Thoracic-to-hip circumference ratio as a novel marker of type 2 diabetes, independent of body mass index and waist-to-hip ratio, in Korean adults

CrossMark

Duong Duc Pham [a,b], BonCho Ku [a], Chol Shin [c], Nam H. Cho [d], Seongwon Cha [a], Jong Yeol Kim [a,*]

[a] Korea Institute of Oriental Medicine, 461-24 Jeonmin-dong, Yuseong-gu, Daejeon, Republic of Korea
[b] National Hospital of Traditional Medicine, 29 Nguyen Binh Khiem, Hanoi, Viet Nam
[c] Department of Internal Medicine, Korea University Ansan Hospital, 516, Gojan-1-dong, Danwon-gu, Ansan 425-707, Republic of Korea
[d] Department of Preventive Medicine, Ajou University School of Medicine, Suwon, Republic of Korea

ARTICLE INFO

ABSTRACT

Aims: We compared upper trunk anthropometric indices with overall and central obesity indicators to predict the presence of type 2 diabetes in middle-aged and elderly Korean individuals.

Methods: This cross-sectional investigation included 4079 rural and urban participants aged 40–80 years. Neck, thoracic, waist (WC), and hip circumferences were measured by a reliable and standardized method. The neck-to-hip ratio, the thoracic-to-hip ratio (THR), and the waist-to-hip ratio (WHR) were calculated. A 75-g oral glucose tolerance test was performed. Type 2 diabetes was defined based on the guidelines of the World Health Organization (1999).

Results: The receiver operator characteristic curve analysis indicated that THR and WHR were better than body mass index (BMI) and other anthropometric indices at predicting the presence of type 2 diabetes. The adjusted odds ratios (OR) across quartiles of THR were slightly higher than the ORs for WHR, particularly in the highest quartile (odds ratios and 95% CI: 2.11 (1.47–3.04) versus 1.95 (1.37–2.77) in men; 3.40 (2.18–5.31) versus 2.31 (1.48–3.60) in women). The associations of THR and WHR with type 2 diabetes remained significant, despite a slight attenuation after a multivariate adjustment for BMI. The joint effect of BMI and THR on the risk of type 2 diabetes was larger than that of BMI and WHR.

Conclusions: THR may be a novel marker of type 2 diabetes, particularly in women, and its association with diabetes was independent of BMI and WHR.

* Corresponding author at: Department of Medical Research, Korea Institute of Oriental Medicine (KIOM), 461-24 Jeonmin-dong, Yuseong-gu, Daejeon 305-811, Republic of Korea. Tel.: +82 42 868 9489; fax: +82 42 868 9480.
E-mail address: ssmed@kiom.re.kr (J.Y. Kim).

1. Introduction

Type 2 diabetes has become a global epidemic health problem worldwide, and it is closely related to numerous cardiometabolic complications of obesity [1]. Body mass index (BMI) has been the most commonly used measure of overall obesity to reflect total body fat, although the index cannot distinguish between muscle and fat mass [2]. Many studies have demonstrated that excessive accumulation of adipose tissue in particular body regions contributes to metabolic complications [3,4].

Vague [5] first proposed that those who have fat predominantly accumulated in the upper body rather than the lower body are more susceptible to metabolic disturbances. For several decades, numerous studies examined this hazardous body shape phenotype; however, most emphasized the impact of body fat centralization, measured by waist circumference (WC) or waist-to-hip ratio (WHR), on the risk of metabolic complications [6,7]. Freedman and Rimm demonstrated that fat accumulation in various regions of the upper trunk had different diabetes correlates independent of abdominal fat [8]. In recent years, interest has increased in the cardiometabolic correlates of upper body subcutaneous (sc) [9,10], intra-thoracic [11,12], and pericardial fat [13]. Kang et al. found that android fat, a fat depot located just above the central fat depot, is more accurate than abdominal visceral adipose tissue (VAT) at predicting metabolic syndrome [14].

