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Association of Waist-Height Ratio with Diabetes Risk: A 4-Year Longitudinal Retrospective Study

Yoon Jeong Son, Jihyun Kim, Hye-Jeong Park, Se Eun Park, Cheol-Young Park, Won-Young Lee, Ki-Won Oh, Sung-Woo Park, Eun-Jung Rhee

Department of Endocrinology and Metabolism, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul, Korea

Background: Waist-to-height ratio (WHtR) is an easy and inexpensive adiposity index that reflects central obesity. In this study, we examined the association of various baseline adiposity indices, including WHtR, with the development of diabetes over 4 years of follow-up in apparently healthy Korean individuals.

Methods: A total of 2,900 nondiabetic participants (mean age, 44.3 years; 2,078 men) in a health screening program, who repeated the medical check-up in 2005 and 2009, were recruited. Subjects were divided into two groups according to development of diabetes after 4 years. The cut-off values of baseline body mass index (BMI), waist circumference (WC), and WHtR for the development of diabetes over 4 years were calculated. The sensitivity, specificity, and mean area under the receiver operator characteristic curve (AUROC) of each index were assessed. The odds ratio (OR) for diabetes development was analyzed for each of the three baseline adiposity indices.

Results: During the follow-up period, 101 new cases (3.5%) of diabetes were diagnosed. The cut-off WHtR value for diabetes development was 0.51. Moreover, WHtR had the highest AUROC value for diabetes development among the three adiposity indices (0.716, 95% confidence interval [CI], 0.669 to 0.763; 0.702, 95% CI, 0.655 to 0.750 for WC; 0.700, 95% CI, 0.651 to 0.750 for BMI). After adjusting for confounding variables, the ORs of WHtR and WC for diabetes development were 1.95 (95% CI, 1.14 to 3.34) and 1.96 (95% CI, 1.10 to 3.49), respectively. No significant differences were observed between the two groups regarding BMI.

Conclusion: Increased baseline WHtR and WC correlated with the development of diabetes after 4 years. WHtR might be a useful screening measurement to identify individuals at high risk for diabetes.

Keywords: Waist-height ratio; Waist circumference; Body mass index; Diabetes

INTRODUCTION

Diabetes is a major global public health problem that is estimated to affect 387 million people worldwide [1]. Recently, the International Diabetes Federation estimated the number of people worldwide with diabetes at 366 million in 2011; this number is expected to rise to 552 million by 2030. According the Korea National Health and Nutrition Examination Survey studies in 2001 to 2013, the age-standardized prevalence of diabetes among adults 30 years of age and older increased from

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Corresponding author: Eun-Jung Rhee
Department of Endocrinology and Metabolism, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, 29 Saemunan-ro, Jongno-gu, Seoul 03181, Korea
Tel: +82-2-2001-2485, **Fax:** +82-2-2001-1588, **E-mail:** hongsiri@hanmail.net

8.6% to 11.0% [2]. To reduce the increased prevalence of diabetes and its complications, it is important to find modifiable risk factors for diabetes.

Abdominal obesity has been proposed to be a strong risk factor for diabetes [3]. Various anthropometric measures have been proposed to reflect adiposity, the most frequently used of which is body mass index (BMI). However, BMI does not take body fat distribution into account. Thus, BMI is a limited measurement because fat distribution has been shown to differ according to age, sex, and ethnicity [4]. Waist circumference (WC) and waist-hip ratio (WHR) have been used to discriminate visceral adiposity from simple obesity. However, WC does not account for differences in height, and could thus lead to overestimation or underestimation of risk for tall and short individuals, respectively. Moreover, the WHR might be inaccurate in persons who have lost weight [5].

Waist-to-height ratio (WHtR) is an alternative measurement for visceral fat. A systematic review published in 2010 concluded that WHtR may be advantageous because it avoids the need for age-, sex-, and ethnicity-specific values [5]. Recent studies found that a WHtR cut-off value of ≥0.5 identified people with high adiposity and was strongly associated with cardiovascular disease. Associations between certain adiposity indexes (such as BMI, WC, WHR, and WHtR) and diabetic risk have been investigated in cross-sectional studies [6-10]; however, these studies have yielded inconsistent results.

In this study, we retrospectively examined the associations of certain baseline adiposity indices (e.g., BMI, WC, WHtR) with diabetes risk over 4 years in healthy subjects. We also attempted to identify the best adiposity index for predicting the development of type 2 diabetes mellitus in a healthy urban Korean population.

