Body Adiposity Index and Metabolic Syndrome Risk Factors in Korean Adults: A Comparison with Body Mass Index and Other Parameters

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A new body adiposity index (BAI) has been proposed that is expected to replace body mass index (BMI). We evaluated the correlations between metabolic syndrome risk factors and BAI, BMI, and other adiposity indices, such as waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR), by sex in the Korean population. We also evaluated whether BAI would be useful to diagnose metabolic syndrome. A total of 20,961 Korean adults who underwent health examinations were included in this study. The metabolic syndrome diagnostic criteria used in this study were those set by the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI). In men (12,719), BMI and WHtR were more strongly correlated to metabolic syndrome risk than BAI, and in women (8,242), WHtR showed the strongest association with metabolic syndrome risk. BAI (area under the curve [AUC] = 0.678) presented lower discriminatory capacity than that of BMI (AUC = 0.836) for diagnosing metabolic syndrome. Moreover, BAI underestimated fat levels in men and women when considering the ability to discriminate overweight and obese individuals. In conclusion, WHtR and BMI in men, and WHtR in women may be better candidates than BAI to evaluate metabolic risk factors in Korean adults.

Key Words: Body adiposity index, Body mass index, Metabolic syndrome, Obesity, Korean

INTRODUCTION

Obesity is a risk factor for many chronic diseases and has become a serious health problem worldwide. Obesity also accompanies metabolic abnormalities, such as hypertension, insulin resistance syndrome, hyperglycemia, and dyslipidemia (Björntorp et al., 1991; Grundy et al., 2005; Villareal et al., 2005; Kang et al., 2016). Body mass index (BMI) has been used as a measure of adiposity but is considered rather inaccurate (Jackson et al., 2002; Garrido-Chamorro et al., 2009; Camhi et al., 2011). A new adiposity index called body adiposity index (BAI) has been purposed as a substitute for BMI. BAI measures body fat using height and hip circumference (HC) but not weight (Bergman et al., 2011). HC reflects sex differences very well
when used to measure adiposity, and BAI reflects adiposity more than that of BMI, which does not consider differences between men and women (Bergman et al., 2011; López et al., 2012). In addition, BAI is related to cardiovascular disease risk factors, but BMI is a better index than BAI when cardiovascular disease risk is determined (Lichtash et al., 2013). BAI is useful in many ethnic groups, but not Asians. Therefore, this study examined the relationships between metabolic syndrome risk factors by sex and adiposity indices, including BAI and BMI, in Korean adults. We also evaluated the utility of BAI and BMI for diagnosing metabolic syndrome.

The aim of this study was to evaluate the correlations between metabolic syndrome risk factors and BAI, BMI, and other adiposity indices, such as waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) by sex in Korean adults.

MATERIALS AND METHODS

Study subjects

This study was carried out on 20,961 Korean adults (age, 20~79 years) who underwent health examinations at J General Hospital, Gyeonggi province, South Korea from January 2010 through December 2012. Metabolic syndrome was diagnosed using the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) criteria as follows: 1) triglycerides ≥ 150 mg/dL or taking medicine for hypertriglyceridemia, 2) high density lipoprotein cholesterol (HDL-C) < 40 mg/dL in men and < 50 mg/dL in women, 3) blood pressure ≥ 130/85 mmHg or taking medicine for hypertension, 4) fasting glucose ≥ 100 mg/dL or taking a hypoglycemic agent, and 5) WC ≥ 90 cm in men and ≥ 80 cm in women, according to the World Health Organization (WHO) Asia-Pacific criteria [WHO, 2004a]. Metabolic syndrome was diagnosed when three of these five criteria were met (Grundy et al., 2005). This study was approved by the Institutional Review Board of J General Hospital and was carried out with approval of the participants after the methods and procedures were explained.

