Original Article

Heterogeneity of body mass index, waist circumference, and waist-to-hip ratio in predicting obesity-related metabolic disorders for Taiwanese aged 35–64 y

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SUMMARY

Background & aims: Obesity-related metabolic disorders such as hypertension, diabetes mellitus, hypercholesterolemia, hypertriglyceridemia, and hyperuricemia are major risk factors for cardiovascular disease. The aim was to compare body mass index, waist circumference, and waist-to-hip ratio as predictors of these metabolic disorders.

Methods: We evaluated 1625 men and 1779 women, aged 35–64 y who participated in the 2001 National Health Interview Survey and 2002 Taiwan Three High Prevalence Survey. Their anthropometric measurements were analyzed as predictors of metabolic disorders using empirical receiver-operating characteristic curves and logistic regression models.

Results: Overall, waist circumference performed well as a predictor of metabolic disorders. Body mass index was the best predictor for men who smoked, whereas waist circumference and waist-to-hip ratio were better alternatives for non-smoking men and women. Anthropometric measures had higher predictabilities for those aged 35–44 y but relatively weak associations with diabetes mellitus for men aged 45–64 y and hypercholesterolemia for men and women.

Conclusions: The associations between anthropometric measures and the metabolic disorders varied with comorbidity, gender, age groups, and smoking status. Waist-to-hip ratio was the best predictor for diabetes mellitus, especially for participants aged 45–64 y. The anthropometric measures did not predict hypercholesterolemia well.

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1. Introduction

Obesity has become a major public health problem in developed and developing countries. It is closely associated with diabetes mellitus and cardiovascular diseases such as ischemic heart disease and stroke, as well as major risk factors for metabolic disorders, including high blood pressure (HBP), diabetes, hypercholesterolemia (H-Chol), hypertriglyceridemia (H-TG), and hyperuricemia (H-UA).1–3 Making use of these associations, simple obesity indexes such as body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), and other related indices such as waist-to-height ratio (WHR) and waist-to-stature ratio (WSR) may serve as predictors of cardiovascular disease and these metabolic disorders. Although the World Health Organization has recommended classifications of body weight based on BMI,4 the anthropometric measurements BMI, WC, and WHR are essentially different in body fat distributions as indexes of overall and central adiposity. Body fat reference measurement determined by dual-energy X-ray absorptiometry has shown that BMI and WC conform better with the screening outcomes than does WHR,5 and the obesity indices may in some cases predict the abnormal metabolic risk factors more adequately than the percentage of body fat.6 Various studies across gender, age, and ethnic groups also indicate that BMI, WC, and WHR may have heterogeneous associations with cardiovascular disease and metabolic disorders and thus play different roles as preferable disease predictors.1–4

For assessing the risk of insulin resistance and type 2 diabetes, WC consistently has higher predictive ability, although the
superiority of BMI and WHR may differ among ethnic groups. A worldwide large-scale case–control study of participants from 52 countries showed that WHR has a significantly stronger association than BMI with the development of myocardial infarction. As for the associations with other cardiovascular risk factors, WC has been recommended as a standard component of risk evaluation in routine clinical practice, whereas BMI and WHR as predictors may differ among gender and ethnic groups. Independent studies of different ethnic groups have also demonstrated evidence of the superiority of other obesity indices such as WHR and WSR than BMI or WHR. However, the three anthropometric measurements as predictors of cardiovascular disease risk factors and health status of the elderly may differ from those of the middle-aged adult population.

Although comparisons of BMI, WC, and WHR as predictors of cardiovascular disease and its risk factors have been studied thoroughly in the several publications, differences in their predictabilities for individual metabolic disorders, especially age and gender interactions, remain unclear. The objective of this study was to investigate how well BMI, WC, and WHR serve as predictors of selected metabolic disorders for different subpopulations of Taiwanese residents aged 35–64 yr. In the following study hypothesis testing, the null hypothesis was that BMI, WC, and WHR have the same predictability for the specific metabolic disorder of the studied subpopulation vs. the alternative that there are heterogeneities among the three anthropometric measures.

2. Subjects and methods

2.1. Subjects

The 2001 National Health Interview Survey was an island-wide cross-sectional health survey with non-institutionalized house-holds selected through a multistage proportional-to-population size sampling design. All residents in the chosen households were interviewed. The 2002 Taiwan Three High Prevalence Survey was a follow-up cross-sectional study of the 2001 survey conducted by the Bureau of Health Promotion, Department of Health of Taiwan. Half the primary sampling units of the 2001 National Health Interview Survey was selected and all household members older than 15 yr were interviewed. WC and hip circumference (HC) were measured, and participants’ fasting blood samples were also drawn. Among these, 1625 men and 1779 women, aged 35–64 yr, were evaluated for the associations between their anthropometric measurements and obesity-related metabolic disorders.

