ORIGINAL CONTRIBUTION

Waist-to-height ratio, waist circumference, and body mass index as indices of cardiometabolic risk among 36,642 Taiwanese adults

Wen-Cheng Li · I-Chuan Chen · Yu-Che Chang · Song-Seng Loke · Shih-Hao Wang · Kuang-Yu Hsiao

Abstract

Purpose We aimed to investigate the association of body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) with cardiometabolic risk.

Methods In this cross-sectional study, 21,038 men and 15,604 women who participated in a health check-up were included.

Results In both men and women, the area under the curve (AUC) of WHtR was significantly greater than that of BMI or WC in the prediction of diabetes, hypertension, high total cholesterol, high triglycerides, and low HDL-cholesterol ($P < 0.05$ for all). The AUC for WHtR in the prediction of metabolic syndrome (MS) was also highest in the women ($P < 0.05$). After adjustment for potential confounders, the odds ratios and 95% confidence intervals for MS for each standard deviation increase in BMI, WHtR, and WC were 1.47 (1.46–1.49), 1.32 (1.31–1.33), and 1.19 (1.18–1.19), respectively. Finally, patients of either sex with a normal BMI or WC level, but with an elevated WHtR, had higher levels of various cardiometabolic risk factors in comparison with their normal BMI or WC, but low WHtR, counterparts ($P < 0.05$ for all).

Conclusion Among Taiwanese adults, a WHtR greater than 0.5 is a simple, yet effective indicator of centralized obesity and associated cardiometabolic risk, even among individuals deemed 'healthy' according to BMI and WC.

Keywords Waist-to-height ratio · Waist circumference · Obesity · Diabetes · Body mass index · Asian

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Introduction

Current estimates from the International Obesity Task Force suggest that at least 1.1 billion people across the globe are overweight and 312 million of them are obese [1]. It is now well established that obesity, as most commonly defined according to body mass index (BMI), substantially increases the risk of type-2 diabetes [2], hypertension [2], cardiovascular disease [3], and all-cause mortality [4]. However, it has become accepted that the location of excess adiposity is a strong determinant of cardiometabolic risk [5]. Specifically, the central deposition of excess weight has been proven to be a stronger predictor of risk of morbidity [6–10] and mortality [11] in comparison with overall obesity, as defined by BMI alone.

Although waist circumference (WC) is often advocated as a simple and accurate anthropometric marker of central obesity and associated cardiometabolic risk [12], and its use has been adopted into clinical screening guidelines [13], the measure is not without limitations. First, WC cutoff points cannot be used universally across gender or race [14]. Indeed, the optimal WC cutoffs for denoting cardiometabolic risk may even differ between Asians from different countries [15, 16]. The application of WC to assess cardiometabolic risk also assumes, albeit erroneously, that risk stratification is not influenced by patient height. For example, it has recently been shown that the risk of metabolic syndrome within a given WC strata is significantly higher among shorter individuals [17].

The waist-to-height ratio (WHtR) is an alternative anthropometric index of central obesity that circumvents the limitations of WC [18]. First, due to the inclusion of height into the index, any potential confounding of cardiometabolic risk by height is avoided. Second, studies have found similar WHtR cutoffs for increased cardiometabolic risk among Caucasian [19] and Asian [20] populations as well as men and women [21]. In fact, a WHtR cutoff value of 0.5 has been proposed as an indicator of cardiometabolic risk for both Japanese [22], Korean [23], and British [19] men and women. Finally, WHtR has also been shown to denote cardiometabolic risk among individuals who are not obese according to other anthropometric indices [23–25].

Despite apparently low levels of obesity [26] relative to those reported in North America [27], the rates of diabetes [28] and metabolic syndrome [29] among Taiwanese are alarmingly high. Thus, there remains a need to elucidate proper anthropometric criteria to delineate Taiwanese individuals at the highest cardiometabolic risk. The aim of the current study was threefold: (1) to investigate the association of BMI, WC, and WHtR with diabetes mellitus, hypertension, dyslipidemia, and metabolic syndrome in a large sample of Taiwanese individuals; (2) to determine the cutoff points of BMI, WC, and WHtR predictive of cardiometabolic risk factors; and (3) to quantify cardiometabolic risk among those who have elevated WHtR, but normal BMI or WC.

