Association between Waist-to-Height Ratio and Metabolic Risk Factors in Korean Adults with Normal Body Mass Index and Waist Circumference

Yong Soon Park¹ and Jun Su Kim²

¹Health Screening Center, Kangbuk Samsung Hospital, Sungkyunkwan University, School of Medicine, Suwon, Korea
²Department of Family Medicine, Busan Paik Hospital, Inje University School of Medicine, Busan, Korea

There is little consensus on the best obesity index associated with metabolic risk factors among the population with normal body mass index (BMI) and waist circumference (WC). We therefore evaluated the association between anthropometric indices and metabolic risk factors in a Korean population with normal BMI and WC. This cross-sectional study involved 2,952 participants aged 20-79 years who had normal BMI and WC, based on the Fourth Korea National Health and Nutrition Examination Surveys conducted in 2008. The receiver operating characteristic (ROC) curves were generated to identify the optimal measurement of obesity for the prediction of metabolic risk factors in this population. The area under the ROC curve value for waist-to-height ratio (WHtR) in prediction of metabolic syndrome (MetS) and its components was higher than that for BMI and WC. Among individuals with normal BMI and WC, prevalence of all metabolic risk factors and MetS significantly increased across the quartiles of WHtR in both men and women. After adjustment for potential confounders, the Odds Ratios (95% confidence intervals) for MetS in the second, third, and fourth quartiles of WHtR compared to the first quartile of WHtR were 3.53 (2.12-5.89), 6.06 (3.52-10.43), and 7.11 (4.08-12.38) in men, and 1.66 (1.01-2.72), 2.79 (1.81-4.30), and 2.82 (1.76-4.52) in women, respectively. In conclusion, WHtR has the best predictive value for evaluating the metabolic risk factors compared to BMI or WC alone among subjects with normal BMI and WC.

Keywords: body mass index; metabolic syndrome; risk factors; waist circumference; waist-to-height ratio


Obesity is associated with an increased risk of diabetes mellitus, hypertension, dyslipidemia, and cardiovascular disease (CVD) as a result of excess body fat (Hubert et al. 1983). Most epidemiological and clinical studies on obesity have used body mass index (BMI) to measure body fat. However, BMI has several limitations for estimating obesity for some individuals and does not reflect the distribution of fat on the body (Blair et al. 1984; Frankenfield et al. 2001). Compared with BMI, measures of abdominal adiposity appear to be more strongly associated with metabolic risk factors (Despres and Lemieux 2006).

Waist circumference (WC) is generally recommended as the most informative index for abdominal fat distribution. However, WC thresholds cannot be used universally across gender, ethnic groups, or country (Misra et al. 2005). It was emphasized that Asians, who are of lower height than Caucasians, are predisposed to visceral or abdominal obesity (WHO 2000), perhaps leading to a greater prevalence of CVD risk factors at a lower BMI in Asians than in Caucasians (Deurenberg-Yap et al. 2002). In addition, short subjects with WC at a specified cutoff point will have more abdominal fat than tall subjects with the same WC.

Accordingly, waist-to-height ratio (WHtR), as an alternative anthropometric index of abdominal obesity that avoids the limitations of WC by adjusting for variations in height, appears to be more easily measurable and more strongly associated with metabolic risk than other simple anthropometric indices (Ashwell and Hsieh 2005; Lee et al. 2008; Li et al. 2011).

WHtR has also been shown to identify metabolic risk among individuals deemed ‘healthy’ according to BMI or WC (Hsieh et al. 2000; Srinivasan et al. 2009; Li et al. 2011). Because most Asians are not markedly obese, despite having metabolic risk factors, WHtR has an important role as a single index for identifying persons at metabolic risks. Although studies relating WHtR to cardiovascular risk factors are emerging among individuals who are not obese according to other anthropometric indices, there...
is a paucity of information on the utility of WHtR in assessing metabolic risk among the population with normal ranges of both BMI and WC. Moreover, there are no reports of a relationship between an obesity index and metabolic risk among individuals with normal BMI and WC. The purpose of this study was to evaluate BMI, WC, and WHtR as anthropometric indices and to assess their associations with metabolic risk factors in a Korean adult population with normal BMI and WC.