Anthropometric measurements and calculations

Systolic and diastolic blood pressure was determined using a mercury sphygmomanometer after the subject rested for 10 min in a sitting position. Body weight was measured to the nearest 0.1 kg using an electronic scale. Height was measured to the nearest 0.1 cm using a stadiometer. BMI was calculated as weight (kg) divided by height (m) squared (kg/m²). WC and HC were measured using a tape at the point midway between the lateral lower rib and iliac crest and at the level of the trochanters (± 0.1 cm), with the feet 20~30 cm apart to make weight even and while the subject exhaled. The WHR was calculated as WC divided by HC, and the WHtR was calculated by dividing WC by height (cm). BAI was calculated using Bergnam's formula: (hip circumference)/(height)^1.5 - 18. BMI was divided into four categories: underweight (< 18.5 kg/m²), ideal weight (18.5~22.9 kg/m²), overweight (23~24.9 kg/m²), and obese (> 25 kg/m²) (James, 2004; WHO expert, 2004b; Kor Endoc Soc., 2010). The BAI categories were: underweight, ideal weight, overweight, and obese, according to criteria from Gallagher et al. (Gallagher et al., 2000).

Laboratory evaluation

Venous blood was taken from the antecubital vein with EDTA anticoagulant to obtain whole blood and without anticoagulant to obtain serum. Blood samples were taken following a 12 h overnight fast, and serum was collected after centrifugation. Blood was stored at -20°C, and the analyses were performed within one day. Total cholesterol, triglycerides, HDL-C, low density lipoprotein cholesterol (LDL-C), fasting glucose, uric acid, and high sensitivity C-reactive protein (hs-CRP) were measured using an automatic TBA-200FR NEO chemical analyzer (Toshiba, Tokyo, Japan). Glycated hemoglobin (HbA1C) was measured by high performance liquid chromatography using a Variant II system (Bio-Rad, Hercules, CA, USA). Insulin was measured by an electrochemiluminescence immunoassay using a Modular Analytics E170 (Roche, Basel, Switzerland).

Statistical analysis

Statistical analysis was carried out using SPSS statistics
21.0 software (SPSS/IBM, Chicago, IL, USA). Results are expressed as the mean ± standard deviation or percentages. The unpaired Student’s t-test was used to evaluate differences in anthropometric and biochemical characteristics between sexes (Table 1). The difference in the prevalence of metabolic syndrome between sexes was assessed with the \( \chi^2 \) test. Bivariate correlations between parameters, such as BAI, BMI, WC, WHR, WHtR, and metabolic risk factors were ascertained by Pearson’s or Spearman’s correlation analyses. Receiver operating characteristic (ROC) curves were used to determine the discriminatory capacities of BMI and BAI for metabolic syndrome. Cutoff values were derived mathematically from ROC curves. \( P \) value < 0.05 was considered significant.

**RESULTS**

Age and anthropometric characteristics of the participants categorized by sex are shown in Table 1. Significantly higher weight, height, BMI, WC, HC, BMI, WHR, and \( \text{WHtR} \) values were detected in men compared to women. Women had a higher BAI than that of men. Men had significantly higher systolic and diastolic pressures than those of women. Men presented with significantly higher total cholesterol, LDL-C, triglycerides, insulin, HbA1C, uric acid, and hs-CRP values than women, whereas HDL-C was higher in women. The prevalence of metabolic syndrome was significantly higher in men (11.84%) than in women (6.78%) using

