Usefulness of relative fat mass in estimating body adiposity in Korean adult population

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Abstract. Various indicators have been suggested as replacements of body mass index (BMI) for estimating body fat percentage, including the recently introduced relative fat mass (RFM). However, RFM has not been assessed in different ethnicities; therefore, we evaluated whether RFM can be used to estimate body fat percentage in Korean adults and whether RFM is a useful indicator of obesity. Based on the Korea National Health and Nutrition Examination Survey (KNHANES) 2008–2011, we analyzed a total of 18,706 individuals (7,970 men, 10,643 women) aged ≥20 years who underwent dual-energy X-ray absorptiometry. We compared obesity (body fat ≥25% for men, 35% for women) misclassification rate of RFM (≥25 for men, 35 for women) and BMI (≥25 kg/m²). Diagnostic accuracy and optimal cut-offs of BMI and RFM were verified by comparing area under the receiver operating characteristic curve (AUC). RFM and BMI misclassification rates were similar obesity diagnosis based on body fat percentage (27.9% vs. 27.8%) among men. RFM misclassification rate was lower than that of BMI (22% vs. 45%) in women. AUC of RFM was higher in men (AUC: 0.79 vs. 0.78; p = 0.004) and lower in women (AUC: 0.80 vs. 0.83) than those of BMI (p < 0.001). In this study, RFM showed diagnostic accuracy for detecting excess body fat percentage, comparable to that of BMI. Using RFM with BMI could be beneficial in improving the diagnostic accuracy of obesity assessment in women.

Key words: Relative fat mass, Adiposity, Body mass index, Obesity

OBESITY, defined as excess body fat, is a global public health concern as it is associated with major risk factors for cardiovascular disease, certain types of cancer, and mortality in the general population [1-3]. Body fat percentage is theoretically a better index for evaluating excess body adiposity than BMI, but most assessments of obesity for health are based on BMI-defined obesity. As several sophisticated techniques for measuring body composition are not feasible for routine clinical purposes, numerous simplified indexes have been suggested as alternatives to BMI, to better estimate body fat percentage. Other anthropometric indexes, including waist circumference (WC), waist-to-hip ratio, and waist-to-height ratio (WHtR), can provide supplemental information regarding body adiposity [4].

Accurate body fat measurement and diagnosis of obesity is integral to providing effective treatment for people at risk. However, BMI has limited diagnostic accuracy for body fat measurements according to age and sex [5, 6]. Recently, Woolcott et al. [7] suggested that the relative fat mass (RFM) equation, which is based on the height-to-WC ratio, is more accurate than BMI to estimate body fat percentage. However, RFM was developed among American adults of Mexican, European, or African ethnicity; therefore, the RFM needs to be validated in other ethnic groups. Thus, the purpose of the present study was to validate the diagnostic performance of RFM as an indicator, based on body fat percentage in Korean adults.

Materials and Methods

Participants

This study included data of the Korea National Health and Nutritional Examination Survey (KNHANES) IV and V (2008–2011), a nationwide, cross-sectional survey representing the noninstitutionalized civilian population in South Korea, conducted by the Korea Centers for Disease Control and Prevention. Participants in the KNHANES underwent dual-energy X-ray absorptiometry (DXA) from July 2008 through May 2011. Among the 37,753 participants in the KNHANES 2008–2011, a total 18,706 individuals aged ≥20 years underwent DXA. We excluded pregnant women and those missing anthropometric measurements; overall, 91 participants were excluded from the study due to missing anthropometric...
data. One person was excluded because their reported weight (138.9 kg) exceeded the weight limit of the DXA scanner (136 kg). Another participant had an exceptionally large WC (WC 166.1 cm, height 166.4 cm, body weight 68.9 kg), which was considered an error; the individual was excluded from analysis. After all exclusions, 18,613 subjects were finally included in the analysis.

**Demographics and anthropometric measurements**

Health examinations and interview surveys were performed by trained and certified staff, according to the KNHANES protocol. Participants reported their demographic characteristics and medical history via face-to-face interviews. Standardized techniques and equipment were used to measure all anthropometric indices, and health examinations were performed in mobile examination centers. Height was measured to the nearest 0.1 cm using a stadiometer (seca 225; seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kg using a balance beam scale (GL-6000-20; G-TECH, Seoul, Korea) with participants wearing light clothing. WC was measured to nearest 0.1 cm at the midpoint between the lower border of the rib cage and the iliac crest, using a tape measure (seca 200). BMI was calculated as weight/height$^2$ (kg/m$^2$). The RFM equation is calculated as RFM = 64 − (20 × (height/WC)) + (12 × sex), where sex = 0 for men and 1 for women.

