

Measurement of Waist Circumference

Midabdominal or iliac crest?

WEN-YA MA, MD^{1,2}
 CHUNG-YI YANG, MD³
 SHYANG-RONG SHIH, MD, PHD⁴
 HONG-JEN HSEIH, MD⁵
 CHI SHENG HUNG, MD⁶
 FU-CHUN CHIU, MD⁶
 MAO-SHIN LIN, MD^{4,7}

PI-HUA LIU, PHD⁸
 CYUE-HUEI HUA, BS⁹
 YENH-CHEN HSEIN, BS⁹
 LEE-MING CHUANG, MD, PHD^{4,7,10}
 JOU-WEI LIN, MD, PHD⁶
 JUNG-NAN WEI, PHD¹¹
 HUNG-YUAN LI, MD, PHD⁴

OBJECTIVE—Waist circumference (WC) is used to define central obesity. This study aimed to compare the performance of two recommended locations of WC measurement.

RESEARCH DESIGN AND METHODS—A cohort of 1,898 subjects who were without diabetes from 2006 to 2012 were followed for a median of 31 months (Taiwan Lifestyle Study). The WC-IC, recommended by the National Cholesterol Education Program Third Adult Treatment Panel, was measured at the superior border of the iliac crest, and the WC-mid, recommended by World Health Organization and International Diabetes Federation, was measured midway between the lowest ribs and the iliac crest. The abdominal subcutaneous fat area (SFA) and visceral fat area (VFA) were assessed by computed tomography.

RESULTS—There was greater difference between WC-IC and WC-mid measurements in women than in men ($P < 0.001$). Both WC-IC and WC-mid correlated significantly with BMI, VFA, and SFA (all $P < 0.001$). WC-mid was better correlated to VFA than WC-IC, particularly in women, and it correlated more strongly to blood pressure, plasma glucose, hemoglobin A_{1c}, triglyceride levels, HDL cholesterol, and C-reactive protein (all $P < 0.05$). The association of WC-mid with hypertension, diabetes, and metabolic syndrome was slightly better than that of WC-IC (area under the receiver operator curve 0.7 vs. 0.69, 0.71 vs. 0.68, and 0.75 vs. 0.7, respectively; all age-adjusted $P < 0.05$). With 90 cm (male)/80 cm (female) as criteria for central obesity, WC-mid, but not WC-IC, predicted the incidence of diabetes development (age-adjusted $P = 0.003$).

CONCLUSIONS—WC-mid is a better measurement to define central obesity than WC-IC, particularly in women.

Diabetes Care 36:1660–1666, 2013

Central obesity is associated with clustering of cardiovascular risk factors. People with central obesity are known to be at higher risk of developing hypertension, diabetes, dyslipidemia, and metabolic syndrome (MS) (1). To measure central obesity, waist circumference (WC) appears to be a better indicator than

BMI and waist-to-hip ratio. WC measurement is convenient, and it is more strongly correlated with intra-abdominal fat content and cardiovascular risk factors (2–5). However, the recommended locations for WC measurements vary (6–8). The World Health Organization and the International Diabetes Federation (IDF) suggest measuring WC in the horizontal plane midway between the lowest ribs and the iliac crest (WC-mid). In contrast, the National Cholesterol Education Program Third Adult Treatment Panel (NCEP ATP III) recommends measuring in the horizontal plane of the superior border of the iliac crest (WC-IC).

The recommended cutoff values of WC for central obesity vary among different ethnic groups (9–12). Asians tend to have more body fat per BMI than Caucasians (13), which indicates greater potential for Asians to develop hypertension, diabetes, and dyslipidemia at lower BMIs (14,15). In 2000, the Asia-Pacific Perspective: Redefining Obesity and its Treatment Conference recommended cutoff values for central obesity for Asians of 90 cm WC-mid for males and 80 cm WC-mid for females (16). In 2004, Tan et al. (17) tested these cutoffs in a cross-sectional study in an Asian population and found that the prevalence of MS using these cutoffs was comparable with that in developed countries. However, instead of WC-mid, WC was measured at the narrowest area below the costal region. These cutoff values have been adopted by the modified NCEP ATP III (7) and the IDF (8), which means that the criteria for WC association with metabolic disease in Asian populations are based on the proportion of cases identified rather than on the performance of WC in predicting risk. A number of different cutoff values for WC have been proposed based on correlations to visceral adiposity, disease identification, or disease prediction (10,11,18), and all are different.

The aim of the study is to comprehensively compare the performance of WC-IC and WC-mid to define central obesity. We investigated their performance in a large cohort including 1,898 subjects. We studied their relationship to abdominal visceral fat area (VFA) and

From the ¹Department of Internal Medicine, Division of Endocrinology, Cardinal Tien Hospital, Xindian, Taiwan; the ²School of Medicine, Fu Jen Catholic University, New Taipei City, Taiwan; the ³Department of Medical Imaging, National Taiwan University Hospital, Taipei, Taiwan; the ⁴Department of Internal Medicine, National Taiwan University Hospital, Taipei, Taiwan; the ⁵Department of Radiology, National Taiwan University Hospital Yun-Lin Branch, Yun-Lin, Taiwan; the ⁶Department of Internal Medicine, National Taiwan University Hospital Yun-Lin Branch, Yun-Lin, Taiwan; the ⁷Graduate Institute of Clinical Medicine, College of Medicine, National Taiwan University, Taipei, Taiwan; the ⁸Clinical Informatics and Medical Statistics Research Center, Chang Gung University, Taoyuan, Taiwan; the ⁹Division of Clinical Pathology, National Taiwan University Hospital Yun-Lin Branch, Yun-Lin, Taiwan; the ¹⁰Graduate Institute of Epidemiology and Preventive Medicine, National Taiwan University College of Public Health, Taipei, Taiwan; and the ¹¹Chia Nan University of Pharmacy and Science, Tainan, Taiwan.

