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Cross-Validation of BMI-Based Equations for Predicting Percent Body Fat in Female Collegiate Athletes

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ABSTRACT

Esco MR, Williford WN, Russell AR. Cross-Validation of BMI-Based Equations for Predicting Percent Body Fat in Female Collegiate Athletes. **JEPonline** 2011;14(3):43-52. The purpose of this study was to cross-validate three body mass index (BMI) based equations for predicting body fat percentage (BF%) in college-age female athletes. Seventy-five female athletes from the National Association for Intercollegiate Athletics participated in the study. Height and weight were taken for each subject to determine BMI. Three regression equations for estimating BF% based on BMI previously developed by Deurenberg et al. (DBMI-BF), Gallagher et al. (GBMI-BF), and Jackson et al. (JBMI-BF) were used in the study. Dual energy X-ray absorptiometry (DEXA) was used to obtain the criterion BF% values. The results showed no significant difference (P > 0.05) in mean BF% values between 2 of the BMI-based BF% (DBMI-BF = 27.7 ± 2.9%, JBMI-BF = 28.4 ± 4.7%) equations versus DEXA (27.7 ± 6.2%), while GBMI-BF (30.2 ± 4.7%) was significantly (P < 0.05) higher compared to the criterion. The standard error of estimate ranged from 4.53% to 4.82%, total error ranged from 4.67% to 5.41%, and the limits of agreement ranged from approximately 12.1% above to 9.4% below the DEXA BF% values for each equation. Due to the findings of this investigation, BMI-based BF% equations could potentially be utilized within a field setting to predict mean BF% for an entire group of female athletes, but would not be appropriate for predicting BF% for individuals. Thus, extreme caution must be taken when using the BMI-based BF% equations to estimate BF% for this population.

Key Words: Body Composition, Women, Dual X-Ray Absorptiometry

INTRODUCTION

Body mass index (BMI), also known as Quetelet's index, is the ratio of body weight to height. It has become the primary method to establish the standards for and to determine the prevalence of overweight and obesity (16,25). The advantage of using BMI is that it is easy to assess, as height and weight are the only variables needed, and there are minimal errors of measurement due to intra- or inter-observer variation. Body mass index is widely used to assess risk for developing health problems related to being overweight or underweight (1,16,25). For example, stroke, coronary artery disease, hypertension, and type 2 diabetes are among the problems associated with a high BMI (1,16,25), while menstrual dysfunction, low bone mineral density, and eating disorders are among the problems associated with an extremely low BMI (17). Due to the negative consequences of extremely low or high BMI values, the World Health Organization (25) and the National Institute of Health (16) have established cut-points based on BMI for underweight (BMI < 18.5 $kg \cdot m^{-2}$), normal weight (BMI between 18.5 to 24.9 $kg \cdot m^{-2}$), overweight (BMI between 25 to 29.9 $kg \cdot m^{-2}$), and obesity (BMI $\geq$ 30 $kg \cdot m^{-2}$).

A disadvantage of BMI is that it does not distinguish between fat tissue and lean body mass. Athletic individuals usually have lower body fat percentage (BF%) and greater muscle mass compared to the general population. At any given BMI, an athlete could have a lower BF% compared to a non-athlete (19). Thus, BMI often misclassifies athletes of normal BF% as being overweight (12,18,19,24). For this reason, BMI does not appear to be an appropriate substitute for BF% when determining an athlete's body composition. Strength and conditioning specialists, sports nutritionists, and coaches commonly rely on quick, inexpensive field techniques, such as skinfold thickness measurements or bioelectrical impedance analysis to estimate BF% in athletic groups (2,7,8,10,13).

In this regard, there have been several regression equations developed that are based on BMI that provide a reasonable estimate for BF% in the general population (6,9,11). The BMI-BF% equations can be attractive methods for estimating BF% in an athletic field setting because they can easily be performed within large groups, since height and weight are the primary variables that need to be measured. However, the data on the accuracy of BMI-based BF% equations for determining BF% specifically for college-age female athletes is limited. Therefore, the purpose of this study was to cross-validate three BMI-based BF% equations (6,9,11) for estimating BF% in collegiate female athletes using the dual energy X-ray absorptiometry (DEXA) as the criterion. Since BMI alone (i.e., when not used in a regression model) often misclassifies athletes of normal BF% as being overweight (18,19,24), it was hypothesized that the BMI-based BF% equations would not be accurate for estimating BF% in this cohort.