**DXA measurements**

In the KNHANES, body composition was assessed using a DXA scanner (QDR4500A; Hologic, Inc., Bedford, MA, USA), in accordance with the manufacturer’s acquisition procedures. The results of DXA scans were analyzed using industry standard techniques with Hologic Discovery software (version 13.1). All subjects changed into light clothing and removed all jewelry and anything else that could interfere with the results. DXA measurements included fat mass (g), fat-free mass (g), and fat percentage of the whole body (%).

**Definition of obesity**

All subjects were classified as underweight (<18.5 kg/m$^2$), normal weight (18.5–22.9 kg/m$^2$), overweight (23.0–24.9 kg/m$^2$), or obese (≥25 kg/m$^2$), according to the World Health Organization (WHO) recommended BMI cut-off values for the Asia-Pacific region [8]. Obesity, diagnosed based on body fat percentage, was defined as having body fat ≥25% for men and 35% for women [9]. This is close to the results of several studies to determine the cut-offs of body fat percentage which can predict the risk of cardiovascular disease among East Asian population (24–25.7% for men and 33–36% for women) [10-12].

**Statistical analyses**

Baseline and anthropometric characteristics are presented as mean and standard deviation for all continuous variables, and frequency and percentage for categorical variables. Due to known differences in body composition, all analyses were stratified by sex. The sex differences of measured variables were determined using an independent $t$-test. The coefficient of determination ($R^2$) was computed using a linear regression model to estimate the goodness-of-fit of the line for BMI and RFM to whole body fat percentage. We graphically examined the performance of BMI and RFM to measure body fat percentage using the Bland–Altman method. The diagnostic accuracy of BMI and RFM was evaluated by comparing sensitivity, specificity, positive and negative predictive values, and misclassification rate. Receiver operating characteristic (ROC) analysis [13] was used to determine the percentage of area under the ROC curve (AUC). The appropriate cut-off points of BMI and RFM, considering body fat percentage-defined obesity, were determined using the Youden index [14] (maximum value of (sensitivity + specificity − 1)). SPSS version 19.0 (SPSS Inc., Chicago, IL, USA) was used for all analyses. A two-tailed $p$-value <0.05 was considered statistically significant.

**Ethics statement**

This study was approved by the institutional review board of S hospital in Seoul, Korea (approval ID: SGPAIK 2018-11-025). All subjects signed an informed consent form.

**Results**

In this study, the final analysis included 7,970 men and 10,643 women (Table 1). Of these, 36.0% of men and 29.4% of women were classified as obese based on BMI. A total 30.5% of men and 37.2% of women were defined as obese based on body fat percentage. Using the same RFM cut-offs as for body fat percentage, 39.8% of men and 57.5% of women were obese.

Fig. 1 shows the performance of BMI and RFM for estimating body fat percentage in the KNHANES population. The linear regression model for BMI explained 39% and 46.1% of the variance for body fat percentage in men and women, respectively. The linear regression model for RFM explained 44.2% and 38.1% in men and women, respectively. In the Bland–Altman plots (Fig. 2), the RFM tended to overestimate body fat percentage by a mean 1.32% (95% limits of agreement: ±8.11%) in men and 2.63% (95% limits of agreement: ±9.47%) in women.

In men, BMI and RFM were similar in overall diagnostic performance; in women, however, the misclassifi-
cation rate of RFM was lower than that of BMI across all age groups (Table 2). In the age group ≥60 years, RFM had very high sensitivity but poor specificity (99.4% sensitivity and 11.3% specificity). The AUCs for BMI and RFM to detect values of body fat percentage for obesity in men and women are presented in Fig. 3. The diagnostic accuracy of RFM for obesity was better than that of BMI in men (AUC: 0.79 vs. 0.78; p = 0.004) and inferior to that of BMI in women (AUC: 0.80 vs. 0.83; p < 0.001).

Table 1  Baseline characteristics of 18,163 study participants from the KNHANES 2008–2011

| Age group (yr) | Total (N = 18,613) | Men (N = 7,970) | Women (N = 10,643) | p-value |
|---------------|-------------------|----------------|--------------------|---------|
| 20–39         | 49.9 ± 16.2       | 49.8 ± 16.1    | 49.9 ± 16.3        | 0.464   |
| 40–59         | 5,817 (31.3)     | 2,495 (31.3)   | 3,322 (31.2)       |         |
| ≥60           | 5,768 (31.0)     | 2,479 (31.1)   | 3,289 (30.9)       |         |

