middle-aged women (*86,87*). Additionally, Liu and Manson (*88*) reviewed several analyses of morbidity. They found a direct association between "normal range" (BMI 18.5-24.9 kg/m^2), the typical 5-10 kg of weight gain that occurs during adulthood in Western populations, and increased risk of hypertension, type 2 diabetes mellitus and myocardial infraction (*88*).

Similar findings in Japanese adults were also documented (*89,90*). Yanai et al. noted that the prevalence of overweight in Japanese populations increased with increasing age in both sexes, especially in women (*91*). To elucidate the relationship between body weight gain and future disease, Matsuura et al. (*89*) investigated retrospectively the correlation between changes in BMI and morbidity in 1,869 (1,194 males and 675 females; 30-60 years of age) university graduates (from 10 to 40 years post-graduate) using a questionnaire survey. Subjects were classified into three groups based on BMI between the entrance health examination and the present; "obesity" (BMI $\geq$ 23.0 and $\geq$ 25 kg/m^2, respectively, weight gain during this period was > 5 kg); "unchanged" (BMI < 23.0 and < 25 kg/m^2, respectively, and weight gain was $\leq$ 5 kg); "masked obesity" (BMI < 23.0 and < 25 kg/m^2, respectively, and weight gain was > 5kg). The frequency of "masked obesity" (28%, n = 526) was markedly higher than that of "obesity" (16%, n = 302). The observation of "masked obesity" increased progressively with age and paralleled the age-dependent change in waist circumference. Total morbidity (associated with obesity) between "masked obesity" and "obesity" was equivalent, 61% (34%) and 63% (32%), respectively. On the other hand, "unchanged" indicated 46% (19%), which was significantly lower than either "obesity" and "masked obesity". Based on these results, they suggested that weight gain is a critical factor for morbidity, even when the present body weight is not considered overweight.

The existence of a subgroup of individuals possessing normal body weight, but displaying a cluster of obesity-related phenotypic characteristics, was initially proposed in the 1980s (*92*). Since this discussion, an accumulating body of evidence suggests a high prevalence of these individuals in the general population (*93,94*). These metabolically obese, normal-weight (MONW) individuals display early signs of insulin resistance, hyperinsulinemia and dyslipidemia, despite a normal weight status based on traditional criteria (e.g., BMI, height/weight tables, etc.) (*93*). The presence of these metabolic and cardiovascular disease risk factors might go undetected for years as young age, sex and normal body weight mask the need for early detection and treatment (*95*). Dvorak et al. (*95*) hypothesized that MONW young women would exhibit higher levels of total and visceral fat and lower levels of physical activity than normal women. The described anthropometric variables and BF% of MONW women appear almost equivalent compared with "masked obese" women in this investigation employing the BMI cutoff point "in Japanese" classification (BMI $\geq$ 25.0 kg/m^2). Thus, it is suggested that the findings among MONW women are applicable to "masked obesity". Dvorak et al. (*95*) found that 18% of subjects classified with impaired insulin sensitivity exhibited normal body weight and BMI. Furthermore, young MONW women with impaired insulin sensitivity showed a cluster of risky phenotypic characteristics, including low free-living physical activity energy expenditure and increased total and visceral fatness (*95*). Additionally, even small increases in body fatness (2-3 kg) within a normal range of BMI negatively affect insulin sensitivity (*95*). They suggested that young women with BMI < 26.0 kg/m^2 but with a BF% > 30% are probably at higher risk for impaired insulin sensitivity and a potentially early onset of type 2 diabetes mellitus, hypertension and cardiovascular disease (*95*). These findings support the notion that BMI is a poor marker with respect to identification of women at risk for the development of insulin resistance and associated co-morbidities. From this perspective, a natural suggestion that individual-evaluation, rather than mass-evaluation, of body fatness appears to be more important with respect to preventive medicine (*96*).

5. Strategy for "Masked Obesity"

Often, the choice of anthropometric indicators is a matter of convenience rather than science (*97*). This investigation clearly demonstrated that BMI appears to be a valuable indicator of body fatness for mass-evaluation, although BMI is a poor surrogate for body fatness for individual-evaluation (*77,78*). "Masked obesity" is defined as less than the overweight cutoff point by BMI classification and positive-BF% (BF% $\geq$ 85^{th} percentile) in this investigation. Therefore, it is suggested that body composition measurement is required for individual-evaluation, especially for BMI < 25.0 kg/m^2 individuals. This simple strategy is a troubling matter; however, results are consistent with previous populations studies (*30,31,98*). For example, Heitmann et al. (*31*) investigated the 22-year mortality risk associated with BMI, BFM and FFM, with the purpose of examining whether the U-shaped relationship observed between BMI and premature death might depend on a mixed risk function related to body composition in 787 Swedish men born in 1913. They illustrated that at the high end of BMI, muscular subjects might well be misclassified as overweight when, in fact, they are lean. More surprisingly, less than half of the subjects characterized by a low BMI (66/147) were actually lean in terms of body fat (*31*). They demonstrated that total mortality was a linear increasing function of high BFM and low FFM (*31*).