METHODS

Subjects

Seventy-five female athletes from the National Association for Intercollegiate Athletics participated in the study and provided written informed consent. The athletes were recruited from the basketball, soccer, tennis, and softball teams at Auburn University Montgomery, Montgomery, AL. Descriptive statistics for the participants are represented in Table 1. Each subject completed a health history questionnaire. Those who were apparently healthy, free from cardiopulmonary, metabolic, and/or orthopedic disorders, and not pregnant were included in the data collection process. Data were collected from 7:00 to 11:00 a.m. during any day of the week. The subjects were instructed to not eat or drink for at least 12 hours before testing, and to not exercise or consume alcohol 24 hours prior to the testing. This study was approved by the Institutional Review Board for Human Subjects.

Procedures

Height was measured with a wall-mounted stadiometer (SECA). The subjects stood erect, without shoes, and with their hands to their sides. All values for height were rounded to the nearest 0.1 cm. Body weight was measured to the nearest 0.1 kg with a calibrated digital scale (TANITA BWB-800A). The subjects were measured while wearing light clothing without shoes. Body mass index was calculated as weight (kg) divided by height (m^2). All values for BMI were rounded to the nearest 0.1 $kg \cdot m^{-2}$. Body fat percentage was predicted by using the following three previously developed BMI-based regression equations: Deurenberg et al. (6) (DBMI-BF); Gallagher et al. (9) (GBMI-BF); and Jackson et al. (11) (JBMI-BF). Please refer to Table 2 for the actual equations.

Table 1. Descriptive statistics for the study's participants (n = 75).

	Mean ± SD
Age (yrs)	**20.7 ± 2.3**
Height (cm)	**166.4 ± 6.8**
Weight (kg)	**65.7 ± 8.5**
BMI ($kg \cdot m^{-2}$)	**23.7 ± 2.5**

BMI = Body Mass Index

Table 2. BMI-based BF% regression equations that were cross-validated within the study.

Study	Abbreviation	Equation
Variable 1	**JBMI-BF**	BF% = (4.35 × BMI) – (0.05 × BMI2) – 46.24
Variable 2	**GBMI-BF**	BF% = 76.0 – (1097.8 × [1/BMI]) – (20.6 × sex) + (0.053 × age) + (95.0 × Asian × [1/BMI]) – (0.044 × Asian × age) + (154 × sex × [1/BMI]) + (0.034 × sex × age); sex = 1 for male and 0 for female; Asian = 1 for Asians and 0 for the other races
Variable 3	**DBMI-BF**	BF% = (1.20 × BMI) + (0.23 × age) – (10.8 × sex) – 5.4; sex = 1 for male and 0 for female.

Dual energy X-ray absorptiometry was chosen as the criterion variable due to its ability to assess bone mineral density, which can vary in a female athletic population (4,15,23). The DEXA machine that was used in this study was a GE Lunar Prodigy (Software version 10.50.086, GE Lunar Corporation, Madison, WI), which was previously compared with another GE Lunar Prodigy and a strong correlation was found (r = .99). Before each testing day the DEXA was calibrated using the manufacturer's standard calibration block. Subjects wore clothing (T-shirt and shorts) without metal and were required to remove metal objects from their body, as well as their shoes before each scan. During the DEXA screenings, the subjects laid supine with their arms by the sides and knees and ankles held together with Velcro straps.

Statistical Analyses

A repeated measures analysis of variance (ANOVA) was performed to determine the difference between DEXA obtained BF%, and the three BMI-based BF% equations (i.e., JBMI-BF, GBMI-BF, DBMI-BF). A Bonferroni post hoc analysis was used as a follow-up to further examine group differences in the BF% values. Bland-Altman plots were also formed to identify the limits of agreement between the criterion and predicted values (3). Pearson product correlation coefficient, constant error (CE), standard error of estimate (SEE), and total error (TE) were also calculated for the three prediction equations. A priori statistical significance was set at $P < 0.05$, except for the

Bonferroni Post hoc analysis which was adjusted to P < 0.008. All statistical analysis was completed using SPSS version 16.0.