Body girth measurements at multiple regions of the trunk can provide information on particular local fat accumulation, whereas girth ratios may reflect the fat distribution pattern and body shape. Numerous epidemiological studies have used WHR as a determinant of the fat distribution pattern; however, WHR, which contains information on abdominal fat and hip fat, does not reflect the concrete image of fat distribution. In addition, whether body fat distribution provides more accurate information on the risk of type 2 diabetes than total body fat remains controversial [15]. Because of the increasing evidence of metabolic correlates of upper trunk fat, we assess the association of upper trunk circumferences and their ratios to hip circumference (HC) with type 2 diabetes and examine whether these anthropometric indices can predict type 2 diabetes more accurately than overall obesity (assessed by BMI) and central obesity (assessed by WC and WHR) indicators.

2. Materials and methods

2.1. Participants

The current study was designed as a cross-sectional investigation as part of the Korean Health and Genome Epidemiology Study (KHGES), an ongoing perspective cohort study [16]. A total of 7629 participants aged 10 years or more were recruited using a two-stage cluster sampling method by telephone or mail from June 2009 to December 2011 at the Korea University Ansan Hospital and the Center for Clinical Epidemiology of Ajou University Hospital. The Ansan cohort data represent an urban community, and the Ansung cohort data represent a rural community. In this analysis, we included only participants aged 40–80 years and excluded participants who had been diagnosed with diabetes and/or were receiving medication for hypertension, diabetes, dyslipidemia, and who had missing data on body composition indices, body measurements, blood pressure, fasting plasma glucose (FPG), 2-h post-load plasma glucose, or smoking and drinking information. The analysis was performed on 4079 participants (1967 men and 2112 women). This study was approved by the National Institute of Health Ethics and the Institutional Review Board of the Korean Health and Genomic Study, Ajou University. All of the participants gave their written informed consent.

2.2. Anthropometric indices and body composition measurements

Body measurements were measured horizontally with a tapeline to the nearest 1 mm by trained operators following the standardized operating procedure developed by Jang et al. [17]. It has been revealed that these measurements have a high reliability with relative total technical error of measurement were 0.68%–2.18% [17]. Neck circumference (NC) was measured at the lower margin of the thyroid cartilage while participants sat on a chair with their heads positioned horizontally. Thoracic circumference (ThC), WC, and HC were measured while participants stood erect and breathed naturally. The tapeline was positioned at the left and right prominences of the 7th–8th costochondral junctions, and the ThC value was recorded between inspiration and expiration. WC and HC were measured at the umbilicus scar and upper margin of the pubis, respectively. The neck-to-hip circumference (NHR), thoracic-to-hip circumference (THR), and waist-to-hip circumference (WHR) ratios were defined as NC, ThC, and WC divided by HC, respectively. Thus, the upper-trunk-related anthropometric indices were NC, ThC, NHR, and THR.

Body height and weight were measured using a digital scale (GL-150; G Tech International Co., Ltd., Uijeongbu). Participants wore casual clothing. The mandibular plane was parallel to the floor. BMI was calculated as weight (kg) divided by height squared (m^2). Body fat mass (BFM) was assessed using a bioelectrical impedance analyzer (BIA) (INBODY 720, Biospace Korea). In addition, body fat percent (BFP) was calculated by dividing BFM by body weight.

2.2.1. Definition of type 2 diabetes
The measurements of blood pressure, fasting and 2-h post-load glucose concentration, and lipid profiles have been described in detail in a previous study [18]. Type 2 diabetes was defined as a FPG $\geq$ 126 mg/dl [7.0 mmol/l] and/or a 2-h post-load plasma glucose $\geq$200 mg/dl [11.1 mmol/l], according to the 1999 World Health Organization diagnostic criteria [19].

2.3. Confounding factors

Participants were classified as current smokers if they smoked currently, ex-smokers if they had smoked previously but had quit, and nonsmokers if they had never smoked. The same classification was applied for alcohol consumption.