Methods

Study subjects

This study is based on data acquired in the Fourth Korea National Health and Nutrition Examination Survey (KNHANES IV-2), conducted in 2008. The KNHANES was a cross sectional and nationally representative survey conducted by Korea Centers for Disease Control and Prevention to assess the health and nutritional status of the civilian noninstitutionalized population of Korea. The sampling frame was based on the population census survey conducted by Statistics Korea in 2005. A stratified, multistage probability sampling design was used for the selection of household units. In the KNHANES IV-2, there were 264,186 primary sampling units by proportional allocation, each of which contained about 60 households. Two hundred sampling frames from primary sampling units were randomly sampled, and 23 households from each sampling frame were sampled using a systemic sampling method. Finally, 12,528 individuals in 4,600 households were sampled, and 9,744 of them participated after a fasting period of at least 8 hours by using the autoanalyzer (ADVIA 1650®, Bayer, Tarrytown, New York, USA). Body weight was measured in kilograms by mobile scale (GL-6000-20®, CASKOREA, Seoul, Korea) while the participant was dressed in a light gown without shoes. Using a fiberglass tape measure (SECA 11-146), WHtR was calculated as WC (cm) divided by height (cm) squared (kg/m²).

Study measurements

The survey consisted of a health interview survey, a health examination survey, and a nutrition survey. The survey collected data via face-to-face interviews and self-administered questionnaires in the households and by direct standardized physical examinations conducted in specially equipped mobile examination centers. The sequence of the health survey administration involved intake, receipt of informed consent, blood pressure (BP) measurement, anthropometric measurement, blood sampling, and completion of the questionnaire. A structured interview about health-related behaviors, health status and socio-demographic characteristics was performed by trained interviewers.

A standardized questionnaire regarding age, gender, medical history, drug use, smoking status, alcohol consumption, and other lifestyle risk factors was prepared. For smoking, subjects were divided into smokers and non-smokers. Smokers were defined as those who had smoked ≥ 100 cigarettes over their lifetimes, and non-smokers were defined as those who had smoked < 100 cigarettes or had never smoked. Alcohol drinkers were defined as those who ingested alcohol ≥ 1 time per month. Physical activity was defined as regular walking exercise ≥ 5 times per week.

BP was measured 3 times at 5-min intervals using a standard mercury sphygmomanometer (Baumanometer®, WA Baum Co., Inc., Copiague, New York, USA). The average of the second and third measurements was used as the final BP. Anthropometric data, including height, body weight, and WC, were measured according to standardized guidelines. Height was measured in centimeters with the head and hip touching the wall by mobile anthropometer (SECA 225®, SECA Deutschland, Hamburg, Germany). Body weight was measured in kilograms by mobile scale (GL-6000-20®, CASKOREA, Seoul, Korea) while the participant was dressed in a light gown without shoes. Using a fiberglass tape measure (SECA 11-146), WC was measured in centimeters without compression of the soft tissue along the middle horizontal line between the inferior margin of the last rib and the iliac crest. The feet were 25-30 cm apart in a stable, standing position for this measurement. BMI was calculated by dividing body weight by height squared (kg/m²), and WHtR was calculated as WC (cm) divided by height (cm). Fasting plasma glucose (FPG), total cholesterol (T-C), triglyceride (TG), and high density lipoprotein cholesterol (HDL-C) were measured after a fasting period of at least 8 hours by using the autoanalyzer (ADVIA 1650®, Bayer, Tarrytown, New York, USA).

Metabolic syndrome (MetS) was defined in this study as ≥ 2 risk factors of four MetS components according to the American Heart Association/National Heart Lung and Blood Institute (AHA/NHLBI) criteria (Grundy et al. 2005), except the abdominal obesity component. High BP was defined as a systolic blood pressure (SBP) of ≥ 130 mmHg, a diastolic blood pressure (DBP) of ≥ 85 mmHg, or treatment of previously diagnosed hypertension. High fasting glucose was defined as an FPG level of ≥ 5.6 mmol/l or previous treatment for diabetes mellitus. High TG was defined as a TG level of ≥ 1.69 mmol/l or antilipemic drug use, and low HDL-C was defined as an HDL-C level of < 1.03 mmol/l for men or < 1.29 mmol/l for women.

