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Waist-to-hip ratio is a better anthropometric index than body mass index for predicting the risk of type 2 diabetes in Taiwanese population

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Abstract

Body mass index (BMI) has been reported to be related to the risk of type 2 diabetes and hypertension. However, waist circumference or waist-to-hip ratio (WHR) can better reflect the accumulation of intra-abdominal fat and might be a better predictor than BMI of the risk of type 2 diabetes and hypertension. We hypothesized that other anthropometric indices rather than BMI could more accurately predict the risk of type 2 diabetes and hypertension. The purpose of this study was to determine which anthropometric index can be a better predictor for forecasting the risk of type 2 diabetes and hypertension in the Taiwanese population. We conducted a cross-sectional study and reviewed data derived from the Nutrition and Health Survey in Taiwan, 1993-1996. The subjects were 2545 men and 2562 women, aged 18 to 96 years. Receiver operating characteristic curve analysis was used to measure the predictive diabetic and hypertensive performance of each anthropometric measurement based on the area under the curve (AUC). Among 5 anthropometric indices, WHR had a significantly adjusted odds ratio (OR) and the highest AUC (0.72 for men and 0.80 for women) to predict the risk of type 2 diabetes. Although BMI had a significantly adjusted OR, the AUC was not the highest among the 5 anthropometric indices used to predict the risk of hypertension. Our findings suggested that WHR is a better anthropometric index for predicting the risk of type 2 diabetes, and the optimal cutoff values of WHR are considered as 0.89 for men and 0.82 for women in the Taiwanese population.

Keywords: Waist-to-hip ratio; Type 2 diabetes; Receiver operating characteristic curve; Optimal cutoff value; Taiwan; Human
Abbreviations: AUC, area of under curve; BMI, body mass index; CI, confidence interval; HC, hip circumference; OR, odds ratio; ROC, receiver operating characteristic; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

1. Introduction

Body mass index (BMI), a general measure of obesity, has been reported to be closely related to the risk of type 2 diabetes and hypertension [1-3]. Because diabetic and hypertensive risks are related to intra-abdominal fat rather than subcutaneous fat [4,5], waist circumference (WC) or

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waist-to-hip ratio (WHR) can better reflect the accumulation of intra-abdominal fat compared with BMI, which is affected by the height index. WC or WHR has been shown to be a better predictor of the risk of type 2 diabetes and hypertension than BMI [6-9]. However, age [10-12], sex [13], and ethnicity [14-16] can confound the predictive accuracy of WC or WHR.

Adipose tissue distribution is affected by age. The consequence of abdominal obesity might be insulin resistance, which can lead to impaired glucose tolerance and progression to type 2 diabetes [10,17,18]. Age has been shown to be a confounder in the BMI-specific associations between WHR and glycemic status [10]. Because diabetic and hypertensive risks are related to visceral fat mass, anthropometric indices might not be good predictors of risk in young or older subjects [10,12,19]. Sex difference is also a confounder in the predictive risks of diabetes and hypertension. Sex hormone concentration has an influence on body fat accumulation and the development of insulin resistance [20,21]. Abdominal fat might be more important than the total body fat in predicting the risk of type 2 diabetes in women [13]. In addition to BMI, WC, and WHR, waist-to-height ratio (WHtR) was shown to be an independent variable in predicting risk of developing hypertension and abnormal glucose tolerance in both sexes [22-24]. The WHtR, an indicator of both abdominal fat and body weight, might be another simple index that can be used to predict the risk of type 2 diabetes and hypertension. Ethnicity is another confounder in the predictive risk of type 2 diabetes and hypertension [14]. Asians generally have smaller frames and lower body fat distribution than whites, even when they have similar BMI [25,26]. However, Asian Indians have more abdominal fat than whites [27]. A prevalent difference in the association between BMI and hypertension was observed in 3 different ethnic groups including Chinese, Filipinos, and whites [14]. Different cutoff values for anthropometric indices seem to be required to correlate the risk of type 2 diabetes and hypertension in different ethnic groups.

Since 2002, type 2 diabetes has been the 4th and hypertension the 10th leading causes of death in Taiwan [28]; it is important to identify a convenient, sensitive screening index for predicting the risk of type 2 diabetes and hypertension in the general Taiwanese population. However, the evidence demonstrating the correlation of BMI, WC, WHR, WHtR, or WC/BMI ratio with the risk of type 2 diabetes and hypertension in the Taiwanese population is scant and inconsistent. We hypothesized that other anthropometric index rather than BMI could more accurately predict the risk of type 2 diabetes and hypertension. Therefore, the purpose of this study was to ascertain which anthropometric index can be better at predicting the risk of type 2 diabetes and hypertension in the Taiwanese population. Because receiver operating characteristic (ROC) plots can provide an index of a precise and valid measure of diagnostic accuracy [29], ROC analysis was then used to detect which level of anthropometric indices mark thresholds for type 2 diabetes and hypertension.