Subjects and methods

Subjects

Data on 38,406 adult (≥18 years) Taiwanese subjects who had health check-ups in 2010 were retrospectively collected from the health centers located in four separate branches of Chang-Gung Memorial Hospital, including the Keelung and Linkou branches of northern Taiwan and the Chiayi and Kaohsiung branches of southern Taiwan. Subjects with incomplete data, as well as those who were pregnant or had a chronic disease that may affect the metabolic status or body composition (e.g., thyroid or hypothalamic disease, chronic hepatitis, and cirrhosis), were excluded from analysis ($n = 1,764$). The sample used for the current analysis consisted of 21,038 men and 15,604 women.

Collection of data

All data collection was conducted during a single visit by full-time nurses at the health examination center who had received uniform training and adhered to the standard operating procedure (SOP). Nurses at each participating health center administered questionnaires regarding lifestyle (including smoking and drinking), medical history (including past illness history and medication history), and physiological conditions (including pregnancy and fasting time) to all subjects during their health check-up. The nurses verified the completion of each questionnaire prior to collection. During the same visit, blood pressure, height, weight, and waist circumstance were measured, and fasting blood samples were taken. All subject information was coded electronically and entered into a central subject record database. In order to ensure quality control, a monitor was employed by the investigational institution to review the data collection process through sampling with an SOP check list.

Anthropometric measurements

The height meter was calibrated daily using a one-meter standard bar from the Bureau of Standards, Metrology, and Inspection, Taiwan. Height was measured while subjects stood erect, barefoot, with feet together, looking forward. The weight scale was calibrated daily using two 20-kg standard weights. Weight was measured by an automatic

scale with subjects wearing light shirt and shorts or a skirt. BMI was then calculated as weight in kg divided by height in meters squared (kg/m^2). Normal BMI level was classified as 18.5–23.9 kg/m^2, as per the guidelines set forth by the Taiwan Department of Health. WC was measured at the mid-level between the iliac crest and the lower border of the twelfth rib while the subject stood with feet 25–30 cm apart. A normal WC level in men and women was defined as <90 and <80 cm, respectively.

Measurement of cardiometabolic risk factors

After a 10-min rest, blood pressure (BP) was recorded with the subject in the seated position using an automated sphygmomanometer placed on the subject's right arm. BP was measured three times, and the lowest reading was recorded. Individuals were deemed hypertensive if they were taking antihypertensive medications, if they self-reported a diagnosis of hypertension, if their systolic pressure was above 140 mm Hg, if their diastolic pressure was above 90 mm Hg, or if a combination of these features was recorded [30]. Subjects fasted for a minimum of 12 h and avoided a high-fat diet and alcohol consumption for at least 24 h prior to phlebotomy. A fasting venous blood sample was obtained between 5:30 am and 11:00 am and stored in a 4 °C refrigerator prior to analysis in the hospital laboratory. Clinical chemistry workup included total cholesterol, HDL-C, TG, fasting plasma glucose (FPG), and uric acid. Blood tests were carried out by the College of American Pathologists (CAP)-accredited hospital laboratory in accordance with the laboratory SOP. Participants were considered to have diabetes if they reported current usage of antidiabetic medications, reported a previous diagnosis of diabetes or had an FPG glucose above 126 mg/dl [31]. In terms of lipid variables, the cutoff points were as follows: hypercholesterolemia (plasma TC ≥240 mg/dl and/or use of medications to lower blood cholesterol), hypertriglyceridemia (TG ≥200 mg/dl), low HDL-C (HDL-C <40 mg/dl in men and women), and high LDL-C (LDL-C ≥160 mg/dl and/or use of medications to lower blood cholesterol) [32].