Statistical analysis

Statistical analyses were performed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA) software packages. Continuous variables were tested for normality using the graphical tools and the Kolmogorov-Smirnov test. The values of total energy intake and TG were log transformed to improve the normality of distribution. Continuous data were expressed as mean and standard error, and categorical data were expressed as estimated proportion and standard error or 95% confidence interval (CI), as appropriate. Comparisons of baseline characteristics were made using a Student’s t-test or chi-square test. The receiver operating characteristic (ROC) curves were generated to identify the optimal measurement of obesity for the prediction of metabolic risk factors in the normal BMI and WC population. The ROC curve analysis was used to calculate differences in the area under the ROC curve (AUC), which were used to identify the most powerful obesity index. The subjects were divided into four quartile groups by WHtR, the optimal obesity index to predict metabolic risk, according to gender. Comparisons among the four quartile groups of WHtR were made using an analysis of variance (ANOVA) with Bonferroni correction for continuous data and a chi-square test for categorical data. The prevalence of metabolic risk factors and MetS by four quartile groups of WHtR were analyzed according to gender. Multiple logistic regression analyses were used to calculate
the odds ratios (ORs) and 95% CIs of metabolic risk factors and MetS across the four quartile groups of WHtR, after controlling for potential confounders such as age, total energy intake, alcohol consumption, smoking status, and menopause (only for females). The subjects in the first quartile of WHtR were used as the reference in this analysis. All estimates were calculated based on sample weights, which were evaluated with consideration of the sampling rate, response rate, and age and sex proportion of the reference population. We adjusted the analyses for the complex sample design of the survey. All analyses were two-sided, and \( P \)-values of < 0.05 were considered statistically significant.

**Results**

**Basic characteristics of the study subjects**

Table 1 shows the basic characteristics of subjects examined in this study. The mean age of study subjects was 43.1 years (SE 0.4), and 56.5% (SE 1.1; \( n = 1,828 \)) of the subjects were women. Age- and sex-adjusted means of BMI, WC, and WHtR (× 100) were 22.09 kg/m\(^2\) (SE 0.03), 77.1 cm (SE 0.2), and 47.09 (SE 0.001), respectively. MetS, defined as the presence of ≥ 2 of four components in this study, was present in 26.8% (SE 1.0; \( n = 912 \)) and 32.6% (SE 1.6; \( n = 430 \)) of men and 22.4% (SE 1.1; \( n = 482 \)) of women. There was no difference between men and women in age and WHtR, while anthropometric data, including height, body weight, WC, and BMI were higher in men than in women. There was a significant difference between subjects with and without MetS in age, sex, and all anthropometric indices. Higher systolic and diastolic BP, FPG, and TG levels and a lower HDL-C level were found in men than in women as well as in subjects with MetS compared to those without MetS. The prevalence of smoking status, alcohol drinking status, and regular walking exercise were more common in men. No significant differences between men and women were noted in T-C level, antihypertensive drug use, hypoglycemic agents use, and antidyslipidemic drug use. A significant difference in alcohol drinking status and regular walking exercise was not found between subjects with and without MetS.

**Association of obesity indices and metabolic risk factors using the ROC curves**

The ROC curves for discriminating metabolic risk factors by BMI, WC, and WHtR for male and female subjects are shown in Table 2. For women, regarding all metabolic risk factors and MetS, the AUC values for...
WHtR were significantly higher than for WC and BMI. For men, with predicting high BP, high FPG, low HDL-C, and having MetS, the AUC values for WHtR were higher than for WC and BMI. Regarding high TG in men, the AUC values for WHtR and WC were similar, and both were higher than for BMI.