2. Materials and methods

2.1. Subjects and design

The study data were obtained from the Nutrition and Health Survey in Taiwan (1993-1996), a national survey that was conducted to examine the changes in nutrition and health status of Taiwanese individuals. This survey was conducted by the Bureau of Health Promotion of the Department of Health in Taiwan. A stratified, multistage clustered sampling scheme was performed [30,31], and the detailed procedure has been described elsewhere [30]. Briefly, data were drawn from 7 geographical districts (ie, Hakka, mountainous, east coast area, Peng-Hu, metropolitan, provincial cities and urbanization class townships, and class II rural townships) according to their geographic location and degree of urbanization. Three townships or city districts in each stratum were selected with the selection probability proportional to their size (PPS). In each selected township/city district, *lins* (the smallest administrative unit) were selected by PPS. Four households were selected randomly from each selected *lin*. The standardized, structured questionnaires were used to collect data on the nutrition status, lifestyle, nutrition-related knowledge, attitude and practice, and nutrition-related disease status of subjects via face-to-face interviews. Subjects reported to a local clinical research station in the morning to have fasting blood drawn and undergo a physical examination. The target population included individuals aged 4 years and older in this national survey. There were 5107 adult subjects (2545 men and 2562 women) aged 18 years and older included in the present study. Each subject gave informed written consent.

2.2. Data collection

A household interview and physical examination were completed by technicians who received a 1-week training course [30]. Demographic data including age, sex, smoking, and drinking habits were recorded. Clinical hematologic measurements including total cholesterol (TC), triglyceride (TG), and low- and high-density lipoprotein cholesterol were determined. Anthropometric measurements were carried out after the subjects had removed their shoes and heavy clothes. Body weight was measured to the nearest 0.1 kg using a weighing scale [32]. Body height was measured to the nearest 0.1 cm using a wall-glued metal measuring tape and an acute-angled head piece while the subjects stood against a plumb-checked vertical wall and wore no shoes. The BMI (in kilograms per meter squared) was calculated from height and weight measurements. The WC measurement (measured to the

Table 1
Demographic characteristics and anthropometric indices of subjects with and without type 2 diabetes mellitus[a]

Variables	Men (n = 2545)		Women (n = 2562)		Total (N = 5107)	
	Yes (n = 111)	No (n = 2434)	Yes (n = 149)	No (n = 2413)	Yes (n = 260)	No (n = 4847)
Age (y)	59.3 ± 9.9	47.4 ± 17.4 *	63.9 ± 10.7	46.7 ± 17.5 *	61.9 ± 10.6	47.0 ± 17.5 *
Weight (kg)	69.0 ± 10.1	64.6 ± 10.5 *	59.1 ± 9.8	57.2 ± 9.9	63.3 ± 11.1	60.7 ± 10.9 *
Height (cm)	165.9 ± 5.7	165.7 ± 6.5	152.2 ± 6.6	154.6 ± 6.0 *	158.1 ± 9.2	159.9 ± 8.4 *
BMI (kg/m^2)	25.0 ± 3.1	23.5 ± 3.4 *	25.5 ± 3.9	24.0 ± 4.1 *	25.3 ± 3.6	23.7 ± 3.8 *
Obesity (%)[b]	19.8	8.4 *	23.5	13.3 *	21.9	10.9 *
WC (cm)	87.0 ± 8.5	81.0 ± 9.8 *	83.8 ± 9.0	75.3 ± 10.1 *	85.2 ± 8.9	78.3 ± 10.3 *
Central obesity (%)[c]	25.2	10.2 *	46.3	20.2 *	37.3	15.2 *
HC (cm)	95.4 ± 6.2	93.8 ± 6.2 *	95.8 ± 8.2	95.1 ± 7.3	95.6 ± 7.4	94.5 ± 6.8 *
WHR	0.9 ± 0.1	0.9 ± 0.1 *	0.9 ± 0.1	0.8 ± 0.1 *	0.9 ± 0.1	0.8 ± 0.1 *
WHtR	0.5 ± 0.1	0.5 ± 0.1 *	0.6 ± 0.1	0 .5 ± 0.1 *	0.5 ± 0.1	0.5 ± 0.1 *
WC/BMI ratio	3.5 ± 0.2	3.5 ± 0.3	3.3 ± 0.3	3.2 ± 0.3 *	3.4 ± 0.3	3.3 ± 0.3 *
Smoking, n (%)	80 (72.1)	1652 (67.9)	15 (10.1)	223 (9.2)	95 (36.5)	1875 (38.7)
Drinking, n (%)	25 (22.5)	690 (28.3)	8 (5.4)	138 (5.7)	33 (12.7)	828 (17.1)

Values are expressed as mean ± standard deviation, unless otherwise indicated.