A diagnosis of metabolic syndrome was defined as a subject presenting at least 3 of the 5 factors described by the Third Adult Treatment Panel (ATP III) of the National Cholesterol Education Program (NCEP) [33]. The diagnostic criteria were defined as follows: (1) high blood pressure (a systolic blood pressure ≥130 mm Hg and/or diastolic pressure ≥85 mm Hg, under treatment, or already diagnosed with hypertension); (2) high serum triglyceride (≥150 mg/dl or under treatment); (3) decreased HDL-C (<40 mg/dl for males and <50 mg/dl for females or under treatment); (4) hyperglycemia (FBG ≥100 mg/dl, under treatment, or previously diagnosed with diabetes mellitus);

and abdominal obesity. Waist circumference cutoffs were modified for Asian populations [2]. A waist circumference ≥90 cm for men and ≥80 cm for women plus the other two risk factors or the waist circumstance within the threshold plus the other three or more risk factors resulted in a diagnosis of metabolic syndrome.

Statistical analyses

Comparisons between men and women were made using independent samples t tests for continuous data and chi-square tests for categorical data. Pearson's correlation coefficients were used to determine the correlation between anthropometric indices and cardiometabolic risk factors. A receiver operating characteristic (ROC) curve is a graphical plot of the true-positive rate (sensitivity) versus the false-positive rate (100-specificity) for a binary variable across a range of thresholds. In the current study, the ROC curves were used to demonstrate the discriminatory ability of an anthropometric index (e.g., WC) over the entire range of possible values in the detection of a cardiometabolic outcome (i.e., diabetes) as quantified by the area under the curve (AUC). The optimal cutoff point for each anthropometric variable in the prediction of a given cardiometabolic outcome was established based on the highest combination of sensitivity and specificity. Odds ratios (ORs) were calculated using multiple logistic regression analysis and are presented with their 95% confidence intervals (CIs). $P < 0.05$ was considered to be statistically significant. The data were analyzed using SPSS version 12.0 for Windows (SPSS, Inc, Chicago, IL, USA). Pairwise comparison of ROC curves was made using MedCalc for Windows, version 9.38 (MedCalc Software, Mariakerke, Belgium).

Results

The basic characteristics and the prevalence of cardiometabolic risk factors of the 21,038 men and 15,604 women in the study sample are presented in Table 1. The men and women in the sample were comparable in terms of mean age (37.2 ± 9.4 and 37.3 ± 10.4 years, respectively, $P = 0.437$), prevalence of diabetes (1.3 vs. 1.2%, $P = 0.477$), and high total cholesterol (5.2 vs. 5.0%, $P = 0.467$). However, there were significant differences between the men and women in all other assessed variables (all $P < 0.001$). Specifically, men had a higher BMI (24.8 ± 3.5 vs. 22.5 ± 4.0 kg/m^2), WC (84.8 ± 9.1 vs. 73.3 ± 9.4 cm), and WHtR (0.49 ± 0.05 vs. 0.46 ± 0.06) in comparison with women. The prevalence of hypertension (6.2% vs. 3.8%), smoking (29.6% vs. 8.8%), alcohol consumption (37.5% vs. 11.5%), high TG (13.3% vs.

Table 1 Characteristics of study population

	Men (n = 21,038)	Women (n = 15,604)	P value
Age (years)[a]	37.24 ± 9.39	37.33 ± 10.35	0.437
BMI (kg/m2)[b]	24.82 ± 3.54	22.52 ± 3.95	<0.001*
WC (cm)[a]	84.76 ± 9.07	73.26 ± 9.36	<0.001*
WHtR[a]	0.494 ± 0.053	0.462 ± 0.061	<0.001*
SBP (mm Hg)[a]	126.67 ± 13.87	115.91 ± 15.69	<0.001*
DBP (mm Hg)[a]	78.90 ± 10.14	72.22 ± 10.00	<0.001*
FBG (mg/dl)[a]	91.93 ± 18.48	90.27 ± 18.68	<0.001*
TC (mg/dl)[a]	184.18 ± 33.01	179.57 ± 33.17	<0.001*
TG (mg/dl)[a]	130.57 ± 103.71	86.01 ± 58.12	<0.001*
HDL-C (mg/dl)[a]	49.72 ± 11.16	61.29 ± 13.34	<0.001*
TC/HDL-C ratio[a]	3.87 ± 1.08	3.05 ± 0.82	<0.001*
Diabetes mellitus, n (%)[b]	278 (1.3)	193 (1.2)	0.477
Hypertension, n (%)[b]	1,311 (6.2)	594 (3.8)	<0.001*
High TC, n (%)[b]	1,094 (5.2)	785 (5.0)	0.467
High TG, n (%)[b]	2,797 (13.3)	590 (3.8)	<0.001*
Low HDL-C, n (%)[b]	3,530 (16.8)	532 (3.4)	<0.001*
Current drinker, n (%)[b]	7,897 (37.5)	1,794 (11.5)	<0.001*
Current smoker, n (%)[b]	6,230 (29.6)	1,377 (8.8)	<0.001*