Corresponding authors: Jung-Nan Wei, wei.j5209@msa.hinet.net, and Hung-Yuan Li, larsli@ntuh.gov.tw.

Received 22 July 2012 and accepted 15 November 2012.

DOI: 10.2337/dc12-1452

This article contains Supplementary Data online at <http://care.diabetesjournals.org/lookup/suppl/doi:10.2337/dc12-1452/-/DC1>.

W.-Y.M., C.-Y.Y., and S.-R.S. contributed equally to this study.

J.-N.W. and H.-Y.L. contributed equally to this study.

© 2013 by the American Diabetes Association. Readers may use this article as long as the work is properly cited, the use is educational and not for profit, and the work is not altered. See <http://creativecommons.org/licenses/by-nc-nd/3.0/> for details.

metabolic abnormalities. We compared their associations with metabolic diseases. We also compared their ability to predict the future development of metabolic disease. The optimal cutoff values for central obesity were explored.

RESEARCH DESIGN AND METHODS

Participants

From 2006 to 2012, individuals aged ≥ 18 years who had received health examinations at the National Taiwan University Hospital Yun-Lin branch during the previous year and had fasting plasma glucose (FPG) levels < 126 mg/dL (7 mmol/L) were invited to participate in the Taiwan Lifestyle Study (19–22). Diabetes status and medications were evaluated by a questionnaire completed with the aid of trained nurses. Participants who had FPG values > 126 mg/dL (7 mmol/L) or who received medications for diabetes were excluded. The questionnaire, along with anthropometric measurement and risk-factor assessment, were used to assess participants' medical and metabolic status. Abdominal computed tomography (CT) was performed to measure abdominal fat areas. All study participants were contacted by telephone, e-mail, or postal mail 1–3 years after the initial visit, and follow-up visits were scheduled according to the respondent's availability. Written informed consent was obtained from each individual. The study was reviewed and approved by the institutional review board.

Anthropometry

Anthropometric measurement of each subject was performed by trained nurses in the morning after fasting for at least 8 h. Body height was recorded to the nearest 0.5 cm and body weight to the nearest 0.1 kg. BMI was defined as body weight (kilograms) divided by the square of body height (meters). WC-IC was measured in the horizontal plane at the superior border of the right iliac crest. WC-mid was measured in the horizontal plane midway between lowest rib and the iliac crest. Both WC-IC and WC-mid were measured to the nearest 0.1 cm at the end of a normal expiration. Before recording the measurement, the nurse would ensure that the tape was snug but did not compress the skin and was parallel to the floor. The reproducibility was assessed. WC-IC and WC-mid were measured repeatedly in 10 men and 10 women by 3 trained nurses

on 3 consecutive days. The coefficients of variation for WC-IC were 0.8% (range 0.5–1.7%) for women and 0.6% (range 0.3–1.4%) for men. The coefficients of variation for WC-mid were 0.4% (range 0–0.7%) for men and 0.9% (range 0.5–1.9%) for women.

Risk factor measurements

Blood pressure was recorded to the nearest 2 mmHg by a mercury sphygmomanometer with the arm supported at heart level after sitting quietly for 10 min. Well-trained nurses took three separate readings at 1-min intervals. The average of the last two readings was used for analysis. FPG was measured after fasting for at least 8 h. A standard oral 75-g glucose tolerance test was performed to measure 2-h postprandial plasma glucose (2hPG). Plasma glucose and fasting serum total cholesterol, triglycerides (TG), HDL cholesterol (HDL-C), LDL cholesterol (LDL-C), and high-sensitivity C-reactive protein (hsCRP) concentrations were measured with an automatic analyzer (Toshiba TBA 120FR; Toshiba Medical Systems Co., Ltd., Tokyo, Japan). HbA_{1c} was measured by automatic analyzers (HLC-723 G7 HPLC systems; Tosoh Corporation, Tokyo, Japan). The HbA_{1c} assay was certified by the National Glycohemoglobin Standardization Program (23) and standardized to the Diabetes Control and Complications Trial reference assay.

Quantification of abdominal adipose tissue by CT

Imaging of each subject in a supine position was performed on a 16-MDCT scanner (LightSpeed 16; GE Healthcare, Milwaukee, WI) (120 kVp, 400 mAs, slice thickness 5 mm). Image analysis software (ImageJ, version 1.44; National Institutes of Health, Bethesda, MD) was used with an attenuation range of -50 to -250 Hounsfield units to quantify the abdominal subcutaneous fat area (SFA) and VFA, expressed in centimeters squared, on a single cross-sectional image obtained at the level of the umbilicus.

Definitions

Hypertension was present if blood pressure was $\geq 140/90$ mmHg or if the subject was taking medication for hypertension. Diabetes was diagnosed when FPG was ≥ 126 mg/dL (7 mmol/L), 2hPG ≥ 200 mg/dL (11.1 mmol/L), and HbA_{1c} $\geq 6.5\%$ or if the subject was taking medication for diabetes (24). MS was defined in accordance with the updated NCEP ATP III guideline (7).