[a] Values are significantly different between the yes and no subgroups within the group by Student *t* test or Mann-Whitney rank sum test for a continuous data and x^2 test or Fisher exact test for categorical data.

[b] Obesity is defined as BMI at least 27 kg/m^2 for both men and women.

[c] Central obesity is defined as WC at least 90 cm for men and at least 80 cm for women.

* $P < .05$.

nearest 0.1 cm) was determined with the use of a soft measuring tape at the level of the natural waist, which was identified as the level at the hollow molding of the trunk when the trunk was bent laterally [33]. Hip circumference (HC, measured to the nearest 0.1 cm) was measured at the level of the greater trochanter. WHR, WHtR, and WC/BMI ratio were also calculated. Subjects with type 2 diabetes mellitus or hypertension were identified by self-report. Obesity was defined as BMI at least 27 kg/m^2 for both men and women [34,35], and central obesity was defined as WC at least 90 cm for men and WC at least 80 cm for women according to the criteria of the Department of Health, Taiwan [36].

2.3. Statistical analyses

Data were analyzed with SAS statistical software (version 9.1.4; SAS Institute, Inc, Cary, NC). Previous studies [37] indicated that the sensitivities of WHR were 0.71 for men and 0.79 for women in discriminating the risk of type 2 diabetes. Therefore, the required sample size of 275 subjects allowed a level of significance of $\alpha = .05$ and a power of

Table 2
Demographic characteristics and anthropometric indices of subjects with and without hypertension[a]

Variables	Men (n = 2545)		Women (n = 2562)		Total (N = 5107)	
	Yes (n = 327)	No (n = 2218)	Yes (n = 421)	No (n = 2141)	Yes (n = 748)	No (n = 4359)
Age (y)	61.4 ± 11.6	45.9 ± 17.1 *	61.3 ± 12.2	45.0 ± 17.3 *	60.5 ± 11.9	45.5 ± 17.2 *
Weight (kg)	68.6 ± 10.8	64.1 ± 10.3 *	60.8 ± 9.9	56.6 ± 9.8 *	64.3 ± 11.0	60.2 ± 10.7 *
Height (cm)	163.9 ± 6.1	166.1 ± 6.5 *	151.6 ± 5.8	155.0 ± 6.0 *	157.2 ± 8.5	160.2 ± 8.4 *
BMI (kg/m^2)	25.4 ± 3.3	23.2 ± 3.3 *	26.4 ± 3.8	23.6 ± 4.0 *	26.0 ± 3.6	23.4 ± 3.7 *
Obesity (%)[b]	19.9	7.3 *	27.1	11.4 *	23.9	9.3 *
WC (cm)	87.4 ± 8.8	80.2 ± 9.6 *	82.7 ± 9.0	74.5 ± 10.0 *	84.8 ± 9.2	77.2 ± 10.2 *
Central obesity (%)[c]	25.4	8.7 *	40.6	18.0 *	34.0	13.3 *
HC (cm)	96.2 ± 6.2	93.4 ± 6.1 *	97.8 ± 7.8	94.6 ± 7.2 *	97.1 ± 7.2	94.0 ± 6.7 *
WHR	0.9 ± 0.1	0.9 ± 0.1 *	0.8 ± 0.1	0.8 ± 0.1 *	0.9 ± 0.1	0.8 ± 0.1 *
WHtR	0.5 ± 0.0	0.5 ± 0.1 *	0.5 ± 0.1	0 .5 ± 0.1 *	0.5 ± 0.1	0.5 ± 0.1 *
WC/BMI ratio	3.5 ± 0.3	3.5 ± 0.3	3.2 ± 0.3	3.2 ± 0.3	3.3 ± 0.3	3.3 ± 0.3 *
Smoking, n (%)	190 (58.1)	1542 (69.5)	39 (9.3)	199 (9.3)	229 (30.6)	1741 (39.9)
Drinking, n (%)	78 (23.9)	637 (28.7)	24 (5.7)	122 (5.7)	102 (13.6)	759 (17.4)

Values are expressed as mean ± standard deviation, unless otherwise indicated.

[a] Values are significantly different between the yes and no subgroups within the group by Student *t* test or Mann-Whitney rank sum test for a continuous data and x^2 test or Fisher exact test for categorical data.

[b] Obesity is defined as BMI at least 27 kg/m^2 for both men and women.

[c] Central obesity is defined as WC at least 90 cm for men and at least 80 cm for women.

* $P < .05$.

80%. Differences in male and female subjects' demographic data, clinical hematologic measurements, and anthropometric indices were analyzed by Student t test or Mann-Whitney rank sum test. For categorical response variables, differences between the 2 groups were assessed by x^2 test or Fisher exact test. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) for type 2 diabetes or hypertension were calculated from the multiple logistic regression model [38] according to the second and third tertiles of BMI, WC, WHR, WHtR, and WC/BMI ratio in each sex group and cutoff values. Because our interest was the relationship, no weight was used in multiple logistic regression and ROC curve analyses.