METHODS

Subjects

This was a retrospective study, and subjects were the participants in Kangbuk Samsung Health Study, a large database from the participants in medical health checkup program at the Health Promotion Center of Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul, Korea. This health checkup program promotes the health of employees through regular check-ups and increase early detection of diseases. Most of the examinees are employees and family members of various industrial companies from all around the country. Large proportion of the subjects undergo examinations annually or biannually.

Initial dataset composed of the data from the 10,868 participants who performed health check-up twice in 4 years of interval, in 2005 and 2009. Baseline anthropometric indices (e.g., BMI, WC, WHtR) and various metabolic parameters were measured. Furthermore, lifestyle factors (e.g., smoking, alcohol drink, exercise) were checked. Among these participants, 7,968 subjects were excluded due to the presence of diabetes and missing data, especially WC and lipid profiles. Final analyses were performed in 2,900 non-diabetic subjects (2,078 men [71.7%] and 822 women [28.3%]) with mean age of 44.3 years. Subjects were divided into two groups according to development of diabetes after 4 years, and examined baseline characteristics in general populations and between groups. We also analyzed the cut-off values of each baseline anthropometric indices which could predict development of diabetes during follow-up, and their sensitivity, specificity, and area under the curves (AUCs). Odds ratio (OR) and 95% confidence intervals (CIs) of three baseline anthropometric indices were estimated after adjustment of confounding variables.

All participants provided written informed consent for the use of their medical check-up data in this study. The design, protocol, and consent procedure of this study were reviewed and approved by the Institutional Review Board of Kangbuk Samsung Hospital (KBS12089) and are all in accordance with the Helsinki Declaration of 1975.

Anthropometric and laboratory measurements

Height and weight were measured twice and then averaged. The WHtR was calculated as the WC (cm) divided by the height (cm) and dichotomized (<0.5 vs. ≥0.5) according to the recommended criteria [11]. The BMI was calculated by dividing the weight (kg) by the square of the height (m). The WC was measured in the standing position, at the middle point between the anterior iliac crest and the lower border of the rib, by a single examiner. WC values were available only for 2,900 subjects due to inconsistencies in the measurement method. Blood pressure was measured twice using a standardized sphygmomanometer after 5 minutes of rest and then averaged. All subjects were examined after an overnight fast. The hexokinase method was used to determine the fasting glucose concentrations (Hitachi Modular D2400, Roche, Tokyo, Japan). Fasting serum insulin concentrations were determined by electrochemiluminescence immunoassay using a Hitachi Modular E170. Homeostatic model of the assessment of insulin resistance (HOMA-IR) was calculated using the following equation:

[fasting insulin (IU/mL)×fasting glucose (mmol/L)]/22.5 [12]. An enzymatic calorimetric test was used to measure the serum total cholesterol (TC) and triglyceride (TG) concentrations.

All subjects with underlying diabetes at baseline were excluded from the study. The presence of diabetes mellitus was determined by self-questionnaires completed by the participants and the fasting glucose diagnostic criteria outlined by the American Diabetes Association [13]. Development of diabetes was assessed in every year's examination with the same diagnostic criteria of diabetes mellitus.

Alcohol and smoking habits were determined by self-questionnaires. Alcohol consumption was defined as drinking more than 3 times a week. Fat mass was measured by segmental bioelectric impedance, using eight tactile electrodes according to the manufacturer's instructions (InBody 3.0, Biospace Co. Ltd., Seoul, Korea).

Statistical analysis

All data were analyzed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA). Baseline characteristics were examined by using chi-square tests. Data that didn't follow normal distribution (such as TG, HOMA-IR) were analyzed after logarithmic transformation. Then we analyzed the cut-off values of each baseline anthropometric indices in newly diagnosed diabetes group, and calculated their sensitivity, specificity, and mean area under the receiver operator characteristics curves (AUROC) values and their 95% CIs by using receiver operating characteristic curves, to find better diagnostic predictor. Multivariate logistic regression analysis was used to estimate the ORs and 95% CIs of newly developed type 2 diabetes to BMI, WC, and WHtR, after adjusting for potential confounders including age, sex, serum glucose, HOMA-IR, TC, TG, fat mass, hypertension, smoking, alcohol drinking, vigorous exercise. Statistical significance was defined as $P<0.05$.