All numbers are means ± standard deviation unless specified

P values are from [a] independent two sample t tests or [b] chi-square tests

BMI body mass index, *WC* waist circumference, *WHtR* waist-to-height ratio, *FBG* fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol

* Indicates significant difference between men and women, $P < 0.05$

Table 2 Pearson's correlation coefficients between anthropometric indices and cardiometabolic risk factors in men and women

	BMI		WC		WHtR	
	Men	Women	Men	Women	Men	Women
SBP	0.367*	0.443*	0.359*	0.423*	0.363*	0.437*
DBP	0.345*	0.379*	0.333*	0.348*	0.343*	0.348*
FBG	0.159*	0.260*	0.181*	0.286*	0.205*	0.296*
TC	0.188*	0.193*	0.204*	0.201*	0.237*	0.233*
TG	0.263*	0.362*	0.275*	0.382*	0.293*	0.402*
HDL-C	−0.329*	−0.346*	−0.330*	−0.344*	−0.325*	−0.339*
Uric acid	0.330*	0.406*	0.306*	0.381*	0.289*	0.383*

Data are correlation coefficients

BMI body mass index, *WC* waist circumference, *WHtR* waist-to-height ratio, *FBG* fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol

* $P < 0.05$

3.8%), and low HDL-C (16.8% vs. 3.4%) was also higher in the men than in the women, respectively.

The correlations between anthropometric indices and cardiometabolic risk factors are shown in Table 2. In both men and women, BMI, WC, and WHtR were all significantly correlated with each cardiometabolic risk factor ($P < 0.05$). In comparison with BMI and WC, the WHtR

was a stronger correlate of FBG, TC, and TG in both men and women.

The AUCs of the three anthropometric indices in the prediction of cardiometabolic risk factors are shown in Table 3. In both sexes, the AUC of WHtR was significantly higher than that of BMI or WC in the prediction of diabetes mellitus, hypertension, high TC, high TG, and low HDL-C

Table 3 AUC for various anthropometric indices and cardiometabolic risk factors in men and women

Risk factor	BMI	WC	WHtR
Men (n = 21,038)			
Diabetes mellitus	0.624 (0.592, 0.656)	0.689 (0.683, 0. 695)	0.741 (0.735, 0.747)*
Hypertension	0.593 (0.586, 0.600)	0.704 (0.698, 0.710)	0.735 (0.729, 0.741)*
Metabolic syndrome	0.839 (0.833, 0.846)	0.861 (0.855, 0.867)*	0.858 (0.852, 0.864)
High TC	0.619 (0.603, 0.635)	0.629 (0.613, 0.644)	0.652 (0.637, 0.667)*
High TG	0.705 (0.659, 0.714)	0.705 (0.696, 0.714)	0.720 (0.711, 0.729)*
Low HDL-C	0.509 (0.502, 0.512)	0.678 (0.668, 0.687)	0.680 (0.671, 0.689)*
Women (n = 15,604)			
Diabetes mellitus	0.771 (0.764, 0.778)	0.827 (0.821, 0.833)	0.845 (0.840, 0.851)*
Hypertension	0.797 (0.791, 0.804)	0.814 (0.807, 0.820)	0.835 (0.829, 0.841)*
Metabolic syndrome	0.897 (0.890, 0.905)	0.915 (0.908, 0.921)	0.920 (0.914, 0.926)*
High TC	0.657 (0.638, 0.676)	0.660 (0.641, 0.680)	0.684 (0.665, 0.702)*
High TG	0.784 (0.768, 0.801)	0.798 (0.782, 0.814)	0.818 (0.803, 0.832)*
Low HDL-C	0.765 (0.746, 0.785)	0.761 (0.742, 0.780)	0.763 (0.745, 0.782)