Furthermore, ROC curve analysis was used to measure the predictive power of each anthropometric index based on the area under the curve (AUC). The optimal cutoff values of BMI, WC, WHR, WHtR, and WC/BMI ratio were defined as the minimal value of $r\left(r=\sqrt{[(1-\text{Specificity})-0]^2+(\text{Sensitivity})^2}\right)$. Statistical results were considered to be significant at $P < .05$. Values presented in the text are means ± standard deviation.

3. Results

In total, 2545 men and 2562 women were included in this study. Subjects' ages ranged from 18 to 96 years, with mean and median ages of 47.7 and 48.0 years, respectively. There were 260 subjects (111 men, 149 women) with type 2 diabetes mellitus and 748 subjects (327 men, 421 women) with hypertension. The prevalence rates of type 2 diabetes and hypertension were 5.1% and 14.6% for the total population, respectively; women had a higher prevalence of type 2 diabetes (5.8% vs 4.4%) and hypertension (16.4% vs 12.8%) than did men. Basic characteristics of the population are shown in Tables 1 and 2. Generally speaking, male and female subjects with either type 2 diabetes or hypertension were significantly older and had a higher BMI, WC, WHtR, and WC/BMI ratio than subjects without type 2 diabetes or hypertension. The mean BMI of both men and women was less than 27 kg/m^2, which was not considered to be indicative of obesity. However, regarding individual obesity, 8.8% of men and 13.8% of women were considered to be obese (BMI at least 27 kg/m^2) with 10.7% of men and

Table 3
The OR for type 2 diabetes mellitus in relation to each anthropometric index after adjustment for potential confounders

	Men (n = 2545)							Women (n = 2562)					
	Age adjusted		Age, smoking, and drinking adjusted		Age, smoking, drinking, TC, and TG adjusted			Age adjusted		Age, smoking, and drinking adjusted		Age, smoking, drinking, TC, and TG adjusted	
	OR	95% CI	OR	95% CI	OR	95% CI		OR	95% CI	OR	95% CI	OR	95% CI
BMI (kg/m^2)							BMI (kg/m^2)						
>25.74	3.55	2.30-5.50	3.45	2.20-5.44	2.91	1.65-5.12	>26.63	2.16	1.43-3.25	2.12	1.36-3.32	2.09	1.19-3.68
23.39-25.74	2.22	1.27-3.86	2.30	1.29-4.09	2.05	1.05-4.01	23.73-26.63	1.63	1.05-2.53	1.61	0.99-2.62	1.37	0.73-2.55
<23.39	1.00		1.00		1.00		<23.73	1.00		1.00		1.00	
BMI (kg/m^2)[a]							BMI (kg/m^2)[a]						
>25.74					1.96	0.97-3.94	>26.63					0.82	0.42-1.59
23.39-25.74					1.32	0.64-2.73	23.73-26.63					0.76	0.38-1.50
< 23.39					1.00		<23.73					1.00	
WC (cm)							WC (cm)						
>87.80	3.32	2.12-5.19	3.25	2.04-5.19	2.94	1.57-5.45	>82.60	2.94	1.99-4.33	3.43	2.23-5.26	4.36	2.21-8.58
81.30-87.80	2.21	1.34-3.66	2.08	1.23-3.53	2.03	1.05-3.96	74.90-82.60	1.64	1.03-2.62	1.83	1.10-3.06	2.09	1.02-4.60
<81.30	1.00		1.00		1.00		<74.90	1.00		1.00		1.00	
WHR							WHR						
>0.91	3.58	2.27-5.67	3.46	2.14-5.60	3.70	1.88-7.26	>0.84	3.71	2.52-5.46	4.22	2.76-6.46	9.13	3.71-22.46
0.87-0.91	2.81	1.71-4.61	2.68	1.59-4.50	3.20	1.61-6.35	0.79-0.84	1.40	0.84-2.33	1.20	0.66-2.18	3.23	1.22-8.51
<0.87	1.00		1.00		1.00		<0.79	1.00		1.00		1.00	
WHR[b]							WHR[b]						
>0.91					2.51	1.17-5.38	>0.84					8.88	3.36-23.47
0.87-0.91					2.58	1.23-5.43	0.79-0.84					2.90	1.06-7.95
<0.87					1.00		<0.79					1.00	
WHtR							WHtR						
>0.53	3.32	2.14-5.18	3.39	2.13-5.37	2.97	1.58-5.59	>0.54	3.07	2.10-4.49	3.50	2.30-5.34	4.74	2.35-9.56
0.49-0.53	1.88	1.12-3.15	1.71	0.99-2.95	1.77	0.89-3.51	0.49-0.54	1.44	0.88-2.38	1.52	0.87-2.63	2.09	0.94-4.62
<0.49	1.00		1.00		1.00		<0.49	1.00		1.00		1.00	
WC/BMI ratio							WC/BMI ratio						
>3.63	0.97	0.57-1.65	0.85	0.48-1.49	0.76	0.40-1.45	>3.35	1.73	1.15-2.59	1.70	1.08-2.68	1.48	0.82-2.66
3.46-3.63	1.88	1.17-3.01	1.77	1.08-2.89	1.42	0.81-2.49	3.17-3.35	4.43	0.90-2.27	1.55	0.94-2.55	1.48	0.80-2.72
<3.46	1.00		1.00		1.00		<3.17	1.00		1.00		1.00	