To execute this simple strategy in the form of individual-evaluation of body composition, many convenient BF% measurement techniques for field studies have been developed (*99*). For example, bioelectrical impedance analysis (BIA) as a new method, is readily applied and suitable (*29,45,97-103*). In contrast, skinfold thickness (SFT) measurements, a traditional method, can provide a reasonable assessment of body fat (*46,47,60,99,104-106*). Additionally, the investigation of Piers et al. (*78*) suggests that improved equation models for these methods can provide more accurate body composition determination. Kitano et al. compared three distinct protocols for evaluation of body composition: DXA, SFT and BIA (*107*). Their findings suggest that although different cutoff points are required to define high-BF% for each method, both SFT and BIA are suitable for population studies (*107*). This observation is consistent with our previous study: comparisons conducted between underwater weighing, SFT and BIA (*45*). It is suggested that a common cutoff point for women of 30% of BF% to degree of obesity would result in a different evaluation by SFT (*45*). The cutoff point to degree of obesity should be considered according to the method of measurement (*45*).

Interestingly, Himes suggested that associations between fatness and among anthropometric indicators (BMI, triceps-, subscapular- and sum of these SFT, and waist circumference) change further during the adult years (*97*). Friedle et al. also demonstrated that for women, anthropometry could provide better estimates of fatness than BMI; however, the approach remains relatively insensitive to short-term alterations in body composition (*108*). Based on these findings, estimation of body composition by anthropometric indicators appears difficult. For men, fat loss is well represented by a simple decrease in the abdominal girth measurement, even for the leanest men (*109*). However, for women, no equivalent single site of fat deposition that adequately represents fat loss exists; changes occur in the thighs, hips, abdomen and upper arms (*110*). Friedl et al. suggested that, for healthy young non-obese women, none of the equations tested were very accurate with respect to detection of changes in BF% after physical training (*108*). However, at the same time, they suggested that the circumference- and SFT-based equations are the most suitable equations tested for prediction of body fat (*108*).

In consideration of health risks, recent studies demonstrated that SFT measurements might complement other established measurements for predicting abnormal glucose and insulin regulation (*111,112*). Nakamura et al. also found that BMI and SFT were more relevant to the prediction of atherogenic risk factors than waist to hip ratio in 492 young adult (mean ± SD; 26.3 ± 3.9 years of age) Japanese women (*113*). These findings suggest that combination of anthropometric variables, rather than utility of a single variable, appears to afford a more reasonable indicator to estimate body composition and/or health risks. Van Itallie demonstrated the cross-classification of distribution of body weight and sum of triceps- and subscapular-SFT measurements based on the first National Health and Nutrition Examination Survey, 1971-74 (NHANES I), which generated data on both relative weight and relative fatness of the U.S. adult population (*114*). Similarly, a new model was revealed to estimate body density for contemporary young Japanese women by simple anthropometric data based on the sum of subscapular- and triceps-SFT and BMI (SFT+BMI model) (*46*). In comparison with underwater weighing, SFT+BMI model performance was highly correlated; moreover, no difference was detected in the mean values predicted by these methods equal to or greater than 25% of body fat subjects (*46*). It appears that the SFT+BMI model is suitable as a screening test for estimation of the degree of obesity in general population surveys, especially among younger Japanese (*46*).

Based on these findings, although body composition is measured by field methods (e.g., anthropometric measurements and BIA), beneficial information is provided with respect to prevention of chronic diseases. Moreover, development of *in vivo* methods applicable to the study of human body composition continues, in conjunction with more advanced reference models that utilize information obtained with these technologies (*115*). Thus, body composition should be measured in individual clinical management programs or in epidemiologic and clinical studies (*96*). For this reason, the following matter cannot be excluded: classification of an individual as lean, when in fact that individual is truly high-BF%, might place the individual at risk for disease associated with obesity and potentially delay possible beneficial therapy (*25*).

V. CONCLUSION

The main conclusions of this study can be summarized as follows:

1. BMI $\geq$ 25.0 kg/m^2 category is determined as positive-BF% for mass-evaluation as a result of quite high specificity.
2. BMI appears to be a valuable indicator of body fatness for mass-evaluation.
3. Body composition measurement is necessitated by individual-evaluation of body fatness focused on preventive medicine due to the poor representation of body composition by BMI in young Japanese women, especially among those individuals characterized by BMI < 25.0 kg/m^2.