Statistical analysis

Data are presented as means and SDs for continuous variables and as a percentage for categorical variables. Pearson correlation coefficients and partial correlation coefficients were used to assess the relationship among WC, abdominal fat areas, and metabolic variables. The association of the different diagnostic criteria for central obesity with high VFA and with metabolic disease was analyzed by receiver operating characteristic (ROC) curve analysis. ROC statistics were calculated by using percentile values of disease case measures relative to the corresponding marker distribution among controls (25,26). Age was adjusted with a linear regression approach. CIs were calculated by bootstrap methods. Optimal cutoffs were derived from the ROC curve with the shortest distance to sensitivity = 1 and $1 - \text{specificity} = 0$. Kaplan-Meier failure curves were used to estimate the cumulative incidence of hypertension, diabetes, and MS in individuals with and without central obesity defined by WC-IC or WC-mid cutoff values. The results were tested by Cox proportional hazard model adjusted for age. A two-tailed *P* value < 0.05 was considered significant. The statistical analyses were performed with STAT/SE 11 for Windows (StataCorp LP, College Station, TX).

RESULTS—The clinical characteristics of the participants ($n = 1,898$) are summarized in Table 1. WC-IC values were significantly higher than WC-mid in both sexes, and the differences between WC-IC and WC-mid were greater in women than in men ($P < 0.001$). WC-IC and WC-mid were less correlated in women. The partial correlation coefficients adjusted for age in men and women were 0.91 and 0.834, respectively.

There were 425 participants, including 150 males and 275 females, who underwent abdominal CT for assessment of abdominal fat areas. Comparing participants with and without CT measurements, those who had CT evaluations showed slightly higher HDL-C (52 ± 12 vs. 50 ± 13 mg/dL; $P < 0.05$) and LDL-C values (121 ± 34 vs. 117 ± 32 mg/dL; $P < 0.05$). Women with CT measurement had higher WC-IC than women without CT measurement (85 ± 9 vs. 83 ± 9 cm; $P < 0.05$). As shown in Table 2, both WC-IC and WC-mid correlated significantly with BMI, total abdominal fat area, VFA, and SFA. WC-mid predicted high VFA (VFA ≥ 50 th percentile in the corresponding

Table 1—Clinical characteristics of the study subjects

Variables	Men	Women
n	758	1,140
Age (years)	52 ± 13.1	49.4 ± 12‡
BMI (kg/m ²)	25.2 ± 3.3	23.6 ± 3.5‡
WC-IC (cm)	90 ± 9*	83 ± 9*‡
WC-mid (cm)	88 ± 9	78 ± 8‡
Difference between WC-IC and WC-mid (cm)	1.7 ± 3.8	5.6 ± 4.8‡
Systolic blood pressure (mmHg)	130 ± 16	120 ± 17‡
Diastolic blood pressure (mmHg)	82 ± 10	77 ± 10‡
Use of medications for hypertension (%)	17	12.4‡
Hypertension (%)	37	23‡
FPG [mmol/L (mg/dL)]	5.4 ± 1.2 (97 ± 22)	5.2 ± 1.2 (93 ± 21)‡
OGTT 2-h plasma glucose [mmol/L (mg/dL)]	7.4 ± 3.7 (133 ± 67)	7 ± 3.3 (126 ± 59)†
HbA _{1c} (%)	5.9 ± 0.9	5.7 ± 0.9†
Use of medications for diabetes (%)	2.8	1.1†
Diabetes (%)	15	10‡
Total cholesterol [mmol/L (mg/dL)]	5 ± 0.9 (193 ± 37)	5.1 ± 0.9 (196 ± 36)†
HDL-C [mmol/L (mg/dL)]	1.2 ± 0.3 (45 ± 11)	1.4 ± 0.3 (54 ± 12)‡
LDC-C [mmol/L (mg/dL)]	3.1 ± 0.8 (120 ± 32)	3 ± 0.8 (116 ± 32)†
TG [mmol/L (mg/dL)]	1.6 ± 1.6 (145 ± 142)	1.2 ± 0.8 (103 ± 70)‡
Use of medication for dyslipidemia (%)	3.6	1.4†
Plasma hsCRP (mg/dL)	0.22 ± 0.66	0.17 ± 0.3†

Data are mean ± SD unless otherwise indicated. OGTT, oral glucose tolerance test. * $P < 0.001$ vs. WC-mid; † $P < 0.05$ vs. men; ‡ $P < 0.001$ vs. men.

sex) more often than WC-IC in women (area under the ROC [AUC] 0.825 for WC-IC, 0.860 for WC-mid; $P = 0.0142$), but not in men (AUC 0.855 WC-IC, 0.865 WC-mid; $P = 0.454$).

The data presented in Supplementary Table 1 show that both WC-IC and WC-mid correlated significantly with systolic and diastolic blood pressure, FPG, 2hPG, HbA_{1c}, TG, HDL-C, and hsCRP in both sexes, and WC-mid was better correlated

than WC-IC with these metabolic variables in both sexes. Similar findings were noted after adjusting for age (data not shown).