[a] Additionally adjusted for WHR.
[b] Additionally adjusted for BMI.

21.5% of women having central obesity (WC at least 90 cm for men and at least 80 cm for women).

Tables 3 and 4 show the ORs for developing type 2 diabetes and hypertension by tertiles of BMI, WC, WHR, WHtR, and WC/BMI ratio. Generally speaking, the age-adjusted OR for type 2 diabetes and hypertension in both male and female subjects was significantly increased in the second or third tertiles of BMI, WC, WHR, WHtR, and WC/BMI ratio. When smoking, drinking, TC, and TG were included in the regression model, the significance remained in the second and third tertiles for BMI, WC, and WHR only. We simultaneously adjusted BMI and WHR into the model. After the adjustments, the ORs for type 2 diabetes only slightly decreased but remained significant for WHR but not for BMI, whereas the ORs for hypertension slightly decreased but remained significant for BMI but not for WHR.

The ROC curve was calculated to compare the predictive power of all anthropometric indices for the risk of type 2 diabetes and hypertension (Figs. 1 and 2). Among 5 anthropometric indices, WHR appeared to have the highest AUC (0.72 for men and 0.80 for women) to predict the risk of type 2 diabetes. The optimal cutoff values for WHR to determine the risk of developing type 2 diabetes were 0.89 for men and 0.82 for women, respectively. Although BMI had significantly adjusted ORs, the AUC was not the highest among all anthropometric indices to predict the risk of hypertension.

4. Discussion

Several studies have indicated that age is a confounder when using anthropometric indices to predict the risk of type 2 diabetes or hypertension [10,12,19]. Daniel et al [10] stratified subjects into 3 age categories: 18-34 (n = 53), 35-49 (n = 62), and at least 50 years (n = 36), showing that age confounded the association between WHR and glycemic status. We also stratified our subjects according to age but used different categories than the one used by Daniel et al: 18-44 (n = 2266), 45-64 (n = 1855), and at least 65 years (n = 1012). However, relationships between anthropometric indices and type 2 diabetes or hypertension were consistent across age groups (data not shown). We hypothesized that a larger sample size in each age group might increase the

Table 4
The OR for hypertension in relation to each anthropometric index after adjustment for potential confounders

	Men (n = 2545)							Women (n = 2562)					
	Age adjusted		Age, smoking, and drinking adjusted		Age, smoking, drinking, TC, and TG adjusted			Age adjusted		Age, smoking, and drinking adjusted		Age, smoking, drinking, TC, and TG adjusted	
	OR	95% CI	OR	95% CI	OR	95% CI		OR	95% CI	OR	95% CI	OR	95% CI
BMI (kg/m^2)							BMI (kg/m^2)						
>25.74	3.79	2.82-5.10	3.84	2.82-5.23	4.00	2.72-5.87	>26.63	3.28	2.50-4.29	3.44	2.58-4.58	5.12	3.46-7.59
23.39-25.74	2.24	1.56-3.21	2.22	1.52-3.26	2.36	1.51-3.68	23.73-26.63	1.59	1.18-2.14	1.63	1.18-2.26	1.62	1.62-3.74
<23.39	1.00		1.00		1.00		<23.73	1.00		1.00		1.00	
BMI (kg/m^2) [a]							BMI (kg/m^2) [a]						
>25.74					3.17	1.98-5.09	>26.63					4.53	2.94-6.97
23.39-25.74					2.08	1.31-3.29	23.73-26.63					2.35	1.51-3.65
<23.39					1.00		<23.73					1.00	
WC (cm)							WC (cm)						
>87.80	3.02	2.25-4.05	3.18	2.33-4.33	3.19	2.13-4.76	>82.60	2.22	1.70-2.91	2.36	1.77-3.14	2.62	1.77-3.87
81.30-87.80	1.95	1.41-2.70	1.93	1.37-2.73	1.99	1.30-3.03	74.90-82.60	1.35	1.00-1.82	1.51	1.10-2.07	1.80	1.20-2.70
<81.30	1.00		1.00		1.00		<74.90	1.00		1.00		1.00	
WHR							WHR						
>0.91	3.11	2.32-4.16	3.23	2.37-4.33	3.07	2.07-4.56	>0.84	2.00	1.53-2.61	2.05	1.54-2.74	2.10	1.39-3.17
0.87-0.91	1.62	1.16-2.26	1.55	1.37-2.73	1.53	1.00-2.36	0.79-0.84	1.40	1.04-1.89	1.37	0.99-1.89	1.61	1.06-2.43
<0.87	1.00		1.00		1.00		<0.79	1.00		1.00		1.00	
WHR [b]							WHR [b]						
>0.91					1.70	1.08-2.70	>0.84					0.96	0.60-1.54
0.87-0.91					1.20	0.75-1.90	0.79-0.84					1.11	0.71-1.73
<0.87					1.00		<0.79					1.00	
WHtR							WHtR						
>0.53	3.59	2.68-4.81	3.89	2.37-4.39	5.08	3.27-7.88	>0.54	2.66	2.05-4.46	2.85	2.15-3.78	3.51	2.35-5.24
0.49-0.53	2.29	1.66-3.15	2.29	1.08-2.21	3.16	2.00-4.98	0.49-0.54	1.35	0.99-1.85	1.49	1.07-2.08	1.97	1.29-3.03
<0.49	1.00		1.00		1.00		<0.49	1.00		1.00		1.00	
WC/BMI ratio							WC/BMI ratio						
>3.63	0.63	0.45-0.90	0.67	0.47-0.97	0.48	0.32-0.74	>3.35	0.54	0.39-0.74	1.54	0.38-0.77	0.34	0.23-0.53
3.46-3.63	1.40	1.02-1.93	1.40	1.00-1.96	0.95	0.65-1.40	3.17-3.35	0.78	0.57-1.07	0.76	0.54-1.07	0.57	0.38-0.85
<3.46	1.00		1.00		1.00		<3.17	1.00		1.00		1.00	