2.4. Data analysis

The data were analyzed using R software, version 2.14.1, on a Windows 7 platform. The significance level was set to 0.05. A receiver operating characteristic (ROC) curve was used to estimate the predictive performance of BMI and anthropometric indices and to calculate the optimal cutoff points in predicting type 2 diabetes. More area under the ROC curve (AUC) implies more predictive performance. The optimal cutoff for each determinant of type 2 diabetes was determined by the Youden index [20]. A univariate logistic regression was used to assess the association between a one standard deviation (SD) increase in BMI and all anthropometric indices and type 2 diabetes. A multiple logistic regression analysis adjusted for age, habitual smoking, alcohol consumption, and study center was used to evaluate the risk increase by quartiles of BMI and all anthropometric indices. We used the AUC value and the odds ratio (OR) to determine the upper trunk anthropometric index that was most closely associated with type 2 diabetes. Further adjustments for overall obesity (assessed by BMI) and central obesity (assessed by WC and WHR) indicators were included to assess the independent and joint effects of the upper trunk anthropometric index in predicting type 2 diabetes.

3. Results

The characteristics of participants by gender are presented in Table 1. Compared to the women, the men were heavier and taller and had a lower BMI, body fat mass, and fat percent. Additionally, men had larger anthropometric indices and higher risk of type 2 diabetes than women.

3.1. Association of anthropometric indices with type 2 diabetes and their cutoffs

BMI and all anthropometric indices were associated with type 2 diabetes. The ROC analysis indicated that THC had a stronger relationship with type 2 diabetes than BMI, NC, or WC (men: AUC = 0.551 versus 0.533, 0.535, and 0.541; women: AUC = 0.578 versus 0.559, 0.545, and 0.559). THR and WHR (men: AUC = 0.577 and 0.564; women: AUC = 0.606 and 0.582) were stronger markers of type 2 diabetes than BMI and other anthropometric indices. The optimal cutoff points estimated by the Youden index for predicting diabetes for THR and WHR were 0.93 and 0.93 in men and 0.88 and 0.90 in women (Table 2). Each increase in the SD of the THR was associated with a 1.29-fold (1.15–1.45) and a 1.48-fold (1.29–1.70) increase in the odds ratios of type 2 diabetes in men and women, respectively ($p < 0.0001$), whereas those of the WHR were 1.23-fold (1.09–1.39) and 1.38 (1.20–1.58) in men ($p = 0.001$) and women ($p < 0.0001$), respectively (Table 2). After adjustments for potential confounders, including age, habitual smoking, alcohol consumption, and study center, THR and WHR still had a stronger association with type 2 diabetes than BMI and other anthropometric indices. The adjusted ORs for the second, third, and fourth quartiles of THR were 1.48 (1.02–2.14), 1.91 (1.33–2.75), and 2.11 (1.47–3.04) in men and were 1.65 (1.05–2.59), 1.61 (1.02–2.56), and 3.40 (2.18–5.31) in women,

Table 1 – Characteristic of study participants.			
	Men (n = 1967)	Women (n = 2112)	p
Study center			
Ansan n (%)	885 (45.0)	1067 (50.5)	
Ansung n (%)	1082 (55.0)	1045 (49.5)	
Age (yrs)	57.9 (8.3)	57.6 (8.3)	0.27
Body height (cm)	166.9 (5.8)	154.4 (5.7)	<0.0001
Body weight (kg)	66.4 (9.5)	57.5 (8.1)	<0.0001
BMI (kg/m²)	23.8 (2.9)	24.1 (3.1)	0.001
NC (cm)	37.0 (2.2)	32.8 (1.9)	<0.0001
ThC (cm)	86.7 (6.1)	79.1 (7.2)	<0.0001
WC (cm)	85.6 (7.5)	83.7 (8.3)	<0.0001
HC (cm)	91.9 (5.2)	92.3 (5.3)	0.006
NHR	0.40 (0.02)	0.36 (0.02)	<0.0001
THR	0.94 (0.04)	0.86 (0.06)	<0.0001
WHR	0.93 (0.05)	0.91 (0.07)	<0.0001
SBP (mm Hg)	118.6 (15.1)	114.8 (16.5)	<0.0001
DBP (mm Hg)	79.2 (9.8)	75.1 (10.1)	<0.0001
FPG (mg/dl)	98.2 (16.4)	92.8 (11.4)	<0.0001
2 h post-load glucose (mg/dl)	127.0 (51.2)	128.7 (40.8)	<0.0001
Total cholesterol (mg/dl)	191.8 (32.9)	202.2 (33.4)	<0.0001
Triglycerides (mg/dl)	138.4 (70.2)	120.1 (57.5)	<0.0001
HDL cholesterol (mg/dl)	45.3 (12.0)	49.0 (12.6)	<0.0001
LDL cholesterol (mg/dl)	118.8 (30.1)	129.2 (29.9)	<0.0001
Smoking, n (%)			
Non smoker	506 (25.7)	2064 (97.7)	<0.0001
Ex-smoker	810 (41.2)	16 (0.8)	
Current smoker	651 (33.1)	32 (1.5)	
Drinking, n (%)			
Non drinker	482 (24.5)	1526 (72.2)	<0.0001
Ex-drinker	122 (6.2)	33 (1.6)	
Current drinker	1363 (69.3)	553 (26.2)	
Diabetes, n (%)	331 (16.8)	225 (10.7)	<0.0001