RESULTS

There were no significant differences in body fat percentage between the four sports. Thus, the subjects were analyzed as an entire group. Table 3 represents the validity statistics for predicting BF% via the BMI-BF% regression equations compared to the DEXA. According to the repeated measures ANOVA, there was a significant difference in the BF% values between the DEXA and BMI-based BF% equations (P < 0.05). Follow-up analysis showed that there was no significant difference between the mean criterion measure (DEXA) and JBMI-BF and DBMI-BF (P > 0.008). However, estimated BF% from GBMI-BF was significantly higher compared to the DEXA (P < 0.008). Thus, the CE statistic was only significantly different with GBMI-BF compared to the criterion. Similar values were found for the r, SEE, and TE between the three BMI-BF% regression equations (Table 3).

Table 3. Validation for predicting body fat % via the BMI-BF regression equations compared to the DEXA (n = 75).

Method	Mean ± SD	r	SEE	TE	CE ± 2 SD
DEXA (Criterion)	27.7 ± 6.2%	-	-	-	-
DBMI-BF	27.7 ± 2.9%	0.69†	4.53	4.67	-0.01 ± 9.40
GBMI-BF	30.2 ± 4.7%*	0.64†	4.82	5.41	-2.48 ± 9.66
JBMI-BF	28.4 ± 4.7%	0.65†	4.75	4.76	-0.66 ± 9.50

DEXA = Dual energy X-ray absorptiometry; DBMI-BF = BMI-BF% regression equation from Deurenberg et al. (6); GBMI-BF = BMI-BF% regression equation from Gallagher et al. (10); JBMI-BF = BMI-BF% regression equation from Jackson et al. (13); r = Pearson product-moment correlation coefficient; SEE = standard error of estimate; TE = total error; CE = constant error/bias. *Significantly different from DEXA, P < 0.008. †Significant correlation to the DEXA, P < 0.05.

Bland Altman plots exploring for individual differences between the criterion and prediction BF% values are shown in Figures 1-3. The mean bias predicted for the JBMI-BF was -0.1% and the ± 1.96 SD ranged from -10.3% to 8.9% (Figure 1). The mean bias for the GBMI-BF was the largest at -2.5% and ranging (± 1.96 SD) from -12.1% to 7.1% (Figure 2). The mean bias for DBMI-BF was the lowest at 0.0% and ranging (± 1.96 SD) from -9.4% to 9.4% (Figure 3).

DISCUSSION

Due to athletes typically having higher muscle masses at any given BMI compared to non-athletes (19), our hypothesis was that the BMI-based BF% equations would not be an accurate technique when compared to DEXA for estimating BF% in female athletes. The DBMI-BF, GBMI-BF, and JBMI-BF equations were established by Deurenberg et al. (6), Gallagher et al. (9), Jackson et al. (11), respectively and were validated in large samples from the general adult population. These studies showed that when compared to criterion values of DEXA (9) and hydrostatic weighing (6,11), there were no mean differences reported with the BMI-based equations for estimating BF% in the general population.