[a] Additionally adjusted for WHR.
[b] Additionally adjusted for BMI.

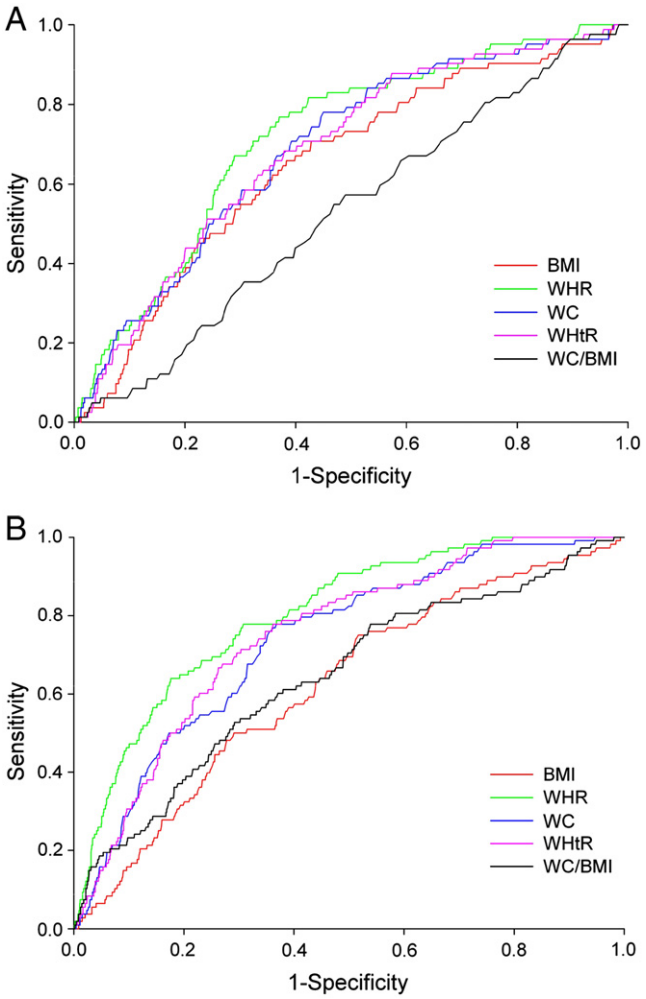

Fig. 1. ROC curves and optimal cutoff values for each anthropometric index in the prediction of type 2 diabetes mellitus. The estimates of AUC, which reflect the overall predictive accuracy, are also shown. A, Men. The AUCs were 0.65, 0.69, 0.72, 0.69, and 0.53 for BMI, WC, WHR, WHtR, and WC/BMI ratios, respectively. The optimal cutoff values of BMI, WC, WHR, WHtR, and WC/BMI ratios for predicting type 2 diabetes were 24.30 kg/m^2, 83.80 cm, 0.89, 0.51, and 3.46, respectively. B, Women. The AUCs were 0.62, 0.74, 0.80, 0.75, and 0.64 for BMI, WC, WHR, WHtR and WC/BMI ratios, respectively. The optimal cutoff values of BMI, WC, WHR, WHtR, and WC/BMI ratios for predicting type 2 diabetes were 24.00 kg/m^2, 78.50 cm, 0.82, 0.52, and 3.23, respectively.

statistical power to eliminate age as the confounder. Therefore, we pooled the data but still adjusted age into the statistical model. The significant finding of this study was that WHR was a better indicator of the risk of developing type 2 diabetes compared with other anthropometric indices in the Taiwanese population, regardless of age.