Values are means (SD) or n (%). p values are calculated from t-tests or chi-square tests for analysis of variance. BMI, body mass index; NC, neck circumference; WC, waist circumference; HC, hip circumference; ThC, thoracic circumference; NHR, neck-to-hip circumference ratio; THR, thoracic-to-hip circumference ratio; WHR, waist-to-hip circumference ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL cholesterol, high-density lipoprotein cholesterol; LDL cholesterol, low-density lipoprotein cholesterol.

respectively, whereas those values for WHR were 1.53 (1.07–2.20), 1.47 (1.02–2.12), and 1.95 (1.37–2.77) in men and 1.60 (1.03–2.49), 1.67 (1.07–2.61), and 2.31 (1.48–3.60) in women, respectively (Table 3).

3.2. Independent and joint effects of the THR and WHR in predicting type 2 diabetes

The second objective of this study was to determine whether THR, the upper-trunk-related anthropometric index that was most related to type 2 diabetes, was an independent determinant of type 2 diabetes to overall and central obesity indicators. Because the data showed that WHR was more closely associated with type 2 diabetes than WC, a comparison of the magnitude of the association with type 2 diabetes was conducted between BMI, WHR, and THR.

The multiple logistic regression analysis showed that the adjustment for potential confounders and BMI slightly attenuated the association between THR and WHR with type

Table 2 – Association of BMI and anthropometric indices with type 2 diabetes.

	OR (95% CI)	AUC (95% CI)	Cutoff	Se	Sp
Men					
BMI (kg/m^2)	1.12 (1.00–1.26)	0.533 (0.497–0.569)	25.7	0.33	0.76
NC (cm)	1.15 (1.02–1.29)	0.535 (0.499–0.570)	38.6	0.30	0.78
ThC (cm)	1.20 (1.06–1.35)	0.551 (0.516–0.586)	89.1	0.42	0.69
WC (cm)	1.16 (1.03–1.30)	0.541 (0.506–0.576)	88.0	0.45	0.63
NHR	1.18 (1.04–1.33)	0.539 (0.505–0.574)	0.42	0.25	0.83
THR	**1.29 (1.15–1.45)**	**0.577 (0.544–0.610)**	0.93	0.74	0.38
WHR	**1.23 (1.09–1.39)**	**0.564 (0.530–0.598)**	0.93	0.65	0.47
Women					
BMI (kg/m^2)	1.23 (1.08–1.40)	0.559 (0.518–0.600)	25.0	0.47	0.66
NC (cm)	1.19 (1.04–1.36)	0.545 (0.540–0.587)	33.3	0.48	0.63
ThC (cm)	1.30 (1.14–1.49)	0.578 (0.539–0.618)	80.5	0.52	0.62
WC (cm)	1.24 (1.08–1.42)	0.559 (0.520–0.599)	83.9	0.57	0.54
NHR	1.22 (1.07–1.40)	0.548 (0.507–0.588)	0.37	0.34	0.75
THR	**1.48 (1.29–1.70)**	**0.606 (0.565–0.646)**	0.88	0.50	0.69
WHR	**1.38 (1.20–1.58)**	**0.582 (0.543–0.622)**	0.90	0.65	0.49