Results in Table 3 show that the identification of individuals with hypertension, diabetes, and MS by WC-IC and WC-mid was fair (AUC 0.68–0.7 for WC-IC and 0.7–0.75 for WC-mid). WC-mid had slightly better association with hypertension, diabetes, and MS

than WC-IC ($P < 0.05$ comparing AUC). The optimal cutoffs for WC-IC and WC-mid varied, depending on which disease to identify. Generally, WC-IC was more sensitive, whereas WC-mid was more specific. WC-mid had a higher age-adjusted AUC than WC-IC for diabetes in men, hypertension in women, and MS in both sexes (Supplementary Table 2). The data in Supplementary Table 3 show that WC-mid at its optimal cutoffs had the highest AUC for hypertension in females and diabetes and MS in both sexes. Using the cutoffs of 90 and 80 cm (males and females, respectively), WC-mid had significantly higher AUC for hypertension and diabetes in women and for MS in both sexes (all age-adjusted $P < 0.05$) (Supplementary Table 3). The differences in AUC for hypertension, diabetes, and MS among four criteria were larger in women (0.04–0.07) than in men (0.02–0.05).

There were 1,503 subjects who stayed in the study for at least 12 months. Among them, 901 (60%) were successfully followed for medical and metabolic status. The median follow-up period was 31 months. The data in Table 3 indicate that the performance of WC-IC and WC-mid to predict incident hypertension, diabetes, and MS was fair (AUC 0.62–0.68 for WC-IC, 0.65–0.68 for WC-mid). The AUCs for WC-IC and WC-mid for hypertension, diabetes, and MS were not statistically different (age-adjusted $P > 0.05$). The optimal cutoff values for WC-IC and WC-mid to predict different diseases varied, and WC-IC was more sensitive, whereas WC-mid was more specific. As demonstrated by the data in Supplementary Table 2, there was no significant

Table 2—Associations between WC-IC and WC-mid, BMI, and abdominal fat areas

	Men		Women	
	WC-IC	WC-mid	WC-IC	WC-mid
Partial correlation coefficients, adjusted for age				
BMI (kg/m ²)	0.76	0.85	0.7	0.83
Total abdominal fat (cm ²)	0.81	0.81	0.75	0.79
Visceral abdominal fat (cm ²)	0.73	0.75	0.63	0.7
Subcutaneous abdominal fat (cm ²)	0.78	0.75	0.7	0.72
To identify high VFA†				
AUC (95% CI)	0.855 (0.796–0.913)	0.865 (0.809–0.92)	0.825 (0.778–0.872)	0.86* (0.817–0.902)
Optimal cutoffs (cm)	88	88	81	77
Sensitivity (%)	76	76	72	73
Specificity (%)	79	80	75	82

Abdominal fat areas were measured by CT. Fat areas were logarithmically transformed for the analyses. All P values for correlation coefficients and partial correlation coefficients were < 0.001 . * $P < 0.05$. †High VFA: VFA ≥ 50 th percentile in the corresponding sex.

Table 3—Different definitions of central obesity to identify or predict hypertension, diabetes, or MS

	To identify disease				To predict disease			
	WC-IC		WC-mid		WC-IC		WC-mid	
AUC (95% CI)								
Hypertension	0.69 (0.66–0.71)		0.7 (0.68–0.73)*		0.68 (0.63–0.74)		0.66 (0.60–0.72)	
Diabetes	0.68 (0.65–0.72)		0.71 (0.67–0.74)*		0.62 (0.56–0.69)		0.65 (0.59–0.72)	
≥2 MS components ^a	0.7 (0.68–0.73)		0.75 (0.72–0.77)*		0.65 (0.61–0.7)		0.68 (0.63–0.73)	
Hypertension								
Cutoffs, male/female (cm)	90/80	88/83	90/80	87/78	90/80	89/84	90/80	90/77
Sensitivity (%)	71	73	58	71	70	66	48	55
Specificity (%)	48	53	66	57	45	58	72	64
Diabetes								
Cutoffs, male/female (cm)	90/80	90/84	90/80	88/79	90/80	90/84	90/80	89/80
Sensitivity (%)	74	71	65	74	78	65	57	58
Specificity (%)	45	56	63	57	42	55	68	67
≥2 MS components ^a								
Cutoffs, male/female (cm)	90/80	89/84	90/80	89/78	90/80	91/84	90/80	85/76
Sensitivity (%)	70	68	60	68	69	54	44	64
Specificity (%)	49	61	71	64	49	65	78	62

^aClustering of two or more components of MS, including fasting plasma glucose ≥100 mg/dL, blood pressure ≥130/85 mmHg, TG ≥150 mg/dL, and low HDL-C (<40 mg/dL in men; <50 mg/dL in women). Subjects taking medications for hypertension, diabetes, or dyslipidemia were considered as meeting the corresponding criteria. *Age-adjusted $P < 0.05$ compared with the AUC of WC-IC.

difference between WC-IC and WC-mid to predict hypertension, diabetes, or MS. However, WC-mid had slightly higher AUCs than WC-IC for diabetes and for hypertension in women (both age-adjusted P values 0.05–0.1). Data in Supplementary Table 3 show that the best criteria for highest AUC depended on the disease to be predicted and the sex to be considered. Using the cutoffs of 90/80 cm (male/female), WC-IC and WC-mid showed similar AUC for hypertension, diabetes, and MS in both sexes (all age-adjusted $P > 0.05$; Supplementary Table 3).