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SUMMARY

Body weight, which consists of body fat mass (BFM) and fat free mass (FFM), is regulated by the balance between food consumption and energy expenditure. Conventionally, it is assumed that an excess body fat percentage (BF%) defines obesity. Numerous reports have shown that body mass index (BMI) is a reasonable indicator of fatness due to the definition of overweight (high-BMI) subjects as obese (high-BF%). This situation indicates that changes in body weight are a suitable reflection of alterations in BFM rather than in FFM. A decreasing BMI trend is evident among young Japanese women. However, previous studies suggest that the ratio of young high-BF% women, who are not screened by BMI cutoff point in Japanese ($\geq$ 25.0 kg/m^2), is increasing. This phenomenon is commonly observed in young Japanese and is referred to as "masked obesity". This observation indicates that not screened BMI often does not correlate with negative-BF%. Recently, classification of body weight based on BMI in adult Asians for the prevention of chronic diseases was proposed by the International Obesity Task Force. An "at risk of overweight" category, BMI of 23.0-24.9 kg/m^2, was added to the "in Japanese" classification.

The National Nutrition Survey of Japan indicated that the lifestyle of Japanese has been westernized, especially in the younger generation. Therefore, it is suggested that a 'Westernized lifestyle' induces peripheral insulin resistance and promotes the development of diabetes among Japanese. It appears significant that classification of an individual as lean, when in fact that individual is truly high-BF%, may put the individual at risk for diseases associated with obesity and potentially delay possible beneficial therapy.

Literature documenting the association between body composition and BMI is relatively sparse. In addition, the screening performance of "at risk of overweight" and classification of BMI of high-BF% individuals in young Japanese women are not found. Therefore, this study investigated the association between body composition and BMI in young Japanese women.

This investigation was conducted from 1994 to 1999. The subject population consisted of 605 female college students in Saitama prefecture. An underwater weighing approach was employed in order to measure BF%. Subject age (y), height (cm), body weight (kg), BMI and BF% expressed as the mean ± SD were 19.6 ± 0.5, 158.7 ± 5.6, 53.8 ± 7.2, 21.3 ±

2.4 and 24.9 ± 4.9, respectively. We defined positive-BF% as ≥ 85th percentile of BF% (29.8%). The results of this study can be summarized as follows:

1. Positive-BF% individuals are often not classified into BMI ≥ 23.0 kg/m^2 as their BMI readings are very broad (18.4-31.7).
2. The range of both 95% CI for prediction of BF% employing BMI and for BMI utilizing BF% were very broad (approximately 20 kg/m^2 and 15%, respectively).
3. The strongest relationship ($r = 0.573$) occurred in "obese" (BMI ≥ 25.0 kg/m^2). Additional significant correlations were also observed; however, correlations of "at risk of overweight" (BMI 23.0-24.9 kg/m^2) and "normal range" (BMI 18.5-22.9 kg/m^2) were low ($r = 0.331$ and 0.385, respectively).
4. Specificity of BMI ≥ 23.0 kg/m^2 was indicated as high (0.853) and Cohen's Kappa coefficient levels were nearly identical to BMI ≥ 25.0 kg/m^2. These findings are significant with respect to sensitivity of BMI ≥ 23.0 kg/m^2 indicating a 1.7-fold greater reading than that of BMI ≥ 25.0 kg/m^2 (0.521 and 0.298, respectively).
5. Positive-BF% individuals appearances increased with increased BMI class. However, false negative (positive-BF% and BMI < 23.0 kg/m^2) readings were observed in 47.9% of positive-BF% individuals.

6. This investigation supports the concept of an "at risk of overweight" (BMI 23.0-24.9 kg/m^2) category focused on preventive medicine as the "at risk of overweight" classification appears to be the threshold of increasing positive-BF% individuals appearance ratio within classified subjects.
7. Approximately 10% of individuals characterized by BMI of 18.5-22.9 kg/m^2 displayed false negative readings, which is the most important finding of the present investigation.

This investigation clearly illustrated that the BMI $\geq$ 25.0 kg/m^2 category is determined as positive-BF% for mass-evaluation. Therefore, BMI appears to be a valuable indicator of body fatness for mass-evaluation. Despite this conclusion, body composition measurement is necessitated by individual-evaluation of fatness focused on preventive medicine due to the poor representation of body composition by BMI among young Japanese women, especially where BMI $<$ 25.0 kg/m^2.