Height (cm) 162.0 ± 9.3 169.5 ± 6.6 156.3 ± 6.6 <0.001
Weight (kg) 62.2 ± 11.4 68.9 ± 10.8 57.1 ± 9.0 <0.001
Waist circumference (cm) 81.2 ± 9.9 84.4 ± 8.9 78.8 ± 10.0 <0.001
BMI (kg/m²) 23.6 ± 3.3 23.9 ± 3.1 23.4 ± 3.5 <0.001
<18.5 830 (4.5) 261 (3.3) 569 (5.3)
18.5–22.9 7,430 (39.9) 2,802 (35.2) 4,628 (43.5)
23–24.9 4,362 (23.4) 2,040 (25.6) 2,322 (21.8)
≥25 5,991 (32.2) 2,867 (36.0) 3,124 (29.4)
RFM 30.4 ± 7.9 23.4 ± 4.5 35.6 ± 5.5 <0.001
Whole-body fat percentage (%) 28.3 ± 7.7 22.1 ± 5.4 33.0 ± 5.5 <0.001
Whole-body fat mass (kg) 17.4 ± 5.7 15.4 ± 5.4 19.0 ± 5.5 <0.001
Whole-body fat free mass (kg) 44.2 ± 9.5 52.9 ± 7.1 37.7 ± 4.8 <0.001
Trunk fat percentage (%) 29.5 ± 8.3 24.4 ± 6.8 33.3 ± 7.3 <0.001

Variables are presented as mean ± standard deviation or number (%). Abbreviations: BMI, body mass index; RFM, relative fat mass; p-value from an independent-sample t-test for continuous variables.

Table 2  Diagnostic accuracy of BMI (≥25 kg/m²) and RFM (≥25 for men and 35 for women) to assess body fat percentage-defined obesity (≥25% for men and 35% for women)

| Age group (yr) | BMI | RFM |
|---------------|-----|-----|
|               | Sen (%) | Spe (%) | PPV (%) | NPV (%) | Mis (%) | Sen (%) | Spe (%) | PPV (%) | NPV (%) | Mis (%) |
| Men Total     | 63.4 | 76.0 | 53.7 | 82.6 | 27.8 | 69.6 | 73.3 | 53.3 | 84.6 | 27.9 |
| 20–39         | 69.2 | 78.3 | 58.4 | 85.2 | 24.5 | 55.6 | 89.3 | 69.5 | 82.1 | 21.0 |
| 40–59         | 67.3 | 68.5 | 44.7 | 84.7 | 31.8 | 70.9 | 68.2 | 45.8 | 86.1 | 31.0 |
| ≥60           | 54.4 | 83.7 | 63.2 | 78.0 | 26.3 | 80.8 | 63.1 | 53.0 | 86.4 | 30.9 |

Women Total 39.2 96.5 96.7 37.6 45.0 92.6 39.4 80.1 67.0 22.0
20–39 27.1 98.8 97.2 46.0 45.2 79.4 64.2 77.9 66.2 26.5
40–59 39.8 94.5 95.8 33.1 47.1 95.7 26.4 80.5 65.8 21.0
≥60 47.9 95.2 97.4 32.3 42.3 99.4 11.3 81.1 83.7 18.8

Abbreviations: BMI, body mass index; RFM, relative fat mass; Sen, sensitivity; Spe, specificity; PPV, positive predictive value; NPV, negative predictive value; Mis, misclassification rate
In the present study, we used data obtained from the KNHANES, a large nationally representative sample of the Korean adult population and showed that RFM could be applied to evaluate body fat percentage. To our knowledge, this is the first study to evaluate the performance of RFM in an Asian population. Woolcott et al. [7], the original developers of the RFM equation, found that RFM had a more linear relationship with body fat percentage than BMI among men and women across ethnic groups, including Mexican-Americans, European-Americans, and African-Americans. In this study, however, RFM showed a better linear relationship with body fat percentage than BMI in men only. From our Bland–Altman plot, we observed that RFM overestimated the body fat percentage, but it was similar to the estimates using BMI. In addition, the 95% limits of agreement between RFM and body fat percentage (men: ±8.11%, women: ±9.47%) were greater than those previously reported (men: ±6%, women: ±8%). These differences may be the result of limitations owing to non-inclusion

**Discussion**

In the present study, we used data obtained from the KNHANES, a large nationally representative sample of the Korean adult population and showed that RFM could be applied to evaluate body fat percentage. To our knowledge, this is the first study to evaluate the performance of RFM in an Asian population. Woolcott et al. [7], the original developers of the RFM equation, found that RFM had a more linear relationship with body fat percentage than BMI among men and women across ethnic groups, including Mexican-Americans, European-Americans, and African-Americans. In this study, however, RFM showed a better linear relationship with body fat percentage than BMI in men only. From our Bland–Altman plot, we observed that RFM overestimated the body fat percentage, but it was similar to the estimates using BMI. In addition, the 95% limits of agreement between RFM and body fat percentage (men: ±8.11%, women: ±9.47%) were greater than those previously reported (men: ±6%, women: ±8%). These differences may be the result of limitations owing to non-inclusion

![Fig. 1](image1.png)  
Regression line with $R^2$ of whole-body fat percentage measured with DXA and estimated using BMI and RFM among participants in the KNHANES 2008–2011 and by sex. $R^2$, coefficient of determination; DXA, dual energy X-ray absorptiometry; BMI, body mass index; RFM, relative fat mass.