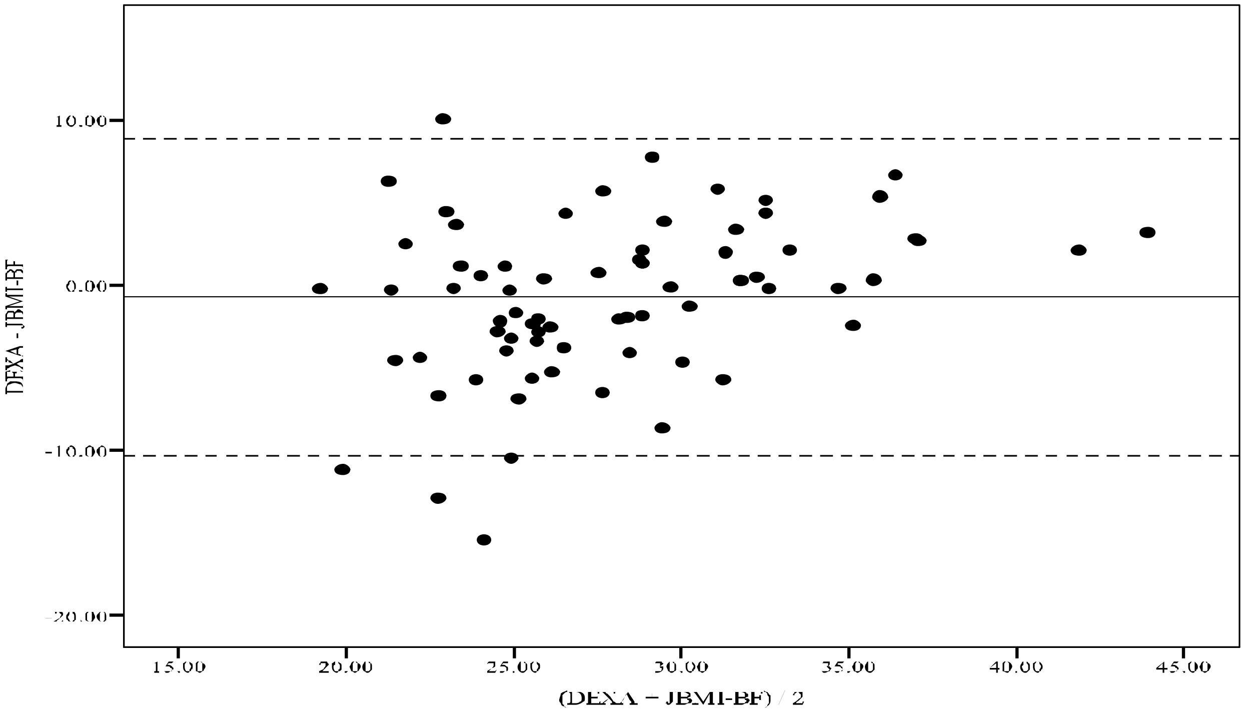

Figure 1. Bland Altman plot comparing the BF% estimated by JBMI-BF with the criterion value (DEXA). The middle line indicates the mean difference between predicted and the actual BF% values; the two outside dashed lines indicate the ± 1.96 SD of the difference.

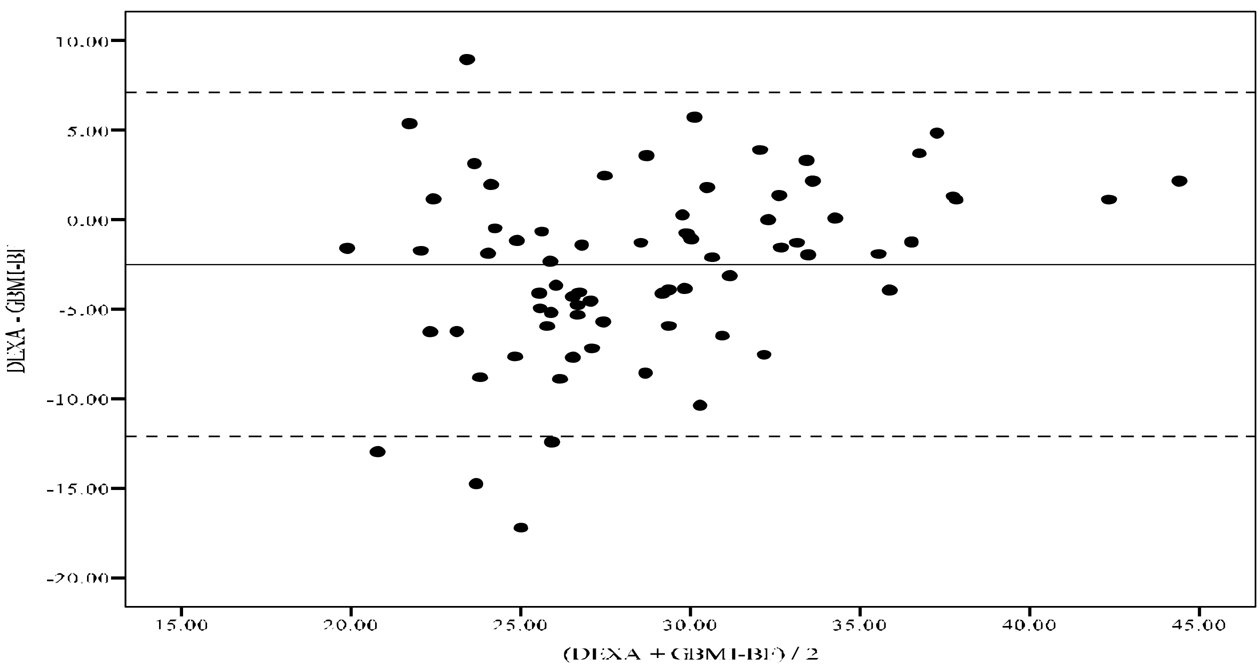

Figure 2. Bland Altman plot comparing the BF% estimated by GBMI-BF with the criterion value (DEXA). The middle line indicates the mean difference between predicted and the actual BF% values; the two outside dashed lines indicate the ± 1.96 SD of the difference.