Characteristics of the study subjects across waist-to-height ratio quartiles

The clinical and biochemical characteristics of study population were summarized according to WHtR quartiles (not shown in table), since WHtR had relatively higher AUC values for metabolic risk factors and MetS than BMI and WC. For both men and women, several variables, including age, BP, FPG, T-C, TG, and history of drug use, exhibited an increasing pattern of lower values in the first quartile and higher values in the fourth quartile, whereas HDL-C showed a decreasing pattern across the quartiles of WHtR. Frequencies of smoking status in men and menopause status in women increased with the WHtR quartiles, and there were significant differences among the quartiles of WHtR ($P < 0.001$). It appeared that there were no significant differences across the quartiles of WHtR for alcohol consumption and regular walking exercise in men and for energy intake, smoking, and regular walking exercise in women. Fig. 1 shows the crude prevalence of metabolic risk factors and MetS by WHtR quartiles. The prevalence of all metabolic risk factors and MetS exhibited an increasing pattern from the first quartile to the fourth quartile of WHtR and had a statistically significant difference according to quartiles in both men and women.

Relationship between waist-to-height ratio quartiles and metabolic risk factors

Multivariate-adjusted ORs for metabolic risk factors and MetS across WHtR quartiles are shown in Table 3. For men, an increasing trend was observed for the ORs of high BP, high FPG, high TG, low HDL-C, and MetS across WHtR quartiles. Men in the second, third, and fourth quartiles of WHtR had significantly higher ORs of high FPG, high TG, low HDL-C, and MetS compared to the first quartile. The ORs of high BP for the second and third WHtR quartiles were not statistically significant compared to the first quartile. The same analysis in women showed an increasing trend for the ORs of high BP, high TG, low HDL-C, and MetS compared to the first quartile. The ORs of high BP for the second and third WHtR quartiles were not statistically significant compared to the first quartile. Those in the third and fourth quartiles of WHtR had significantly higher ORs of low HDL-C and MetS compared to the first quartile. Those in the third and fourth quartiles of WHtR had significantly higher ORs of high BP and high TG, while the ORs of high FPG for the second and third WHtR quartiles were not statistically significant compared to the first quartile.

Discussion

The aim of this study was to evaluate BMI, WC, and WHtR as anthropometric indices associated with metabolic risk factors in a population with normal BMI and WC. On the basis of the AUC analysis to identify the clustering of ≥ 2 components of MetS, we found that WHtR is a better predictor than BMI and WC in a Korean population with normal ranges of BMI and WC.

Previous reports have shown inconsistent results for
the utility of obesity indices to assess the cardiometabolic risks. In a cross-sectional study among German adults, WC or WHtR was found to predict cardiovascular risk better than BMI or WHR, although the differences were small (Schneider et al. 2007). Mojiminiyi et al. (2009), however, proposed that BMI should be the preferred marker of obesity-associated risks in patients with diabetes. In a large cohort of primary care patients, WHtR predicted point prevalence of coronary artery disease, diabetes, and dyslipidemia better than other obesity measurements, whereas BMI best predicted hypertension (Schneider et al. 2006). Our results were consistent, in some respects, with a recent meta-analysis including data on more than 88,000 individuals from diverse populations, which showed that WHtR was the best predictor of cardiovascular risk in both men and women (Lee et al. 2008), although statistically significant differences in AUC between obesity indices were not definitively tested.

It has been debated which measure of obesity should be used in predicting metabolic risk. BMI is the most widely used indicator of obesity, but it poorly discriminates between excess adipose mass and high lean muscle mass and does not consider the distribution of body fat (Romero-Corral et al. 2006). WC is most commonly recommended to assess cardiovascular risk and is used in the definition of MetS (Expert Panel on Detection, Evaluation, and...
Table 3. Adjusted odds ratios of metabolic risk factors in relation to the waist-to-height ratio quartiles according to gender.