2.2. Anthropometric and blood sample measurements

BMI (kg/m²) was calculated based on self-reported height and weight from the 2001 National Health Interview Survey questionnaire. WC and HC were measured with an anthropometric tape to the nearest 0.1 cm. WC was measured by asking the participant to relax and to bend to the left and right a little bit to show the location of the waist. The position was then held fixed by thumbs, and with the participant then standing erect, the measurement was made by circling the anthropometric tape horizontally on the participant’s waist at the designated location. HC was measured at the level of the maximal protrusion of the gluteal muscles. WHR was calculated by dividing WC by HC. Two blood pressure measurements were made 10 s apart, and a third measurement was made if the two were >10 mm Hg apart. Subjects were asked to fast for the 12 h prior to venous blood sample collection, with samples excluded from laboratory analysis if fasting time was <8 h. The blood samples were stored in a refrigerator at –20°C and were sent back by express mail to the research center within 14 d of collection. Fasting plasma glucose, fasting serum uric acid, triacylglycerol, and cholesterol values were measured by technicians at the central laboratory.

2.3. Definitions of the selected metabolic disorders

Hypertension was defined as a systolic blood pressure ≥140 mm Hg, a diastolic blood pressure ≥90 mm Hg, or treatment of previously diagnosed hypertension. Diabetes mellitus was defined as a fasting plasma glucose concentration ≥126 mg/dL or treatment of insulin or hypoglycemic agents. H-Chol was defined as a serum cholesterol concentration ≥240 mg/dL or use of cholesterollowering medication. H-TG was defined as a serum triglyceride concentration ≥200 mg/dL. H-UA was defined as a serum uric acid level ≥7.0 mg/dL for men and ≥6.0 mg/dL for women.

2.4. Statistical analysis

The percentages of subjects characterized as having the selected metabolic disorders, smoking status, and age group distributions (35–44 yr, 45–54 yr, and 55–64 yr) stratified by gender were calculated. Mean values of BMI, WC, and WHR were calculated, and differences in gender for the anthropometric measures and the prevalence of metabolic disorders within each of the age groups were examined by the Student t test and Pearson χ² test separately. Empirical receiver-operating characteristic (ROC) curves of BMI, WC, and WHR in predicting the metabolic disorders stratified by gender and smoking status were obtained. In addition, multivariate logistic regression models adjusting for gender, age groups, and smoking status were used to analyze the relative contributions of the continuous anthropometric measurements in predicting the metabolic disorders.

Simple logistic models stratified by age and gender were also applied, while controlling for smoking status. Likelihood-ratio differences with and without the corresponding anthropometric measurement in the model were calculated and compared with each other. Each anthropometric measurement was categorized into three subgroups for men and women separately; subjects whose measurement fell between the first and the third quartiles were used as the baseline reference group (22.0 ≤ BMI < 26.3, 80.5 ≤ WC < 92.0, 0.85 ≤ WHR < 0.92 for men; 20.8 ≤ BMI < 25.3, 71.0 ≤ WC < 83.2, 0.76 ≤ WHR < 0.83 for women). The model parameter estimates were obtained using generalized estimating equations to account for the correlations that might arise from similarities in diet and lifestyles among household members. The statistical analyses were carried out using SAS software (SAS version 9.1.2002; SAS Institute, Cary NC, USA).

3. Results

3.1. Participant characteristics and prevalence of metabolic disorders

Table 1 summarizes the age distributions, smoking status, mean anthropometric measurements, and prevalence of the metabolic disorders of the participants stratified by gender. The smoking rate for men was substantially higher than that for women in Taiwanese aged 35–64 yr, similar to the prevalence of HBP, H-TG, and H-UA. However, gender differences in these disorders were not significant for the older age group of 55–64 yr. Men also tended to have higher measurements in WC and WHR than those of women, whereas BMI for the age group 55–64 yr was approximately the same. Gender difference in diabetes was not significant, and women tended to have a higher prevalence of H-Chol.
Prevalence, %

metric measurements for H-Chol were only marginally significant for 45–64 y, the likelihood-ratio differences of the three anthropometric measures for men were greater than that of women except for H-TG, whereas WHR and BMI were more likely to be predictors for H-Chol due to their relatively weak associations, as shown by the low likelihood-ratio differences of the corresponding logistic models (Fig. 2). For other cardiovascular disease risk factors, WC predicted hypertension better than BMI and WHR for women aged 35–54 y, whereas the three anthropometric measurements were approximately the same for men within this age range. For both men and women aged 55–64 y, BMI appeared to be a better predictor of hypertension than WHR. Although BMI predicted H-Chol better for smoking men, the anthropometric measures might not be good predictors for H-Chol due to their relatively weak associations, as shown by the low likelihood-ratio differences of the corresponding logistic models (Fig. 2). WC had an overall good performance in predicting H-TG and H-UA for both men and women, whereas BMI and WHR varied with gender and ages for these two metabolic disorders.