There were 639 subjects, including 206 men and 433 women, who did not have hypertension at baseline. During the follow-up period (median 31.7 months, interquartile range 16.1–45.6), 87 subjects developed hypertension. As shown in Fig. 1A and B, there was no difference in the incidence of hypertension in subjects with or without central obesity, neither by WC-IC or WC-mid criteria (both $P > 0.05$). There were 801 subjects, including 292 men and 509 women, who did not have diabetes at baseline. During follow-up (median 30.8 months, interquartile range 16.0–46.3), 60 developed diabetes. As shown in Fig. 1C and D, the cumulative incidence of diabetes was significantly higher in the individuals who met WC-mid criteria for central obesity ($P = 0.003$) and not for those with WC-IC

criteria ($P = 0.112$). There were 587 subjects, including 179 men and 408 women, who had less than two components of MS at baseline. During follow-up (median 31.4 months, interquartile range 16.1–49.6), 162 subjects clustered three or more components of MS. Figure 1E and F shows that the cumulative incidence of MS was not significantly different in subjects who had central obesity by WC-IC criteria ($P = 0.988$) or WC-mid criteria ($P = 0.223$).

CONCLUSIONS—To the best of our knowledge, this is the first comprehensive study to compare different measurements of WC to define central obesity. We showed that WC-mid predicts high VFA better than WC-IC in women. Correlation, as compared by AUC, with hypertension, diabetes, and MS was better by WC-mid criteria than WC-IC criteria. However, the performance of WC-IC and WC-mid to predict hypertension, diabetes, and MS was similar, although only central obesity by WC-mid criteria, and not WC-IC criteria, predicted future diabetes incidence. Overall, our findings suggest that WC-mid is a better measurement of central obesity than WC-IC.

It is practical to keep the current cutoffs for central obesity (i.e., 90 [males]/80 [females] cm). Using these cutoffs, in the current study, we found that the sensitivity of WC-IC measurement values for identifying or predicting hypertension,

diabetes, and MS was greater than that of WC-mid measurements. Since central obesity is a screening tool for metabolic diseases, higher sensitivity of WC-IC values may be a desirable attribute. Furthermore, WC-IC can be more precisely located than WC-mid, which may make it more consistent during follow-up. Therefore, in a recent scientific statement of the American Heart Association, WC-IC with cutoffs at 90/80 (male/female) cm for Asians has been recommended to define central obesity (2). In contrast, WC-mid correlated better to VFA and metabolic variables and worked better to identify and predict metabolic diseases in the current study. These findings suggest that WC-mid is a better measurement for central obesity. Indeed, when optimal cutoffs were used, WC-mid showed better performance than WC-IC did, with more balanced sensitivity and specificity. Furthermore, although measurement of WC-mid is a slightly more complex procedure, findings from the current study and from Mason and Katzmarzyk (27) have shown that the reproducibility of WC-mid measurement is also high. Thus, if modification of the cutoffs for central obesity is to be considered, WC-mid is a better location of measurement than WC-IC.

The impact of the location of WC measurement varies by sex. In the current study, the difference between WC-IC and WC-mid was larger in women (5.6 cm)