RESULTS

General baseline characteristics

The mean participant age was 44.3 years (Table 1). A total of 2,900 participants were included, 2,078 (71.7%) of whom were men. Over a median follow-up time of 48.7 months, 101 subjects (3.5%) developed diabetes. The average baseline glucose, HOMA-IR, TC, and TG levels were 95.7±8.7, 2.09±0.88, 194.5±33.3, and 133.1±84.0 mg/dL, respectively. Regarding baseline anthropometric characteristics, the mean BMI, WC, and WHtR values were 23.8±2.9 kg/m^2, 80.9±9.0 cm, and

Table 1. Baseline Characteristics of the Participants

Characteristic	Total	Men	Women
Number	2,900 (100)	2,078 (71.7)	822 (28.3)
Age, yr	44.3±6.5	44.3±6.2	43.6±6.3
Diabetes development	101 (3.5)	89 (3.06)	12 (0.41)
Glucose, mg/dL	95.7±8.7	96.8±8.8	93.0±7.9
HOMA-IR	2.09±0.88	2.15±0.94	1.97±0.73
TC, mg/dL	194.5±33.3	196.3±33.3	189.8±32.9
TG, mg/dL	133.1±84.0	148.4±90.0	94.4±48.5
Percent body fat, %	16.3±4.6	16.3±4.6	16.5±4.7
BMI, kg/m²	23.8±2.9	24.4±2.6	22.0±2.7
WC, cm	80.9±9.0	84.2±7.3	72.4±7.5
WHtR, cm/cm	0.48±0.04	0.49±0.04	0.45±0.05
Hypertension[a]	1,386 (47.8)	1,200 (41.4)	186 (6.4)
Smoking	2,845 (98.1)	1,486 (51.2)	31 (1.17)
Alcohol consumption	307 (10.6)	298 (10.3)	9 (0.3)
Vigorous exercise	647 (22.3)	430 (14.8)	217 (7.5)

Values are expressed as number (%) or mean±SD.
HOMA-IR, homeostatic model of the assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio.
[a]Systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥80 mm Hg, or on antihypertensive medication.

Table 2. Comparison of Baseline Characteristics according to the Development of Diabetes after 4 Years

Characteristic	Total			Men			Women		
	Developed diabetes	Not developed diabetes	*P* value	Developed diabetes	Not developed diabetes	*P* value	Developed diabetes	Not developed diabetes	*P* value
Number	101 (3.5)	2,799 (96.5)		89 (3.06)	1,989 (68.59)		12 (0.41)	810 (27.93)	
Age, yr	47.1±6.7	44.2±6.5	<0.001	47.1±7.0	44.3±6.1	<0.001	47.0±5.3	43.1±6.1	0.093
Glucose, mg/dL	108.76±9.57	95.23±8.34	<0.001	109.01±9.68	96.22±8.40	<0.001	106.92±8.87	92.79±7.66	<0.001
HOMA-IR	2.79±1.21	2.07±0.86	<0.001	2.84±1.24	2.12±0.91	<0.001	2.37±0.93	1.96±0.72	0.030
TC, mg/dL	209.84±45.42	193.92±32.63	<0.001	209.50±45.20	195.73±32.50	0.005	212.25±48.93	189.48±32.52	0.136
TG, mg/dL	175.12±117.32	131.58±82.22	<0.001	182.6±122.0	146.9±88.0	<0.001	119.9±45.9	94.1±48.4	0.066
Body fat, %	18.86±4.59	16.26±4.58	<0.001	18.58±4.34	16.78±4.57	<0.001	20.98±5.92	16.49±4.60	0.001
BMI, kg/m²	25.8±2.8	23.7±2.8	<0.001	25.9±2.6	24.4±2.6	<0.001	24.6±3.4	22.0±2.7	0.110
WC, cm	86.8±7.2	80.65±9.0	<0.001	88.0±2.6	84.0±7.2	<0.001	77.3±7.1	72.4±7.5	0.180
WHtR, cm/cm	0.52±0.04	0.48±0.05	<0.001	0.52±0.04	0.49±0.04	<0.001	0.48±0.05	0.45±0.05	0.005
Hypertension[a]	68 (2.3)	1,318 (45.4)	<0.001	65 (2.24)	1,135 (39.14)	0.003	3 (0.10)	183 (6.31)	0.739
Smoking	71 (2.4)	1,446 (49.9)	<0.001	71 (2.45)	1,415 (48.79)	0.099	0	31 (1.07)	1.000
Alcohol consumption	15 (0.5)	292 (10)	0.156	15 (0.52)	283 (9.76)	0.489	0	9 (0.31)	1.000
Vigorous exercise	30 (1)	617 (21.3)	0.069	24 (0.83)	406 (14)	0.135	6 (0.21)	211 (7.28)	0.920

Values are expressed as number (%) or mean±SD.
HOMA-IR, homeostatic model of the assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio.
[a]Systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥80 mm Hg, or on antihypertensive medication.

0.48±0.04, respectively.