Data are AUC (95% confidence interval)

BMI body mass index, *WC* waist circumference, *WHtR* waist-to-height ratio, *FBG* fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol

* AUC is significantly larger than the next smaller AUC; significance was calculated only for the difference between parameters with the highest and second highest AUC, $P < 0.05$

Table 4 Cutoff points for anthropometric indices predictive of cardiometabolic risk factors

Risk factor	BMI			WC			WHtR		
	Cutoff	Sensitivity (%)	Specificity (%)	Cutoff	Sensitivity (%)	Specificity (%)	Cutoff	Sensitivity (%)	Specificity (%)
Men (n = 21,038)									
Diabetes mellitus	25.28	60.4	59.8	86.95	68.3	61.3	0.503	78.1	59.7
Hypertension	25.74	62.4	66.7	87.90	64.0	67.03	0.509	69.1	65.8
Metabolic syndrome	25.34	83.1	69.5	89.35	78.4	83.3	0.514	80.1	77.4
High TC	24.53	66.2	51.7	83.65	72.6	78.0	0.482	79.1	44.2
High TG	24.65	75.1	65.4	85.95	70.8	60.5	0.496	75.5	58.2
Low HDL-C	24.74	69.7	58.1	85.95	65.6	60.8	0.496	69.0	58.3
Women (n = 15,604)									
Diabetes mellitus	23.91	72.0	72.4	80.40	70.5	81.5	0.497	80.3	76.3
Hypertension	23.46	77.9	69.8	76.40	80.5	71.3	0.485	81.8	72.3
Metabolic syndrome	23.95	87.4	78.5	73.45	88.0	85.5	0.497	89.2	82.7
High TC	22.59	64.2	61.3	75.70	57.2	67.6	0.470	65.4	63.5
High TG	22.76	82.2	63.4	76.95	75.9	71.6	0.484	78.6	71.5
Low HDL-C	23.10	74.8	66.2	75.70	71.6	67.7	0.467	79.5	61.5

BMI body mass index, *WC* waist circumference, *WHtR* waist-to-height ratio, *FBG* fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol

($P < 0.05$ for all). Additionally, the AUC for the prediction of MS was highest for WHtR in the women (AUC = 0.920), but for WC in the men (AUC = 0.861).

Table 4 summarizes the optimal cutoff points of the three anthropometric indices in the prediction of cardiometabolic risk factors using ROC analysis. Among men, the optimal BMI cutoff values for predicting diabetes mellitus, hypertension, MS, and dyslipidemia varied from 24.5 to 25.7 kg/m²; meanwhile, the optimal WC cutoff values varied from 83.7 to 89.4 cm, and the optimal WHtR

values varied from 0.48 to 0.51. Among women, the BMI cutoff values for predicting cardiometabolic risk varied between 22.6 and 24.0 kg/m^2, while those for WC and WHtR varied between 73.5 and 80.4 cm, and 0.47 and 0.50, respectively.

In order to compare the relative strengths of the association of BMI, WC, and WHtR with MS, we calculated the ORs (95% CI) of MS for each 1 SD increase in the anthropometric indicators. The global goodness of fit of the models was assessed using the Bayesian Information Criterion (BIC). After adjustment for age, gender, tobacco, and alcohol consumption, the OR (95% CI) for MS was higher for BMI (1.473 [1.457–1.489]) than for WHtR (1.320 [1.310–1.330]) or WC (1.188 [1.182–1.194]). The corresponding BIC values were the lowest for WHtR and highest for BMI (data not shown).