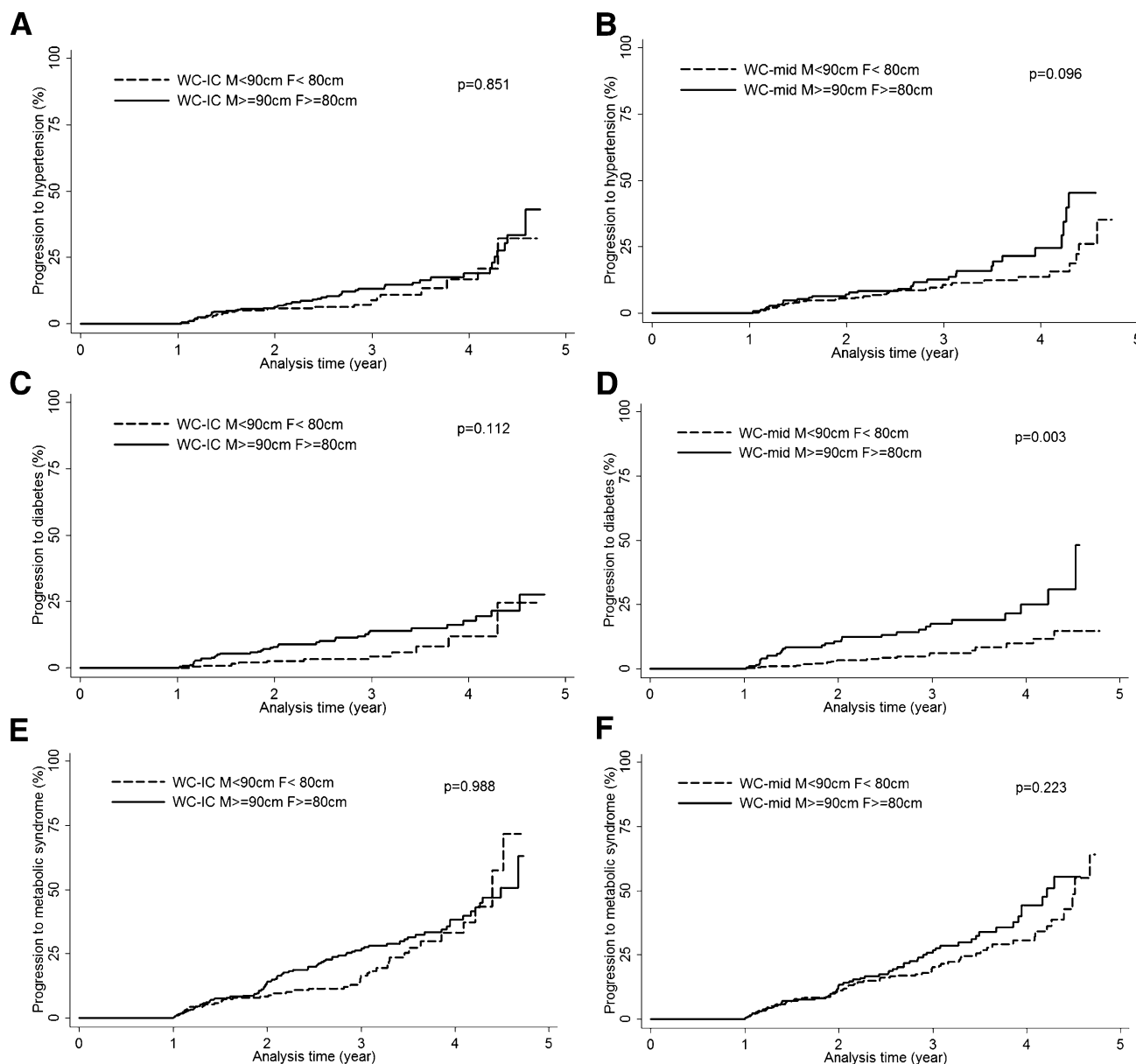


Figure 1—Different definitions of central obesity to predict metabolic diseases. Kaplan-Meier curves for the cumulative incidence of developing hypertension (A and B), diabetes (C and D), or MS (E and F) by WC-IC (A, C, and E) or WC-mid (B, D, and F) to define central obesity. Age-adjusted P values are shown. F, female; M, male.

than in men (1.7 cm), which is in concordance with a report in Caucasians (28). This may explain why the differences between the correlation coefficients of VFA to WC-IC and WC-mid were larger in women than in men in present study (Table 2). It could also explain why WC-mid in women, but not in men, showed significantly higher AUCs than WC-IC for hypertension, diabetes, and MS when cutoffs of 90/80 (male/female) cm were used (Supplementary Table 3). Also, the differences in AUC among the four WC criteria used to identify these diseases were larger in women than in men

(Supplementary Table 3), and similar findings were also reported in the previous study in Caucasians (29). In that study, the differences between WC-IC and WC-mid were 0.4 cm in men and 1.1 cm in women, and the differences in AUC for components of MS among WC-IC, WC-mid, WC at umbilicus, and minimal WC were larger in women (0.053–0.088) than in men (0.003–0.029). All of these findings suggest that the location of WC measurement has greater impact in women than in men.

The optimal cutoffs depend on the diseases to be identified or predicted. In

the current study, the optimal cutoffs for both WC-IC and WC-mid were all different (Table 3). Supporting our findings, the optimal cutoffs for WC were also different for different metabolic diseases in another large cross-sectional study in Taiwan that included 55,563 people (11). In that study, optimal cutoffs were determined based on the performance for identifying at least one disease, including hypertension, diabetes, and dyslipidemia. Moreover, there have been two Chinese studies investigating the optimal cutoffs based on the relationship of WC to VFA (18,30). Bao et al. (30) reported that

individuals in a cross-sectional study with VFA >80 cm² had higher risk of MS. The corresponding WC cutoffs were 90 (male)/85 (female) cm. Ye et al. (18) showed that subjects with VFA >90 cm² have a higher risk of future incidence of diabetes. The corresponding WC cutoffs were 88 (male)/82 (female) cm. In summary, it seems essential to have a consensus for the use of WC before optimal cutoffs can be determined. Questions that should be addressed include the following: for which diseases are associations with WC most important? Are the cutoffs based on disease identification or disease prediction? Should VFA be considered?

In the current study, WC-mid was better correlated to VFA than WC-IC. Various reports have shown that visceral adipose tissue (VAT) produces and releases adipokines, which are linked to the development of metabolic abnormalities (31–33). Fatty acids from VAT drain to the liver, and the increased fat influx may increase hepatic TG content, resulting in increased hepatic glucose output and VLDL TG production (34,35). VAT also secretes higher levels of proinflammatory cytokines than subcutaneous adipose tissue (36,37). All of these mechanisms provide for a potentially pathogenic role of VAT in the development of metabolic abnormalities, and indeed, increased VFA has been associated with increased risk of hypertension, diabetes, and dyslipidemia in humans (38,39). However, WC has been shown to have a stronger correlation to SFA than VFA in Caucasians, indicating that WC is a better index of SFA (28). In present study, although WC also showed stronger correlation with SFA than VFA, the differences in the correlation coefficients were small, especially for WC-mid (0.01–0.04 in men and 0–0.03 in women; Table 2). These findings suggest that WC, particularly WC-mid, can be viewed as an index of both SFA and abdominal VFA in Asians.