Comparison of baseline characteristics between groups

The incidence rates of diabetes according to sex were 89 men (3.06%) and 12 women (0.41%), respectively (Table 2). In the group who developed diabetes, the baseline glucose, HOMA-IR, TC, and TG levels were 108.76±9.57, 2.79±1.21, 209.84±45.42, and 175.12±117.32, respectively. The mean BMI, WC, and WHtR values in this group were 25.8±2.8, 86.8±7.2, and 0.52±0.04 cm, respectively. All variables examined, including adiposity indices and baseline lab results, were higher in men than in women. Sixty-eight subjects (2.3%) had been diagnosed with hypertension at baseline and developed diabetes after follow-up. A total of 71 men (2.4%) were smokers, and 15 men (0.5%) were frequent alcohol drinkers. No women smokers or frequent alcohol drinkers were present in the group. Twenty-four men (0.83%) and six women performed vigorous exercise.

Cut-off value, sensitivity, and specificity of each anthropometric index for predicting the development of diabetes after 4 years

The best WHtR cut-off value was 0.51, which yielded a sensitivity of 60.4% and a specificity of 74.2% (Table 3). The mean AUROC value of WHtR was the highest among the three adiposity indices (AUC, 0.716; 95% CI, 0.669 to 0.763). The best WC and BMI cut-off values were 86.5 and 26.1, respectively. The AUROC values for WC and BMI were 0.702 (95% CI, 0.655 to 0.750) and 0.7 (95% CI, 0.651 to 0.750), respectively. The best cut-off values for men were the same as for the overall group, and the AUC values were ranked the same as for the overall group of subjects. However, for women, the AUC for BMI was the highest (0.725; 95% CI, 0.578 to 0.817), whereas the AUC for WHtR was the lowest (0.679; 95% CI, 0.554 to 0.803).

Odds ratios for the development of diabetes according to each anthropometric index

After adjusting for age, sex, glucose level, HOMA-IR, TC level, TG level, fat mass, hypertension status, smoking status, frequent alcohol drinking, and vigorous exercise, WHtR and WC were significant predictors of the development of diabetes (Table 4). The OR of WHtR was 1.95 (95% CI, 1.14 to 3.34; P=0.015). The OR of WC was 1.96 (95% CI, 1.10 to 3.49; P=0.02). For BMI, the OR was 1.65 (95% CI, 0.90 to 3.05); this ratio was not significant (P=0.11).

Table 3. Cut-off Value, Sensitivity, Specificity, and AUC of Each Anthropometric Index for the Prediction of Type 2 Diabetes

	Men				Women				Total			
	Cut-off value	Sensitivity, %	Specificity, %	AUC (95% CI)	Cut-off value	Sensitivity, %	Specificity, %	AUC (95% CI)	Cut-off value	Sensitivity, %	Specificity, %	AUC (95% CI)
WHtR, cm/cm	0.51	64	64.8	0.697 (0.644–0.749)	0.43	100	38	0.679 (0.554–0.803)	0.51	60.4	74.2	0.716 (0.669–0.763)
BMI, kg/m^2	26.1	50.6	75.9	0.66 (0.602–0.718)	23	66.7	69.8	0.725 (0.578–0.817)	26.1	48.5	80.6	0.7 (0.651–0.750)
WC, cm	86.5	67.4	63.1	0.668 (0.615–0.722)	71.8	83.3	51	0.691 (0.571–0.812)	86.5	60.4	72.5	0.702 (0.655–0.750)

AUC, area under the curve; CI, confidence interval; WHtR, waist-to-height ratio; BMI, body mass index; WC, waist circumference.

Table 4. Multilogistic Regression Analysis with the Development of Diabetes as the Dependent Variable

Variable	Odds ratio	95% CI	*P* value
BMI, kg/m^2	1.65	0.90–3.05	0.11
WC, cm	1.96	1.10–3.49	0.02
WHtR, cm/cm	1.95	1.14–3.34	0.02

Adjusted for age, sex, glucose level, homeostatic model of the assessment of insulin resistance, total cholesterol level, triglyceride level, fat mass, hypertension status, smoking history, alcohol consumption, and vigorous exercise.
CI, confidence interval; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio.

DISCUSSION

In this study, baseline WHtR showed a significant association with the development of diabetes over a median follow-up period of 48.7 months. The OR of WHtR was 1.948 (95% CI, 1.136 to 3.339; $P=0.015$) after adjusting for age, sex, glucose level, HOMA-IR, TC level, TG level, fat mass, hypertension status, smoking status, frequent alcohol drinking, and vigorous exercise. The OR of WC was 1.955 (95% CI, 1.097 to 3.485; $P=0.023$). BMI was not significantly different between the two groups after multivariate logistic regression analysis. The WHtR cut-off value was 0.5117, and the AUC for WHtR was the highest among the three anthropometric indices.