![Fig. 2](image2.png)  
Bland–Altman plots between body fat percentage measured with DXA and estimate using the RFM equation among participants in the KNHANES 2008–2011 and by sex. Red bold lines represent the mean. Blue dotted lines indicate 95% limits of agreement. DXA, dual energy X-ray absorptiometry.
of Asian populations when developing the RFM equation. The differences in the body composition is age-, gender- and ethnicity-dependent. Many scientific reports showed that Asians had a higher body fat percentage at a lower BMI compared to Caucasians [15, 16]. The mean body fat percentage in our subjects (men: 22.1%, women: 33.0%) was lower than that observed in the RFM equation development dataset (men: 28.0%, women: 39.9%). DXA tends to underestimate body fat percentage in leaner individuals [17]; this might be another reason RFM did not perform well in our study population.

The most important factor in determining the clinical usefulness of RFM as an alternative to BMI is the diagnostic accuracy of obesity. Woolcott et al. [7] showed that RFM was superior to BMI in diagnostic accuracy for obesity among men, women, and across ethnic groups. In the present study, the obesity misclassification rate of RFM was similar to that of BMI in men (27.9% vs. 27.8%) and it was significantly lower than that of BMI among women (22% vs. 45%). In particular, the misclassification rate of BMI was high in middle-aged adults, the main target of cardiovascular risk screening, which is similar to the results of Yoon et al. [6]. Based on the currently used clinical cut-off of BMI, the diagnostic performance of RFM seems superior to that of BMI in women, suggesting that RFM can replace or supplement BMI in women. However, if we assume the cut-off based on the ROC curve, the diagnostic accuracy of RFM was not superior to that of BMI.

In choosing whether to adopt RFM as a new index or whether to redefine the proper criteria for BMI, it should be considered whether measuring body weight or WC is more convenient and which indicators can better predict the risk of disease associated with obesity. Measuring WC in a busy medical practice is not easier than measuring body weight and requires professional training to obtain reliable results. Although WC is known to be an important predictor of risk factors for cardiovascular disease [18, 19], many clinicians do not routinely measure WC in practice.

The RFM equation is based on height/WC, and its inverse, the WHtR, is widely used as a tool to predict cardiovascular disease. In this context, RFM not entirely new. Ashwell et al. [20-22] suggested that the WHtR is more predictive than BMI as early indicator of health risks associated with obesity; that author also indicated that the optimal WHtR cut-off value is 0.5 for children and adults in different ethnic groups. When we put in this value into the RFM equation, it becomes 24 in man and 36 in women, similar to the references for body fat percentage-defined obesity. Compared with WHtR, RFM could estimate the body fat percentage as an intuitive value, which would have clinical usefulness.

The strengths of the current study are that the KNHANES dataset is one of largest that includes DXA-derived body composition and is representative of the Korean population. However, our study is not without limitations. We used DXA as a reference method, but the currently accepted “gold standard” is the four-compartment model [23]. However, as the DXA scanner (QDR4500A) was the same as that used by Woolcott et al. [7], there are no concerns with respect to evaluating the validity of RFM. Another limitation of our study is that it was difficult to directly compare misclassification rates because we used different criteria than Woolcott et
al. to classify obesity according to body fat percentage. In that previous study, the authors used arbitrary cut-offs by quintiles (≥22.8% for men and 33.9% for women) whereas we used body fat percentage cut-offs, which are currently used in clinical practice (≥25% for men and 35% for women). In addition, the criteria for obesity based on BMI were also different to those in Western countries (≥30 kg/m²); we used WHO-recommended BMI cut-offs for the Asia-Pacific region (≥25 kg/m²).

In summary, we can conclude that the accuracy of RFM for estimating adiposity in Korean adults is comparable to that of BMI. Based on the current clinically relevant cut-offs for obesity, RFM has a lower misclassification rate than BMI in women. The use of RFM together with BMI to provide additional information when assessing obesity in women could improve diagnostic accuracy. The current study only assessed RFM as a useful estimator of body fat percentage; therefore, prospective studies are needed to determine whether RFM is superior in predicting health risk associated with obesity, in comparison with existing indicators such as BMI, WC, or WHtR.

Acknowledgments

The authors thank the Korea Centers for Disease Control and Prevention, who performed the KNHANES.

Disclosure

There are no known conflicts of interest associated with this publication and research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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