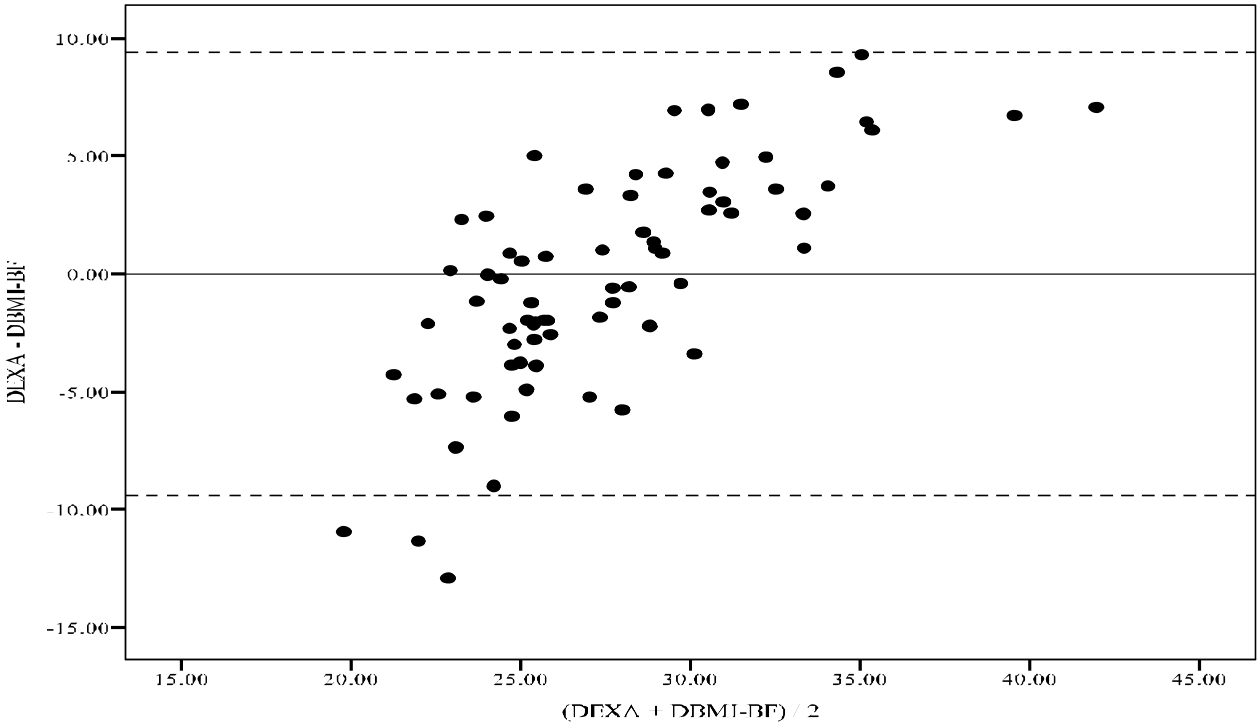

Figure 3. Bland Altman plot comparing the BF% estimated by DBMI-BF with the criterion value (DEXA). The middle line indicates the mean difference between predicted and the actual BF% values; the two outside dashed lines indicate the ± 1.96 SD of the difference.