Various adiposity indices have been studied to assess the risk of diabetes. However, no definitive measurement tools or index for best predicting diabetes has yet been identified. The most widely recognized adiposity index is BMI, which was first used by the World Health Organization [14]. However, BMI is limited in that even though it is correlated with total body fat, it does not reflect body fat distribution. Many reports have described a positive association between visceral fat distribution and metabolic disease risk. Anecdotal evidence from the 1940s onwards supports the idea that individuals with a central type of fat distribution (android type) exhibit higher health risks compared with individuals with the peripheral type of fat distribution (gynoid type) [15,16]. Moreover, BMI cannot distinguish between a person with excess fat and a person with high muscle mass; therefore, they have the same cardiovascular risk based on BMI alone [17]. Due to this limitation, indices such as WC and WHR, which reflect central obesity, have gained popularity for assessing relative visceral fat distribution [5,18]. In another study performed in Koreans, the Healthy Twin Study, WC, WHtR, and BMI showed better predictability for metabolic risks over direct body fat measures [19]. However, these indices also have limitations. Specifically, WC does not account for differences in height. Several studies have reported that individuals with the same WC but different heights are unlikely to have the same cardiometabolic risks [20]. Moreover, WHR might be inaccurate in individuals who have lost weight, because both waist and hip circumference can decrease proportionately, and thus the ratio sometimes changes very little [5,18]. Many studies have also found that the boundary value of WC varies between men versus women, adults versus children, and Asian versus non-Asian populations [5,18,21]. In contrast to both WC and WHR, WHtR includes one constant measure (height), therefore it may correct the WC of the individual. This parameter is also cheaper and easier to measure than BMI. Moreover, the WHtR cut-off value has been shown to be consistent across different ages, sexes, and ethnicities [5,21].

According to recent meta-analyses of several prospective and cross-sectional studies, WHtR and WC are significant predictors of diabetes, cardiovascular disease hypertension, lipid outcomes, and metabolic syndrome. These two indices also have similar ORs and hazard ratios and were found to be stronger predictors than BMI [5,16,18,21]. Moreover, meta-analyses aimed at determining whether WHtR, WC, or BMI is the best screening parameter for cardiometabolic disease found that WHtR had the highest AUROC value, whereas BMI had the lowest. Furthermore, the rank order of WHtR remained consistent throughout all of the studies. The WHtR boundary value most often proposed for predicting diabetes, cardiovascular disease, hypertension, lipid outcomes, and metabolic syndrome is 0.5. The cut-off values reported for diabetes are 0.52 to 0.53; this index yielded consistent performance across ages, sexes, and ethnicities. Moreover, this index can be simply expressed as “Keep your waist circumference to less than half your height” [5,21]. In our study, the same tendency was observed. The OR of WHtR was 1.95 and the OR of WC was 1.96, after adjusting for confounding factors. Thus, both of these indices were statistically significant predictors of the development of diabetes. However, BMI was not significantly different between the groups after adjustment. The WHtR cut-off value was 0.51, and the AUROC of WHtR was the highest among the three adiposity indices.

In our study, we measured anthropometric indices in 2,900 healthy Korean adult individuals, in addition to various parameters that reflect metabolic health status, such as baseline glucose, HOMA-IR, and lipid profiles. We then tracked the development of diabetes after 4 years of follow-up. However, this study did have a few limitations. First, this study has a small sample size of women participants. Second, the number of subjects who developed diabetes after 4 years of follow-up was relatively small. Third, the study population was limited to healthy adults, and thus does not exactly represent the overall Korean population. Fourth, post-challenge glucose levels were not factored into the diagnosis of diabetes. Fifth, baseline hip circumference was not measured; thus, the relationship between WHR and diabetes could not be assessed. Sixth, selection bias could have been present because our study was retrospective in nature.

In conclusion, we found that baseline WHtR and WC are strong predictors of diabetes in a population of healthy Korean subjects. Moreover, WHtR has several advantages as a screening measurement compared with WC. We suggest a WHtR boundary value of 0.5 for defining high risk individuals. In this group, intensive life style modifications should be introduced early to reduce the WC to less than half of the height in order to lower the risk of diabetes. Future studies of large diverse populations are needed to validate the clinical application of this boundary value.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Eun-Jung Rhee *http://orcid.org/0000-0002-6108-7758*

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