<table>
<thead>
<tr>
<th></th>
<th>WHtR-Q2</th>
<th>WHtR-Q3</th>
<th>WHtR-Q4</th>
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<tbody>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High blood pressure a</td>
<td>0.96 (0.62-1.50)</td>
<td>1.26 (0.79-2.02)</td>
<td>1.82 (1.12-2.95)*</td>
</tr>
<tr>
<td>High fasting plasma glucose b</td>
<td>3.04 (1.73-5.34)</td>
<td>3.66 (1.96-6.83)</td>
<td>5.09 (2.83-9.18)</td>
</tr>
<tr>
<td>High triglyceride c</td>
<td>4.48 (2.58-7.77)</td>
<td>6.37 (3.53-11.51)</td>
<td>6.68 (3.63-12.29)</td>
</tr>
<tr>
<td>Low HDL cholesterol d</td>
<td>2.12 (1.32-3.38)</td>
<td>2.98 (1.90-4.66)</td>
<td>3.51 (2.13-5.79)</td>
</tr>
<tr>
<td>Metabolic syndrome e</td>
<td>3.53 (2.12-5.89)</td>
<td>6.06 (3.52-10.43)</td>
<td>7.11 (4.08-12.38)</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td></td>
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</tr>
<tr>
<td>High blood pressure a</td>
<td>1.39 (0.76-2.51)</td>
<td>1.83 (1.12-2.99)*</td>
<td>2.45 (1.37-4.37)</td>
</tr>
<tr>
<td>High fasting plasma glucose b</td>
<td>1.32 (0.80-2.16)</td>
<td>1.45 (0.89-2.38)</td>
<td>1.96 (1.19-3.24)</td>
</tr>
<tr>
<td>High triglyceride c</td>
<td>1.61 (0.96-2.70)</td>
<td>2.64 (1.58-4.43)</td>
<td>2.51 (1.44-4.38)</td>
</tr>
<tr>
<td>Low HDL cholesterol d</td>
<td>1.51 (1.10-2.07)*</td>
<td>2.32 (1.65-3.26)</td>
<td>2.29 (1.53-3.42)</td>
</tr>
<tr>
<td>Metabolic syndrome e</td>
<td>1.66 (1.01-2.72)*</td>
<td>2.79 (1.81-4.30)</td>
<td>2.82 (1.76-4.52)</td>
</tr>
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</table>

WHtR-Q, waist-to-height ratio quartile.

Data expression as odds ratio (95% confidence interval).

Multiple logistic analysis adjusted for age (years), total energy intake (kilocalories per day), alcohol intake (current drinkers or nondrinkers), smoking status (≥ 5 or < 5 packs; only male), menopause (yes or no; only female).

abce Definitions are same as in Table 2.

*P < 0.05; †P < 0.01; ‡P < 0.001: Significance level was set at 0.05 (vs. WHtR-Q1).

Treatment of High Blood Cholesterol in Adults 2001; Alberti et al. 2005; Grundy et al. 2005). WC is a popular anthropometric index for the measurement of abdominal fat distribution, but the use of WC alone may give overestimate the risk in tall subjects and underestimate the risk in short subjects (Hsieh and Yoshinaga 1999). Many studies have suggested that WHtR may be a simple and practical surrogate of central obesity to identify higher metabolic risks (Hsieh and Yoshinaga 1995a, b; Ashwell et al. 1996; Cox and Whichelow 1999; Lin et al. 2002; Ho et al. 2003; Hsieh et al. 2003; Ashwell and Hsieh 2005; Hsieh and Muto 2006; Ashwell and Gibson 2009; Hsieh et al. 2010). Several studies, especially among Asian populations, have reported that WHtR predicts the presence of cardiovascular risk factors better than other anthropometric measurements (Hsieh and Yoshinaga 1995b; Lin et al. 2002; Ho et al. 2003; Hsieh et al. 2003, 2010; Hsieh and Muto 2006). Some studies have also recommended a cutoff level of 0.5 for both men and women for Asian as well as European subjects (Ho et al. 2003; Hsieh et al. 2003; Ashwell and Hsieh 2005). However, a cohort study in Japan did not support the importance of adjusted height in addition to WC to identify presence of multiple cardiovascular risk factors (Nakamura et al. 2011). A Dutch study revealed that height did not significantly influence differences in measures of adiposity or intra-abdominal fat volume in women or the intra-abdominal fat area in both genders (Han et al. 1997). Nevertheless, it is noteworthy that many reports related to WHtR provide evidence for its use as predictor of diabetes, CVD, or related risk factors (Browning et al. 2010). Furthermore, WHtR is more closely associated with metabolic risks than other anthropometric measures, especially in non-obese populations (Hsieh and Muto 2005). Hsieh et al. pointed out that the relative amount of central fat may be more closely associated with metabolic risks than the absolute amount of central fat among a population with moderate BMI, and WC adjusted by height may better reflect the combined metabolic risks (Hsieh et al. 2010). Srinivasan et al. (2009) also emphasized the utility of the WHtR in detecting metabolic risk factors among normal-weight younger adults.