The normal weight subjects (n = 18,186) constituted 49.6% of the total population. Of the 8,594 normal weight men, 233 (2.7%) had central obesity as defined by a WHtR ≥ 0.514. As outlined in Table 5, the centrally obese, normal weight men were older and had greater levels of SBP, DBP, FBG, TC, TG, TC/HDL-C ratio, and uric acid in comparison with their normal weight and non-centrally obese counterparts. Of the 9,592 normal weight women, 600 (6.3%) had central obesity (WHtR ≥ 0.497). The centrally obese, normal weight women were older and had greater levels of SBP, DBP, FBG, TC, TG, TC/HDL-C ratio, and uric acid in comparison with normal weight and non-centrally obese women.

The normal WC subjects (n = 27,469) constituted 47.7% of the total population. Of the 15,261 normal WC men, 1,699 (11.1%) had central obesity as defined by a

WHtR ≥ 0.514; meanwhile, of the 12,208 normal WC women, 678 (5.6%) had central obesity (WHtR ≥ 0.497). Similar to the results reported among normal weight subjects, the centrally obese but normal WC men and women were older and had greater levels of SBP, DBP, FBG, TC, TG, TC/HDL-C ratio, and uric acid in contrast to non-centrally obese and normal WC counterparts (Table 6).

Discussion

Using a BMI cutoff of ≥27.0 kg/m^2, estimates suggest that the prevalence of obesity in Taiwanese men and women is 10.5 and 13.2%, respectively [26]. In contrast, rates of obesity (BMI ≥30.0 kg/m^2) in the United States are approximately three times as high (32.2 and 35.5% in men and women, respectively) [27]. Despite the threefold difference in obesity prevalence, rates of diabetes in Taiwan and United States are nearly identical (9.2% [28] and 7.9% [2], respectively), and rates of metabolic syndrome in Taiwan are not far behind those in the United States (15.7% [29] and 23.7% [34], respectively). Thus, even when applying Asian-specific thresholds, BMI appears to be a relatively poor predictor of cardiometabolic risk among Taiwanese adults. The findings of this study, which include data from over 36,000 men and women, suggest that a simple measure of centralized obesity (WHtR) may be a superior measure of cardiometabolic risk among Taiwanese. Additionally, WHtR may identify cardiometabolic risk even among individuals deemed 'healthy' according to more established indices (BMI and WC).

Table 5 Demographic and cardiometabolic risk factors in normal weight (body mass index 18.5–23.9 kg/m^2) adults by WHtR

	Men (n = 8,594) Waist-to-height ratio			Women (n = 9,592) Waist-to-height ratio		
	<0.514 (n = 8,361)	≥0.514 (n = 233)	P value	<0.497 (n = 8,992)	≥0.497 (n = 600)	P value
Age (years)	35.74 ± 8.73	50.92 ± 14.49	<0.001*	35.96 ± 8.74	44.45 ± 13.83	<0.001*
SBP (mm Hg)	122.26 ± 12.17	129.89 ± 15.05	<0.001*	112.30 ± 12.98	120.11 ± 18.40	<0.001*
DBP (mm Hg)	75.84 ± 8.77	80.28 ± 10.87	<0.001*	70.27 ± 8.81	72.99 ± 10.31	<0.001*
FBG (mg/dl)	89.08 ± 14.03	99.07 ± 26.61	<0.001*	84.62 ± 12.59	92.83 ± 19.08	<0.001*
TC (mg/dl)	177.73 ± 31.09	193.92 ± 37.01	<0.001*	176.41 ± 31.15	186.73 ± 37.14	<0.001*
TG (mg/dl)	102.81 ± 74.84	149.02 ± 119.81	<0.001*	74.23 ± 40.84	105.52 ± 76.79	<0.001*
HDL-C (mg/dl)	53.24 ± 11.34	49.52 ± 10.88	<0.001*	63.64 ± 12.93	58.13 ± 12.76	<0.001*
TC/HDL-C ratio	3.47 ± 0.89	4.07 ± 1.09	<0.001*	2.85 ± 0.66	3.33 ± 0.87	<0.001*
Uric acid	6.25 ± 1.15	6.53 ± 1.32	0.002*	4.51 ± 0.90	4.91 ± 1.16	<0.001*