The strength of this study is in the completeness of its comparison of WC-IC and WC-mid. We compared the biologic roles of WC-mid and WC-IC through their relationships to VFA and metabolic variables. We also investigated their potential for identifying and predicting metabolic diseases. In contrast, this study was limited in that only WC-IC and WC-mid were compared and evaluated. From the literature, there are at least eight different measurement locations for WC (40). However, since WC-IC or WC-mid have been the recommended locations by

World Health Organization, NCEP ATP III, and IDF (6–8), the findings of the current study are practical. Moreover, the study subjects were not a random sample because the incidence of hypertension and diabetes were higher (5.1%/person-year and 2.8%/person-year, respectively). This may be due to a higher percentage of subjects who had prehypertension and prediabetes in the cohort (24 and 39%, respectively), since people at risk are more willing to be followed. However, this did not confound the relationship between WC and metabolic diseases.

In conclusion, WC-mid proved in this study to be a better measurement to define central obesity than WC-IC in Asians, since WC-mid was more closely related to abdominal VFA and metabolic variables and had better results for identifying and predicting metabolic diseases. The impact of location of WC measurement is greater in women. The optimal cutoffs are different when different metabolic diseases are considered. Our data further indicate that there is a need to re-evaluate the location of WC measurement and cutoffs for central obesity in different ethnic groups.

Acknowledgments—This work was supported in part by a grant (NSC 98-2314-B-002-024-MY3) from the National Science Council, Taiwan, and by a grant from National Taiwan University Hospital, Taiwan (NTUH 99-M1404).

No potential conflicts of interest relevant to this article were reported.

W.-Y.M. wrote the manuscript and researched data. C.-Y.Y. researched data. S.-R.S. wrote the manuscript. H.-J.H., C.S.H., F.-C.C., M.-S.L., P.-H.L., and L.-M.C. contributed to the discussion. C.-H.H. and Y.-C.H. researched data. J.-W.L. and J.-N.W. reviewed and edited the manuscript. H.-Y.L. researched data and reviewed and edited manuscript. H.-Y.L. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

The authors thank Chien-Yin Su, Kuan-Yi Wu, Ying-Jhu Liao, and the staff of the Eighth Core Laboratory, Department of Medical Research, and National Taiwan University Hospital for technical and computing assistance. The authors acknowledge the English editorial assistance by Editage English Editing Services, Cactus Communications, Inc. (Philadelphia, PA).

References

- Jacobs EJ, Newton CC, Wang Y, et al. Waist circumference and all-cause mortality in a

large US cohort. *Arch Intern Med* 2010; 170:1293–1301

- Cornier MA, Després JP, Davis N, et al.; American Heart Association Obesity Committee of the Council on Nutrition; Physical Activity and Metabolism; Council on Arteriosclerosis; Thrombosis and Vascular Biology; Council on Cardiovascular Disease in the Young; Council on Cardiovascular Radiology and Intervention; Council on Cardiovascular Nursing; Council on Epidemiology and Prevention; Council on the Kidney in Cardiovascular Disease, and Stroke Council. Assessing adiposity: a scientific statement from the American heart association. *Circulation* 2011;124:1996–2019
- Pouliot MC, Després JP, Lemieux S, et al. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol* 1994;73:460–468
- Rankinen T, Kim SY, Pérusse L, Després JP, Bouchard C. The prediction of abdominal visceral fat level from body composition and anthropometry: ROC analysis. *Int J Obes Relat Metab Disord* 1999;23:801–809
- Lemieux I, Pascot A, Couillard C, et al. Hypertriglyceridemic waist: A marker of the atherogenic metabolic triad (hyperinsulinemia, hyperapoprotein B; small, dense LDL) in men? *Circulation* 2000;102:179–184
- World Health Organization. *Definition, Diagnosis and Classification of Diabetes Mellitus and its Complications: Report of a WHO Consultation*. Geneva, World Health Organization, 1999
- Grundy SM, Cleeman JI, Daniels SR, et al.; American Heart Association; National Heart, Lung, and Blood Institute. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation* 2005;112:2735–2752
- Alberti KGMM, Zimmet P, Shaw J. Metabolic syndrome—a new world-wide definition. A Consensus Statement from the International Diabetes Federation. *Diabet Med* 2006;23:469–480
- Han TS, van Leer EM, Seidell JC, Lean ME. Waist circumference action levels in the identification of cardiovascular risk factors: prevalence study in a random sample. *BMJ* 1995;311:1401–1405
- Park Y-M, Kwon H-S, Lim SY, et al. Optimal waist circumference cutoff value reflecting insulin resistance as a diagnostic criterion of metabolic syndrome in a nondiabetic Korean population aged 40 years and over: the Chungju Metabolic Disease Cohort (CMC) study. *Yonsei Med J* 2010;51:511–518
- Lin WY, Lee LT, Chen CY, et al. Optimal cut-off values for obesity: using simple