Public and clinical concerns in primary care settings about obesity-related health problems have focused on the obese population defined by the measure of BMI. However, some subjects with normal BMI may have abdominal obesity or even metabolic abnormalities (Ruderman et al. 1981). A subgroup of individuals with metabolically obese, despite a normal weight (MONW), displays metabolic disturbances that may predispose them to higher cardiovascular risk (Ruderman et al. 1998). Because subjects with MONW are not overweight or obese, they may delay detection and may not take adequate precautions. In this study of a normal BMI and WC population, the prevalence of MetS defined as the clustering of ≥ 2 components was 26.8%. This level is obviously higher than the prevalence of MONW from studies related to the obesity phenotype, although those values vary with the method and the criteria used (Conus et al. 2007). Because Asians have a larger percentage of body fat at a lower BMI and WC than Western populations, metabolic risks associated with obesity may appear to occur at a lower BMI and WC in Asians (Lin et al. 2002; Hyun et al. 2008; Li et al. 2008). The subset of individuals who are normal BMI and WC is usually considered a healthy, normal population, but some of these individuals may have an abnormal metabolic status. Because a considerable number of individuals are metabolically obese...
but normal BMI and WC, they may miss opportunities for screening and could easily fail to notice their undesirable health status. Interestingly, even though the subjects in this study were normal BMI and WC, approximately one-fourth of the study population had a WHtR of more than 0.5. Meanwhile, the cutoff point of WHtR can be important in assessing metabolic risks in practical aspects. As shown in the figure, the prevalence of metabolic syndrome linearly increased according to the quartiles of WHtR in men, but not in women. It could indicate that there may be no cutoff point of WHtR in men. Much more research remains to be done on the cutoff of obesity indices to predict metabolic risks in clinical practice.

The present study has some limitations. First, the cross-sectional design of this study limited our ability to make inferences about causal relationships. Second, the survey was completed at a single visit, which cannot account for inherent variability in some laboratory tests and measurements. Finally, our study had no data directly assessing body fat mass and distribution. Despite these limitations, our study has an advantage in measuring the obesity indices in a simple and inexpensive way to predict metabolic risk in a relatively large number of subjects. The survey was conducted recently in a nationwide, population-based, and representative sample of Korean individuals, and all analyses in this study were based on sample weights and adjusted for the complex sample design of the survey. Thus, these results can be generalized for the entire Korean adult population. There is little information on the usefulness of anthropometric indicators in screening for metabolic risks among the population with normal BMI and WC. This study may be the first report of anthropometric indices to evaluate the clustering of metabolic risks among a normal BMI and WC population.

In conclusion, our results suggest that WHtR might be used as a simple and optimal anthropometric indicator to predict metabolic risks for screening, particularly for those at increased health risks with normal BMI and WC. Because WHtR is more predictable than BMI or WC alone for evaluating the clustering of metabolic risk factors among subjects with normal BMI and WC. WHtR may be used as an effective and reliable index in general populations. Various efforts, such as intervention programs and health education, could be applied to individuals with normal BMI and WC who present relatively high WHtR before the onset of overt obesity and metabolic syndrome.

Conflict of Interest

There are no conflict of interest in all of authors to declare

References