### Table 1. Anthropometric characteristics and biochemical blood parameters in this study

| Variables                  | All (n=20,961) | Men (n=12,719) | Women (n=8,242) | \( P \) value |
|----------------------------|----------------|----------------|-----------------|---------------|
| Age (years)                | 45.72±11.22    | 46.08±10.97    | 45.16±11.58     | <0.001        |
| Weight (kg)                | 66.29±12.19    | 72.49±10.24    | 56.73±8.07      | <0.001        |
| Height (cm)                | 166.38±8.76    | 171.36±6.37    | 158.70±5.94     | <0.001        |
| Waist circumference (cm)   | 79.55±9.35     | 83.77±7.62     | 73.05±7.95      | <0.001        |
| Hip circumference (cm)     | 93.46±6.01     | 95.01±5.73     | 91.07±5.63      | <0.001        |
| BMI (kg/m\(^2\))           | 23.83±3.22     | 24.65±2.94     | 22.55±3.23      | <0.001        |
| BAI (kg/m\(^2\))           | 25.69±3.53     | 24.41±2.83     | 27.66±3.59      | <0.001        |
| WHR                        | 0.85±0.88      | 0.88±0.59      | 0.80±0.10       | <0.001        |
| WHtR                       | 0.47±0.05      | 0.48±0.04      | 0.46±0.05       | <0.001        |
| Systolic BP (mmHg)         | 109.53±14.16   | 112.76±13.12   | 104.54±14.26    | <0.001        |
| Diastolic BP (mmHg)        | 70.48±10.41    | 72.94±9.89     | 66.72±9.82      | <0.001        |
| Total cholesterol (mg/dL)  | 193.05±34.01   | 195.21±34.06   | 189.70±33.66    | <0.001        |
| HDL cholesterol (mg/dL)    | 55.91±13.44    | 52.00±11.89    | 62.01±13.45     | <0.001        |
| LDL cholesterol (mg/dL)    | 118.37±30.96   | 121.94±30.61   | 112.88±30.70    | <0.001        |
| Triglyceride (mg/dL)       | 123.12±84.01   | 144.28±92.03   | 90.44±55.84     | <0.001        |
| Fasting glucose (mg/dL)    | 90.54±18.58    | 92.74±20.58    | 87.16±14.32     | <0.001        |
| Insulin (μU/mL)            | 4.88±3.05      | 5.19±3.23      | 4.52±2.79       | <0.001        |
| HbA1C (%)                  | 5.60±0.70      | 5.66±0.77      | 5.51±0.57       | <0.001        |
| Uric acid (mg/dL)          | 5.31±1.46      | 6.03±1.28      | 4.21±0.95       | <0.001        |
| hs-CRP (mg/dL)             | 0.26±0.58      | 0.27±0.63      | 0.25±0.47       | 0.024         |
| MetS AHA/NHLBI (%)         | 9.85           | 11.84          | 6.78            | <0.001        |

Values are means ± SD.

**Abbreviations:** BMI, body mass index; BAI, body adiposity index; WHR, waist hip ratio; WHtR, waist height ratio; BP, blood pressure; HDL, high density lipoprotein; LDL, low density lipoprotein; hsCRP, high sensitivity C-reactive protein; MetS, metabolic syndrome; AHA/NHLBI, American Heart Association/National Heart, Lung, and Blood Institute.
the AHA/NALBI criteria.

The prevalence of obesity in the entire cohort was 34.53% (43.4% in men and 20.72% in women) using BMI ≥ 25 kg/m² and 4.26% (6.9% in men and 0.2% in women) using the BAI classification. Figures 1 and 2 compare the prevalence rates of overweight and obesity in men and women using the BMI and BAI categories. Overweight men were classified as heavier when they were assessed with BAI, whereas obese men were heavier when checked with BMI (Fig. 1). In addition, the overweight and obese groups of women were classified as heavier when they were checked with BMI (Fig. 2). Tables 2 and 3 show the relationships between the anthropometric variables and metabolic syndrome risk factors in men and women, respectively. BMI was most strongly associated with weight, total cholesterol, HDL-C, and LDL-C \((P < 0.001)\). WC was most strongly associated with triglycerides \((P < 0.001)\). WHtR was most strongly associated with systolic and diastolic blood pressures and fasting glucose \((P < 0.001)\). In women, BMI was most strongly associated with weight \((P < 0.001)\), and WC was most strongly associated with HDL-C \((P < 0.001)\). WHtR was most strongly correlated with systolic and diastolic blood pressures, total cholesterol, HDL-C, LDL-C, triglycerides, and fasting glucose \((P < 0.001)\). However, BAI was most strongly associated with only height in men and women \((P < 0.001)\). The areas under the curve (AUC) for