Among the 5 anthropometric indices used in this study, BMI has been shown to be a powerful predictor of type 2 diabetes [1,13,39,40]. Daniel et al [10] also indicated that BMI confounded the association between WHR and type 2 diabetes. To clarify the effects of BMI and WHR on the risk of type 2 diabetes, we simultaneously adjusted WHR and BMI into the logistic regression model. Our results showed that the association between WHR and type 2 diabetes was not affected by BMI adjustment. Our result was similar to that of a study of another Asian population, Thai adults, in which fasting plasma glucose levels were significantly and positively associated with WHR rather than with BMI [41]. In a 13.5-year follow-up Swedish study, WHR was found to be a sensitive predictor for development of type 2 diabetes in men, even when BMI was considered as a confounder [42]. The limitation of BMI in sensitive prediction of the risk of type 2 diabetes might be that it generally reflects overall obesity but not central obesity.

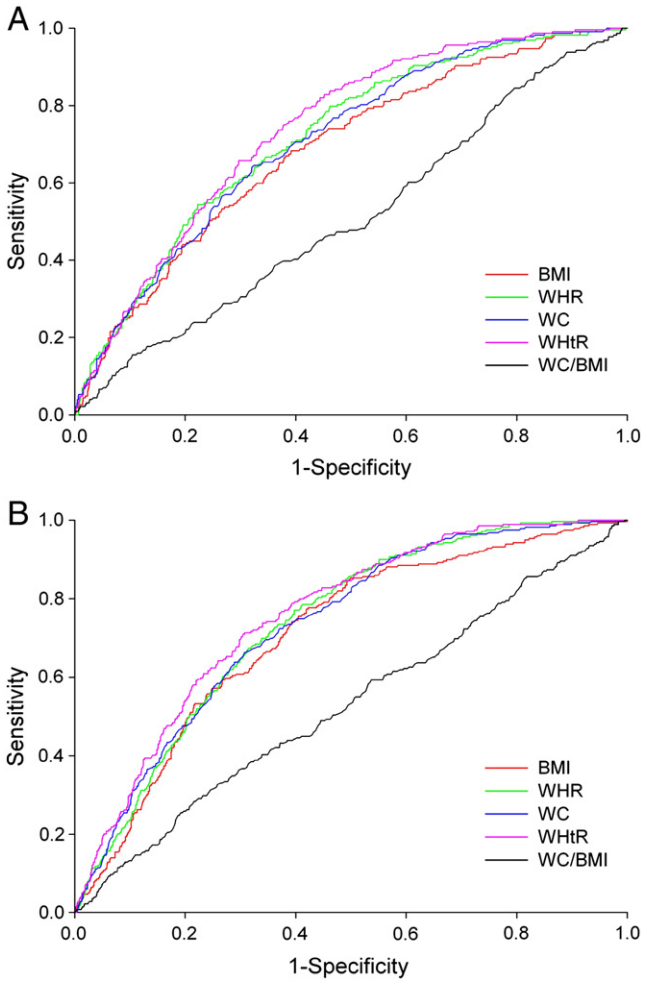

Fig. 2. ROC curves and optimal cutoff values for each anthropometric index in the prediction of hypertension. The estimates of AUC, which reflects the overall predictive accuracy, are also shown. A, Men. The AUCs were 0.69, 0.71, 0.72, 0.74, and 0.51 for BMI, WC, WHR, WHtR, and WC/BMI ratios, respectively. The optimal cutoff values of BMI, WC, WHR, WHtR, and WC/BMI ratios for predicting hypertension were 25.35 kg/m^2, 87.70 cm, 0.85, 0.51, and 3.43, respectively. B, Women. The AUCs were 0.71, 0.73, 0.74, 0.76, and 0.53 for BMI, WC, WHR, WHtR, and WC/BMI ratios, respectively. The optimal cutoff values of BMI, WC, WHR, WHtR, and WC/BMI ratios for predicting hypertension were 25.02 kg/m^2, 77.20 cm, 0.92, 0.51, and 3.19, respectively.