Values are means ± SD, and P values are from independent two sample t tests

FBG fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol

* Indicates significant difference between men and women, P < 0.05

Table 6 Demographic and cardiometabolic risk factors in normal waist circumference (men < 90 cm, women < 80 cm) adults by WHtR

	Men (n = 15,261) Waist-to-height ratio			Women (n = 12,208) Waist-to-height ratio		
	<0.514 (n = 13,562)	≥0.514 (n = 1,699)	P value	<0.497 (n = 11,530)	≥0.497 (n = 678)	P value
Age (years)	35.87 ± 8.42	43.02 ± 11.35	<0.001*	35.57 ± 8.79	44.33 ± 12.81	<0.001*
SBP (mm Hg)	123.59 ± 12.49	129.39 ± 14.03	<0.001*	112.32 ± 13.14	122.83 ± 18.76	<0.001*
DBP (mm Hg)	76.78 ± 9.09	80.89 ± 10.15	<0.001*	70.39 ± 8.93	74.93 ± 10.66	<0.001*
FBG (mg/dl)	89.68 ± 14.31	95.55 ± 21.88	<0.001*	87.47 ± 11.91	94.09 ± 21.37	<0.001*
TC (mg/dl)	179.92 ± 31.56	193.99 ± 35.16	<0.001*	175.83 ± 31.17	188.24 ± 35.63	<0.001*
TG (mg/dl)	111.60 ± 83.77	159.34 ± 132.43	<0.001*	73.78 ± 40.05	113.64 ± 88.51	<0.001*
HDL-C (mg/dl)	51.82 ± 11.28	47.80 ± 10.86	<0.001*	63.60 ± 12.94	57.09 ± 11.98	<0.001*
TC/HDL-C ratio	3.61 ± 0.95	4.22 ± 1.17	<0.001*	2.85 ± 0.67	3.41 ± 0.85	<0.001*
Uric acid	6.39 ± 1.19	6.71 ± 1.28	<0.001*	4.51 ± 0.91	5.06 ± 1.12	<0.001*

Values are means ± SD, and P values are from independent two sample t tests

FBG fasting blood glucose, SBP systolic blood pressure, DBP diastolic blood pressure, TC total cholesterol, TG triglycerides, HDL-C high-density lipoprotein cholesterol

* Indicates significant difference between men and women, P < 0.05

It is generally accepted that obesity, as defined by BMI, increases the risk of type-2 diabetes [2], hypertension [2], cardiovascular disease [3], and all-cause mortality [4]. Unfortunately, the appropriate cutoff points to best identify at-risk individuals are not consistent across different populations. Although a number of authors and groups have proposed alternative BMI criteria specific to Asian populations [35, 36], there currently exists no consensus [37]. In fact, the most recent attempt on behalf of the World Health Organization (WHO) concluded that since the BMI cutoffs at which significant cardiometabolic risk begins varies between 26.0 and 31.0 kg/m^2, depending on country, no attempt was made to redefine cutoff points for Asian populations [37]. Unfortunately, in terms of tracking population obesity level and accurately identifying individuals at cardiometabolic risk, such matters are not trivial. For example, the prevalence of obesity in Taiwan is 10.5% in men and 13.2% in women when using the BMI cutoffs of ≥27.0 kg/m^2, but 2.4 and 5.6%, respectively, when applying the BMI ≥30.0 kg/m^2 cutoffs [26]. The results of our ROC analysis suggest that the ideal BMI cutoffs for identifying cardiometabolic risk in Taiwanese men and women are 24.5–25.7 kg/m^2 and 22.6 and 24.0 kg/m^2, respectively.

Nevertheless, the central deposition of excess weight has been proven to be a stronger predictor of risk of morbidity [6–10] and mortality [11] in comparison with overall obesity. Although WC is often used as a marker of central obesity, and its use has been adopted into clinical screening guidelines [13], WC cutoff points cannot be used universally across gender or race [14]. Indeed, optimal WC cutoffs for denoting cardiometabolic risk may not only differ between Asians and Caucasians [14], but also between

Asians from different countries [15, 16]. It is suggested that optimal WC cutoffs for abdominal obesity among men and women in Japan are 85 and 90 cm [38], respectively, while those in Korea are 90 and 85 cm [39]. By comparison, the results of the current study illustrate that the optimal WC cutoffs for predicting cardiometabolic risk among Taiwanese are between 83.7 and 89.4 cm in men and between 73.5 and 80.4 cm in women. In unison, these results highlight the variability in WC thresholds between race, gender, and even country of origin. Finally, the measurement of WC also ignores the reported influence of height on cardiometabolic risk [17, 40].