Women, in general, had stronger anthropometric measure–comorbidity associations than did men. WC, a measure of central obesity, had an overall good performance as a predictor, which is consistent with the major findings of previous studies.7,9,10

### 3.2. Empirical ROC curves of BMI, WC, and WHR in predicting metabolic disorders

Fig. 1 shows the areas under the curve (AUC) of the empirical ROC curves of BMI, WC, and WHR in predicting the selected metabolic disorders, as stratified by age for the subgroups of smoking men, non-smoking men, and non-smoking women, respectively. Female smokers were excluded from the plots due to low prevalence (only 100 subjects, or 6% of women). The AUCs varied between 0.45 and 0.85 for different age and subgroups. For almost all the subgroups and metabolic disorders, the AUCs across the three age groups were V shaped, with the highest values in the age group 35–44 y followed by 55–64 y. BMI appeared to be a better predictor for men who smoked especially for H-Chol, whereas WC and WHR performed better in particular for diabetes in non-smoking men. The relative performance of the three anthropometric measurements in AUC was approximately the same for female non-smokers. WHR was consistently superior to BMI and WC in predicting diabetes across the three subgroups.

### 3.3. Comparisons of BMI, WC, and WHR in predicting metabolic disorders using logistic regression models

Multiple logistic regression controlling for gender, age groups, smoking status, and gender and smoking interaction showed that BMI, WC, and WHR were non-significant in predicting diabetes, H-Chol, and H-UA, respectively, when the three anthropometric measurements were jointly put in the model. Each of the three anthropometric measurements was significant ($p < 0.0001$) as an independent predictor for the metabolic disorders. Fig. 2 shows the relative contributions of BMI, WC, and WHR for men and women separately by taking the likelihood-ratio differences of the models with and without the corresponding anthropometric measurement term in the model stratified by gender and age. The greater the likelihood-ratio difference, the better the corresponding anthropometric measurement predicts the comorbidity. In general, WC had good performance for both men and women, especially in predicting H-TG and H-UA for men and HBP and H-UA for women. WHR tended to have better predictability than BMI for women except for H-LA, whereas WHR and BMI were approximately the same for men. For both men and women aged 45–64 y, the likelihood-ratio differences of the three anthropometric measurements for H-Chol were only marginally significant ($\chi^2_{4, 95}(2) = 5.99, \chi^2_{4, 99}(2) = 9.21$).

### 4. Discussion

The essentially consistent results using the model-free ROC approach and the logistic regression modeling justified the statistical analysis. In this study, we found that the predictabilities of the three anthropometric measurements varied with the specific metabolic disorders, gender, smoking status, and age groups, which may complement the conclusions of Ho et al.10 Therefore, no single anthropometric measure is consistently better in predicting the studied metabolic disorders.

As predictors for the globally increasing prevalent diabetes, the predictability of all the three anthropometric measures appeared to decrease with age (Fig. 1). This may have to do with the fact that the prevalence of diabetes is increasing with age among the developed and developing countries.17 WHR was a better predictor than WC and BMI for both men and women, which is consistent with the conclusion of Chien et al.8 but is different from that of Wang et al.7 A possible pathophysiologic explanation is that excess intra-abdominal adiposity may have the potential to influence metabolism through alterations in the secretion of adipokines.9 Previous studies have also reported that larger thigh and hip circumferences are associated with better glucose tolerance and an inverse relationship exists between increasing hip circumference and diabetes.8,18 Also, the opposing effects on cardiovascular risk between abnormal and lower body fat tissue are probably related to different biochemical characteristics of fat in these regions, and the ratio of fat to muscle is best estimated by the WHR.1
Differences between WHR and BMI were insignificant for men, when adjusting for smoking status, whereas WHR generally performed better than BMI for women (Fig. 2). One possible explanation for gender differences between the three anthropometric measures might be that “upper body obesity (android, ‘apple shape’ obesity) is more commonly found in men, whereas lower body obesity (gynoid, ‘pear shape’) is more commonly found in women.”