Studies have postulated that the expanded central fat deposits (intra-abdominal fat—WC) release more free fatty acids than peripheral fat deposits (gluteal and subcutaneous fat—HC) to reduce the hepatic clearance of insulin and increase insulin resistance and hyperglycemia [5,43,44]. Although WC is thought to be a better indicator of total body fat than visceral fat [45], WC has been considered as a better predictor of the risk of type 2 diabetes in several studies [46-49]. On the other hand, hips, thighs, and legs were counted as the largest portion of body skeletal muscle, which is the main target organ for insulin and site of resistance [50-53]. In line with previous studies [8,52,53], we found that WHR rather than WC could sensitively predict the risk of type 2 diabetes. However, there does not seem to be any consistent evidence to show the relationship between WC and body fat distribution. Although the National Heart Lung Blood Institute's Obesity Education Initiative Expert Panel indicated that a WC, in addition to a BMI, measurement should be obtained in individuals with a BMI between 25.0 and 34.9 kg/m^2 [54], WC measurement has been challenged because WC does not substantially improve prediction of coronary risk [55] and not alter treatment recommendations for individuals with BMI values between 25.0 and 34.9 kg/m^2 [56]. Because the accumulation of abdominal subcutaneous fat can markedly increase WC, leading to a significant increase in WHR, and WHR can provide additional information about relative accumulation of abdominal fat proportional to body size, it would probably be better to consider both WC and HC simultaneously when the risk of type 2 diabetes is evaluated.

In line with the findings in studies of Chinese [2,14], Japanese [57], Mauritanian [58], and Australian women [59], BMI was a better predictor than WHR of the risk of hypertension in our Taiwanese population. However, not all studies supported the strong association between BMI and the risk of hypertension. Excess body weight and obesity are well recognized to be important risk factors for hypertension, whereas abdominal fat plays a more important role in increasing the release of fatty acid in the portal blood vessels, leading to the development of hypertension [60-62]. BMI is determined from weight and height measurements, presenting the general measure of obesity rather than body fat distribution. That might be the reason why previous studies indicated that central obesity (WC or WHR) has a stronger association with the risk of hypertension [7,49,62-64]. However, the effect of BMI on the risk of hypertension still remained when WHR (abdominal obesity) was taken into account in the present study. Our Taiwanese population had relatively smaller WC compared with whites [7,49,62-64]; therefore, total body fat (BMI) might play a more dominant role than abdominal fat (WC or WHR) in predicting hypertension. However, the AUC curve was not the highest among all anthropometric indices to predict the risk of hypertension. Thus, we could not conclude that BMI is a better predictor for identifying the risk of hypertension. Further study is warranted to study the relationship between BMI and the risk of hypertension in the Taiwanese population.

The cutoff value used in this study to dichotomize WHR representing the risk of type 2 diabetes was 0.89 for men and 0.82 for women, respectively. Our cutoff values were lower than those for African Americans and white Americans (cutoff values for WHR in predicting type 2 diabetes: 0.93-1.03 for men and 0.83-0.99 for women) [8] and a UK population (cutoff values for WHR: 0.95 for men and 0.8 for women) [65], but similar to the cutoff values for a Hong Kong Chinese population (cutoff values for WHR in predicting type 2 diabetes: 0.91 for men and 0.83 for women) [15]. The difference between our Asian subjects and other populations might be due to genetic and ethnic influences.

In addition to BMI, WC, WHR, WHtR, and WC/BMI ratios have been recently used to predict cardiovascular risk [22-24]. However, we did not find WHtR and WC/BMI ratios to be better predictors of type 2 diabetes or hypertension. Since weight, height, WC, and HC are simple indices that can be done by the general population, it is probably adequate to use WHR and BMI to screen individuals for the risk of type 2 diabetes and hypertension, respectively.

An advantage to our study was that the selection biases could be eliminated because the data were from the national survey, which was representative of the general Taiwanese population. However, there are some limitations in this study. First, we defined subjects having type 2 diabetes mellitus and hypertension based on their self-report rather than by measuring their fasting blood glucose or blood pressure. Thus, subjects with mild or even moderate type 2 diabetes or hypertension may not have been accounted for. Second, we could not demonstrate the causal relationship between anthropometric indices and type 2 diabetes mellitus and hypertension because this is only a cross-sectional study. Third, the Taiwanese population generally has much smaller frames and lower subcutaneous fat and intra-abdominal fat distribution when compared with white populations. Therefore, the criteria used to define the obesity (BMI at least 30 kg/m^2) and abdominal obesity (WC at least 102 cm for men and 88 cm for women) in the white population [66] are not comparable with the criteria used in the Taiwanese population.

In conclusion, we have confirmed the hypothesis that WHR rather than BMI could more accurately predict the risk of type 2 diabetes. Among the 5 anthropometric indices used in the present study, although higher values of BMI, WC, WHR, and WHtR were associated with the risk of type 2 diabetes and hypertension, WHR appears to be an independent and better anthropometric index for identifying individuals in the Taiwanese population at high risk of developing type 2 diabetes. The optimal cutoff value for WHR in predicting the risk of type 2 diabetes is considered to be 0.89 for men and 0.82 for women, respectively.

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