Our results were similar, showing that there was either no (i.e., JBMI-BF and DBMI-BF) or little (i.e., GBMI-BF) significant difference in the mean BF% values between the DEXA and the BMI-based BF% equations across the entire cohort of female athletes. The CE/bias was only significantly different between the GBMI-BF and the DEXA. Thus, the BMI-equations of JBMI-BF and DBMI-BF may be acceptable when obtaining a mean BF% for an entire group of female athletes. However, the SEE and TE values were rather large for each of the three regression equations (ranging from 4.53 to 4.82% and 4.67 to 5.41%, respectively). Furthermore, the limits of agreement between the prediction and criterion values were also large, which is obvious when examining Figures 1-3. The Bland-Altman Plots showed that JBMI-BF may be 10.3% above to 8.9% below the DEXA, the GBMI-BF may be 12.1% above to 7.1% below the DEXA, and the DBMI-BF may be 9.4% above to 9.4% below the DEXA. It appears that when used to assess individual BF%, the BMI-equations could grossly misclassify those with healthy BF% as being overfat, or those who are actually overfat as healthy. Therefore, the use of the BMI-based equations for estimating individual BF% for female athletes is unacceptable and not recommended.

Athletes have been shown to have significantly lower levels of BF% compared to non-athletes of the same BMI (19,24). In a large sample of male and female collegiate athletes, BMI alone (i.e., when not utilized in a BF% prediction model) frequently misclassified the subjects who have high muscle masses but low skinfold thickness measurements as being overweight (24). Nevill and colleagues (18) reported similar findings, showing that at any given BMI athletes had lower skinfold thickness compared to non-athletic counterparts. In a study by Ode et al. (19) the BMI/BF% cut-points established by Gallagher et al. (9) have been shown to classify 31% of female athletes with a normal BF% (i.e., BF% < 33%) as being overweight (i.e., BMI $\geq$ 25 $kg \cdot m^{-2}$) compared to only 7% of the non-athletic females. Furthermore, 77% of female athletes with a BMI greater than 25 $kg \cdot m^{-2}$ were classified as normal weight (19). Thus, it is doubtful that BMI used alone accurately represents adiposity in lean athletes.

Other studies have cross-validated BMI-BF% equation within a general population. Compared to hydrostatic weighing, the BMI-BF% of Deurenburg et al. (6) significantly underestimated BF% by 3.4% in young-adult female subjects (21). Another study compared the same equation to the criterion measures of DEXA and hydrostatic weighing (5). The authors concluded that BF% predicted from BMI is valid at a population level (5). However, the SEE and the limits of agreement between the BMI-BF% equation and the criterion measures for females in their study (5) were similar to the current study.

The results of the current study suggests considerable variation in actual BF% at any given BMI-predicted BF%. Athletes typically have larger muscle masses compared to the general, non-athletic population. A muscular female athlete could have a high BMI, even though her actual BF% may be low. In this case, any BMI-based BF% equation would greatly over-estimate BF%. Thus, this study suggests that many female athletes will be misclassified as over fat/overweight when BMI is used as a surrogate to actual BF%, which is congruent with previous research that examined BMI alone (19,20). These equations should not be used as a predictor of individual BF% in female athletes.

The use of DEXA as the criterion variable may be considered a limitation within the study. We chose DEXA as the criterion because it has been previously suggested to be appropriate for body composition research involving female athletes due to the variation in bone mineral density (23). However, current research advocates multi-compartment modeling as the criterion method in validation studies. Moon et al. (14) compared DEXA, hydrostatic weighing, and air displacement plethysmography to a multi-compartment model in NCAA Division I female athletes. Their results showed that DEXA resulted in the largest constant error (-3.71%), the largest total error (4.90%), and had the greatest limits of agreement (-10.10 to 2.68%) (14). More research is warranted to compare BMI-based BF% regression equations to multi-compartment BF% models in female athletes, as well as in other populations.

CONCLUSIONS

The current investigation sought to determine if BMI-based BF% equations were accurate means for determining BF% in female athletes. Our findings showed either no significant difference (JBMI-BF, DBMI-BF) or only a slight significant difference (GBMI-BF) when comparing the group means between the BMI-equations and the criterion measure of DEXA. Thus, for estimating BF% for an entire group of athletes (i.e., when estimating the average BF% of an athletic team), the three equations that were examined in this study are acceptable to use. However, due to the large TE, SEE, and limits of agreement, these equations are not recommended for use when estimating BF% for individual female athletes. The results showed that each equation provides values well above or below the criterion BF% measure. Thus, the utility of the BMI-based BF% equations for estimating individual BF% for this population should be used with extreme caution or not at all. Since female athletes are at increased risk of eating and body image disorders (17,22), misclassifying subjects as being overweight or underweight could have considerable health hazards.

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