The WHtR is an alternative anthropometric index of central obesity that circumvents the limitations of WC by adjusting for variations in height and providing a universal cutoff value equally appropriate for use among Asian and Caucasian, as well as men and women [18, 19, 21–23, 41]. Specifically, Ashwell and Hsieh [18] have recently suggested that a WHtR threshold of 0.5 is appropriate to delineate patients with significant cardiometabolic risk from those without, regardless of sex and race. Our results in Taiwanese adults corroborate these suggestions, finding that the optimal threshold for identifying cardiometabolic risk was between 0.48 and 0.51 in the men and 0.47 and 0.50 in the women. Thus, a major advantage of WHtR over WC appears to be simplicity. Such an advantage could translate to enhanced delivery of public health messages aimed at reducing obesity rates, as well as the clinical screening of individuals at risk of cardiometabolic complications. To that end, Ashwell and Hsieh [18] suggest the following message: "Keep your waist circumference to less than half your height."

Some authors suggest that WHtR may be the best simple anthropometric index for predicting a wide range of cardiometabolic risk factors associated with central obesity [18, 21, 41]. The results of our ROC analyses illustrated that in both sexes, the WHtR was superior to BMI and WC as a predictor of diabetes mellitus, hypertension, high TC, high TG, and low HDL-C. Additionally, in the women, the WHtR was also the best predictor of MS. Nevertheless, the results of logistic regression analysis, which investigated the relationship between a 1 SD increase in any of the three indices and the risk of MS, suggested that an increase in BMI had a slightly greater impact on MS risk in comparison with WHtR and WC. Thus, for optimal assessment of a patient's cardiometabolic risk, it may be ideal to use BMI in concert with a measure of central adiposity such as WC and WHtR, as has been previously suggested in clinical guidelines [13]. In prior studies, WHtR has also been shown to denote cardiometabolic risk among individuals who are not obese according to other anthropometric indices [23–25]. In agreement with these prior observations, the current study found that an elevated WHtR was able to predict elevated cardiometabolic risk in both men and women who had a normal BMI or WC level. Thus, WHtR may also be able to identify cardiometabolic risk among individuals deemed 'healthy' according to BMI and WC.

A number of limitations are inherent to the current study and warrant mention. First, since the study is cross-sectional in nature, future longitudinal studies assessing the prospective risk of cardiovascular disease and related mortality according to each anthropometric index are needed to fully elucidate the reported relationships. Although diet and physical activity are known confounders of the relationship between anthropometry and cardiometabolic risk, due to a lack of relevant data, these variables were not accounted for in the analysis. While we did not quantify the extent of the intra- and inter-observer error in the measurement of the various anthropometric outcomes, we took a number of precautions to ensure quality control in the collection of data (as described in the "Methods" sect.). Finally, we were also unable to examine the potential mechanisms behind the relationship between anthropometric markers and cardiometabolic risk factors. Nevertheless, the notable strength of the current study included data from over 36,000 men and women from both southern and northern parts of Taiwan as well as rigorous and comprehensive statistical analyses.

In conclusion, WHtR is a simple and effective index of cardiometabolic risk among Taiwanese men and women, which may be superior to BMI and WC. Indeed, a WHtR of >0.5 was shown to clearly identify men and women at an elevated risk of diabetes, hypertension, metabolic syndrome, and dyslipidemia. Our findings also highlight the

variability in optimal cutoff points for established anthropometric indices of risk, such as BMI and WC, and reconfirm the notion that these values are lower in Asian versus Caucasian populations. Finally, our analyses revealed that WHtR can identify adults at cardiometabolic risk, even when such individuals are categorized as 'healthy' or 'normal' according to BMI or WC.

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