![Fig. 1. Distribution (%) of men in BAI and BMI categories. See Table 1 for abbreviations.](image)

![Fig. 2. Distribution (%) of women in BAI and BMI categories. See Table 1 for abbreviations.](image)

| Table 2. Correlation between anthropometric parameters and metabolic syndrome risk factors in men |
|-----------------------------------------------|
| Variables                  | BMI     | BAI     | WC     | WHR    | WHtR   |
|-----------------------------|---------|---------|--------|--------|--------|
| Weight (kg)                 | 0.847** | 0.294** | 0.756**| 0.282**| 0.515**|
| Height (cm)                 | -0.004  | -0.542**| 0.105**| -0.161**| -0.294**|
| Systolic BP (mmHg)          | 0.243** | 0.188** | 0.246**| 0.196**| 0.261**|
| Diastolic BP (mmHg)         | 0.244** | 0.164** | 0.244**| 0.197**| 0.245**|
| Total cholesterol (mg/dL)   | 0.148** | 0.119** | 0.138**| 0.089  | 0.144**|
| HDL cholesterol (mg/dL)     | -0.289**| -0.188**| -0.285**| -0.180**| -0.260**|
| LDL cholesterol (mg/dL)     | 0.171** | 0.138** | 0.155**| 0.086**| 0.156**|
| Triglyceride (mg/dL)        | 0.289** | 0.167** | 0.291**| 0.052**| 0.271**|
| Fasting glucose (mg/dL)     | 0.149** | 0.131** | 0.191**| 0.196**| 0.214**|

**P < 0.001.
Abbreviations: See Table 1
BAI and BMI were 0.678 (95% confidence interval [CI], 0.667–0.690) and 0.836 (95% CI, 0.827–0.844), respectively, to compare the discriminatory capacity of BAI and BMI for diagnosing metabolic syndrome using the AHA/NALBI criteria. When metabolic syndrome was diagnosed using BMI, the cut-off value was 25.3, sensitivity was 76.56% (95% CI, 74.7–78.4%), and specificity was 74.98% (95% CI, 74.4–75.6%) (Fig. 3).

Table 3. Correlation between anthropometric parameters and metabolic syndrome risk factors in women

| Variables               | BMI    | BAI    | WC     | WHR    | WHtR   |
|-------------------------|--------|--------|--------|--------|--------|
| Weight (kg)             | 0.856* | 0.453* | 0.729* | 0.221* | 0.567* |
| Height (cm)             | -0.279*| -0.633*| -0.197*| -0.206*| -0.485*|
| Systolic BP (mmHg)      | 0.385* | 0.337* | 0.385* | 0.208* | 0.415* |
| Diastolic BP (mmHg)     | 0.368* | 0.305* | 0.356* | 0.185* | 0.374* |
| Total cholesterol (mg/dL)| 0.239* | 0.232* | 0.239* | 0.130* | 0.266* |
| HDL cholesterol (mg/dL) | -0.290*| -0.217*| -0.304*| -0.161*| -0.304*|
| LDL cholesterol (mg/dL) | 0.304* | 0.283* | 0.310* | 0.166* | 0.337* |
| Triglyceride (mg/dL)    | 0.348* | 0.276* | 0.368* | 0.213* | 0.383* |
| Fasting glucose (mg/dL) | 0.296* | 0.244* | 0.308* | 0.181* | 0.319* |

**P < 0.001.
Abbreviations: See Table 1

**DISCUSSION**

This is one of the first studies in Korean adults to evaluate the applicability of BAI as a method to determine metabolic risk factors by comparing BMI, WC, WHR, and WHtR. Our results show that BAI does not overcome the limitations of BMI and other adiposity indices. Moreover, BAI showed less utility to aid in a diagnosis of metabolic syndrome than that of BMI and WHtR in Korean adults.