- anthropometric indices to predict cardiovascular risk factors in Taiwan. *Int J Obes Relat Metab Disord* 2002;26:1232–1238
12. Misra A, Wasir JS, Vikram NK. Waist circumference criteria for the diagnosis of abdominal obesity are not applicable uniformly to all populations and ethnic groups. *Nutrition* 2005;21:969–976
 13. Deurenberg P, Deurenberg-Yap M, Guricci S. Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. *Obes Rev* 2002;3:141–146
 14. Li G, Chen X, Jang Y, et al. Obesity, coronary heart disease risk factors and diabetes in Chinese: an approach to the criteria of obesity in the Chinese population. *Obes Rev* 2002;3:167–172
 15. Ko GT, Chan JC, Cockram CS, Woo J. Prediction of hypertension, diabetes, dyslipidaemia or albuminuria using simple anthropometric indexes in Hong Kong Chinese. *Int J Obes Relat Metab Disord* 1999;23:1136–1142
 16. World Health Organization/International Association for the Study of Obesity/International Obesity Task Force. *The Asia-Pacific Perspective: Redefining Obesity and its Treatment*. Melbourne, Health Communications Australia, 2000
 17. Tan C-E, Ma S, Wai D, Chew S-K, Tai E-S. Can we apply the National Cholesterol Education Program Adult Treatment Panel definition of the metabolic syndrome to Asians? *Diabetes Care* 2004;27:1182–1186
 18. Ye Y, Bao Y, Hou X, et al. Identification of waist circumference cutoffs for abdominal obesity in the Chinese population: a 7.8-year follow-up study in the Shanghai urban area. *Int J Obes (Lond)* 2009;33:1058–1062
 19. Li HY, Lin MS, Wei JN, et al. Change of serum vascular adhesion protein-1 after glucose loading correlates to carotid intima-medial thickness in non-diabetic subjects. *Clin Chim Acta* 2009;403:97–101
 20. Li HY, Wei JN, Lin MS, et al. Serum vascular adhesion protein-1 is increased in acute and chronic hyperglycemia. *Clin Chim Acta* 2009;404:149–153
 21. Hung CS, Lee PC, Li H-Y, et al. Haemoglobin A1c is associated with carotid intima-media thickness in a Chinese population. *Clin Endocrinol (Oxf)* 2011;75:780–785
 22. Li H-Y, Lin M-S, Shih S-R, et al. The performance of risk scores and hemoglobin A1c to find undiagnosed diabetes with isolated postload hyperglycemia. *Endocr J* 2011;58:441–448
 23. Little RR, Rohlfing CL, Wiedmeyer H-M, Myers GL, Sacks DB, Goldstein DE; NGSP Steering Committee. The national glycohemoglobin standardization program: a five-year progress report. *Clin Chem* 2001;47:1985–1992
 24. American Diabetes Association. Standards of medical care in diabetes—2010. *Diabetes Care* 2010;33(Suppl. 1):S11–S61
 25. Janes H, Pepe MS. Adjusting for covariates in studies of diagnostic, screening, or prognostic markers: an old concept in a new setting. *Am J Epidemiol* 2008;168:89–97
 26. Janes H, Longton GM, Pepe M. Accommodating covariates in ROC analysis. *Stata J* 2009;9:17–39
 27. Mason C, Katzmarzyk PT. Variability in waist circumference measurements according to anatomic measurement site. *Obesity (Silver Spring)* 2009;17:1789–1795
 28. Bosy-Westphal A, Booke CA, Blöcker T, et al. Measurement site for waist circumference affects its accuracy as an index of visceral and abdominal subcutaneous fat in a Caucasian population. *J Nutr* 2010;140:954–961
 29. Mason C, Katzmarzyk PT. Waist circumference thresholds for the prediction of cardiometabolic risk: is measurement site important? *Eur J Clin Nutr* 2010;64:862–867
 30. Bao Y, Lu J, Wang C, et al. Optimal waist circumference cutoffs for abdominal obesity in Chinese. *Atherosclerosis* 2008;201:378–384
 31. Björntorp P. “Portal” adipose tissue as a generator of risk factors for cardiovascular disease and diabetes. *Arteriosclerosis* 1990;10:493–496
 32. Fontana L, Eagon JC, Trujillo ME, Scherer PE, Klein S. Visceral fat adipokine secretion is associated with systemic inflammation in obese humans. *Diabetes* 2007;56:1010–1013
 33. Kissebah AH, Peiris AN. Biology of regional body fat distribution: relationship to non-insulin-dependent diabetes mellitus. *Diabetes Metab Rev* 1989;5:83–109
 34. Jensen MD. Role of body fat distribution and the metabolic complications of obesity. *J Clin Endocrinol Metab* 2008;93(Suppl. 1):S57–S63
 35. Korenblat KM, Fabbrini E, Mohammed BS, Klein S. Liver, muscle, and adipose tissue insulin action is directly related to intrahepatic triglyceride content in obese subjects. *Gastroenterology* 2008;134:1369–1375
 36. Pou KM, Massaro JM, Hoffmann U, et al. Visceral and subcutaneous adipose tissue volumes are cross-sectionally related to markers of inflammation and oxidative stress: the Framingham Heart Study. *Circulation* 2007;116:1234–1241
 37. Cartier A, Côté M, Lemieux I, et al. Sex differences in inflammatory markers: what is the contribution of visceral adiposity? *Am J Clin Nutr* 2009;89:1307–1314
 38. Carey VJ, Walters EE, Colditz GA, et al. Body fat distribution and risk of non-insulin-dependent diabetes mellitus in women. The Nurses’ Health Study. *Am J Epidemiol* 1997;145:614–619
 39. Chan JM, Rimm EB, Colditz GA, Stampfer MJ, Willett WC. Obesity, fat distribution, and weight gain as risk factors for clinical diabetes in men. *Diabetes Care* 1994;17:961–969
 40. Ross R, Berentzen T, Bradshaw AJ, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? *Obes Rev* 2008;9:312–325