Gender differences in prevalence of HBP, H-TG, and H-UA were not significant for the older age group 55–64 y (Table 1). This might be due to endogenous hormone changes, such as testosterone and estrogen in postmenopausal women of this age group, which is known to be associated with incidence of coronary artery disease, metabolic syndrome, and changes in several of its components.

Smoking status also had a significant effect on the predictabilities of the three anthropometric measurements for men: BMI had better predictability for smokers, whereas WC and WHR were better for non-smokers. Pearson correlation coefficients between BMI and WHR were 0.55 for male non-smokers and 0.42 for smokers (WC vs. WHR were 0.78 and 0.68, respectively), whereas the correlations between BMI and WC for the subgroups were approximately the same (0.81 and 0.79, respectively). Thus, smokers appeared to have fat distributions more concentrated on the upper half of the body. The lower correlation coefficients for male smokers might also explain the differences between

Fig. 1. AUCs of the empirical ROC curves of (a) BMI; (b) WC; and (c) WHR in predicting the metabolic disorders for the subgroups smoking men, non-smoking men, and non-smoking women, as stratified by age.

Fig. 2. Likelihood-ratio differences of the logistic regression model with and without the corresponding anthropometric measurement in the model for (a) men; and (b) women.
smoking statuses for men. Because smoking prevalence for women was relatively low, possible smoking effects for women remain unclear from the study.

We excluded subjects younger than 35 y or older than 64 y from the study because the associations between anthropometric measurements and metabolic disorders of children, young adults,22 and the elderly differ from the studied age population.15,16 Also, prevalence of obesity and metabolic disorders tends to increase concurrently for people older than 35 y, reflecting an increased risk of diabetes and cardiovascular disease in most populations. In addition, people aged 35–64 y likely have the most influence in the overall socioeconomic structure and thus have an important impact in health economics. An interesting finding of our study was that the anthropometric measures of the younger age group (35–44 y) were better predictors of metabolic disorders than those of the other two age groups (Figs. 1 and 2). A possible explanation is that the prevalence of obesity and metabolic disorders for the age group 35–44 y tends to be lower than that of the older population, which has slower metabolism and greater related dysfunction. Thus, younger subjects with abnormal weights or WCs were more vulnerable to having certain metabolic disorders. Differences between the age groups 45–54 y and 55–64 y varied with metabolic disorders, and no apparent trend was observed. The V-shaped tendency in ROC curves across the three age groups observed in some of the disorders (Figs. 1 and 2) might be attributable to lifestyle changes and weight control of participants aged 55–64 y, which would have diluted the associations.

This study compared BMI, WC, and WHR by their empirical ROC curves and likelihood-ratio differences in logistic regression models for overall performance in predicting the selected metabolic disorders. As predictors of diabetes and cardiovascular disease and its risk factors, an important issue to be addressed is optimal cutoffs of the three anthropometric measurements. We compared BMI, WC, and WHR for their predictabilities in metabolic disorders that are major risk factors of cardiovascular disease. However, the relative roles of these anthropometric measures in the risk of development of type 2 diabetes and cardiovascular disease and their interactions with the metabolic disorders need further investigation.1,7 Also, depending on the specific definition of metabolic syndrome,9,23,24 which has several of the metabolic disorders as its components, differences in BMI, WC, and WHR remain unclear. We will further explore these topics in future studies.

One major limitation of the present study is that the participants’ BMI values were calculated based on self-reported height and weight of the 2001 National Health Interview Survey questionnaire. Underestimation of BMI might occur due to subjects giving inaccurate information or possible weight changes between 2001 and 2002. However, this might not have much effect on the comparisons with WC and WHR because a slight mean shift in BMI would not affect its correlations with the metabolic disorders. Although we did consider subjects’ smoking status, other possible confounding factors such as kidney function, diet, lifestyle, physical activities, family history, and socioeconomic status were not addressed in the analysis. However, this should not affect the conclusions of the three anthropometric measures, which was based on comparisons within surveys. Another major limitation is that the cross-sectional study may only describe the heterogeneous conclusions of the three anthropometric measures, which was addressed in the analysis. However, this should not affect the association between obesity and diabetes? Diabetes Med 2007;24:1199–204.

In conclusion, our findings showed that as predictors of metabolic disorders the obesity indexes BMI, WC, and WHR varied with sex, age groups, smoking status, and specific comorbidity. These anthropometric measurements are simple to use and are obtained in common clinical practice. To avoid possible misleading conclusions such as using single measure BMI in predicting HBP and diabetes for women rather than using WC and WHR, respectively (Fig. 2b), we recommend that BMI, WC, and WHR be obtained simultaneously for simple useful obesity indexes in predicting different diseases.

Conflicts of interest

There are no conflicts of interest.

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