BMI, which is directly proportional to weight, is the most widely used adiposity index, even though it does not distinguish differences by age and sex and is not useful for athletes who have more muscle mass or in children (Gallaher et al., 1996; Jackson et al., 2002). Bergman et al. proposed the use of BAI to compensate for the limitations of BMI (Bergman et al., 2011). BAI measures body fat percentage using height and HC. In particular, BAI can assess obesity without determining weight and is highly associated with body fat results determined by DXA. However, these studies were carried on African Americans and Mexican Americans only, not Asians. HC shows a sex difference in adiposity more than that of BMI, whereas BAI, which uses HC, is expected to be a better index to predict male and female body fat (Bergman et al., 2011). Some studies have reported that BAI is associated with cardiovascular and metabolic syndrome risk factors (Schulze et al., 2012; Elisha et al., 2013; Freedman et al., 2013; Choi, 2015), but they also...
reported that BMI is a better index than BAI when cardiovascular risk is verified. Therefore, additional investigations on the clinical usefulness of BAI are needed (Bennasar-Veny et al., 2013; Lichtash et al., 2013). Another study reported that WC, which is representative of abdominal adiposity, is more related to cardiovascular risk factors than BMI. The default measure is BMI, which cannot distinguish fat from muscle (Freedman et al., 2012; de Lima et al., 2012). In our study, BMI and the WHtR in males were more strongly associated with metabolic syndrome risk factors than BAI, whereas the WHtR in females was more strongly associated with metabolic syndrome risk factors than BAI. The WHtR is highly associated with the Framingham and REGICOR (Registre Gironí del Cor, Heart Register of Girona) indices, which are criteria for cardiovascular risk (Bennasar-Veny et al., 2013; Melmer et al., 2013). Therefore, the WHtR is expected to be useful as an adiposity index to predict factors associated with metabolic syndrome. Our results show that the AUC of BMI was higher and its discriminatory capacity was higher than that of BAI according to the AHA/NHLBI criteria. BAI is a convenient index for assessing adiposity in men and women without a scale. However, it was not developed to predict cardiovascular and metabolic syndrome risk factors. Therefore, using BAI as a single index to predict the risk for metabolic syndrome should be carefully considered.

Bennasar-Veny et al. (2013) reported that BAI overestimates fat levels in Caucasian men, whereas it classifies > 80% of Caucasian women as normal weight. That is, BAI underestimates fat levels in women. These results demonstrate that BAI overestimates overweight in men compared to BMI, whereas obese men are classified as lighter than when using BMI. BAI classifies > 95% of women as an ideal weight. Thus, BAI underestimates fat levels in men and women. In addition, BAI is reportedly useful for different ethnic groups (Bergman et al., 2011). However, our results and those of Bennasar-Veny et al. (2013) show differences in overweight and obesity rates in men. Thus, it appears that the BAI criteria should be applied based on ethnic group. In particular, when adiposity is checked using the recommended cut-off levels, BAI classifies most females at an ideal weight, indicating that BAI has low sensitivity and specificity. The present study was a cross-sectional retrospective study on Korean adults; thus, these results should not be applied to children or other ethnic groups.

In conclusion, although some authors have reported that BAI is a good tool to assess obesity in Caucasian populations and suggested that it is more practical and easier to use than other adiposity indices, it does not overcome the limitations of BMI and is not a good measure of metabolic risk in the Korean population. Therefore, BAI is less useful than BMI and other adiposity indices, such as the WHR, the WHR, and WC. These indices may be better candidates for clinical use and to evaluate metabolic syndrome risk factors.

**CONFLICT OF INTEREST**

The authors have no conflicts of interest to disclose.

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