OR (95% CI), odds ratio (95% confidence interval) for type 2 diabetes with each standard deviation increase in the independent variables, calculated by univariate analysis; AUC (95% CI), area under the curve values (95% confidence interval) calculated by receiver operating characteristic curve; cut-off, cut-off point for independent variables in predicting type 2 diabetes determined by Youden index; Se, sensitivity; Sp, specificity. The two highest OR and AUC values are in bold. For other abbreviations, see Table 1.

2 diabetes (Supplementary, Table S1). The correlation coefficients between BMI and THR were 0.28 in men and 0.45 in women, whereas the correlation coefficients between BMI and WHR were 0.49 in men and 0.44 in women (Supplementary, Table S2). The adjusted ORs for the THR were higher than those for the WHR in all models, particularly for women (Supplementary, Table S1). Furthermore, there was an increase in the prevalence of type 2 diabetes by tertiles of THR within each tertile of WHR, particularly in the highest WHR tertile (Fig. 1). Within each tertile of WHR, the higher tertiles of THR had a stronger risk of type 2 diabetes, including plasma fasting and 2-h post-load glucose and triglycerides

concentrations, than the lower tertiles (Supplementary, Fig. S1). These results indicate the independent effect of THR on diabetes.

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.diabres.2013.12.022.

To examine the joint effects of BMI, THR, and WHR in predicting type 2 diabetes, we stratified participants using internally calculated cutoffs. The cutoff for BMI (25.7 kg/m^2 for men and 25.0 kg/m^2 for women), THR (0.93 for men and 0.88 for women), and WHR (0.93 for men and 0.90 for women) were calculated from the distribution of the study sample (Table 2).

Table 3 – Adjusted odds ratios of type 2 diabetes by quartiles of BMI and anthropometric indices for men and women.

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Men				
BMI	1	0.79 (0.56–1.13)	0.86 (0.60–1.22)	1.43 (1.02–2.00)[*]
NC	1	0.85 (0.61–1.21)	1.05 (0.74–1.49)	1.67 (1.19–2.34)[**]
ThC	1	1.03 (0.72–1.47)	1.25 (0.88–1.78)	1.71 (1.22–2.40)[**]
WC	1	1.00 (0.71–1.42)	1.21 (0.85–1.72)	1.54 (1.10–2.16)[*]
NHR	1	1.19 (0.84–1.69)	1.17 (0.82–1.66)	1.53 (1.09–2.15)[*]
THR	1	1.48 (1.02–2.14)[*]	1.91 (1.33–2.75)[***]	2.11 (1.47–3.04)[***]
WHR	1	1.53 (1.07–2.20)[*]	1.47 (1.02–2.12)[*]	1.95 (1.37–2.77)[***]
Women				
BMI	1	1.14 (0.75–1.75)	1.32 (0.87–2.00)	1.68 (1.13–2.51)[*]
NC	1	0.90 (0.59–1.37)	1.07 (0.72–1.58)	1.70 (1.16–2.49)[**]
ThC	1	1.11 (0.72–1.71)	1.53 (1.01–2.32)[*]	2.15 (1.43–3.25)[***]
WC	1	1.00 (0.65–1.53)	1.48 (0.99–2.20)	1.51 (1.00–2.29)[*]
NHR	1	1.28 (0.85–1.93)	0.99 (0.65–1.53)	1.86 (1.25–2.77)[**]
THR	1	1.65 (1.05–2.59)[*]	1.61 (1.02–2.56)[*]	3.40 (2.18–5.31)[***]
WHR	1	1.60 (1.03–2.49)[*]	1.67 (1.07–2.61)[*]	2.31 (1.48–3.60)[***]

Data are presented as odds ratio (95% confident interval) adjusted for age, habitual smoking, alcohol consumption, and study center. Quartiles 1, 2, 3, and 4 represent the lowest, low medium, high medium, and highest quartiles, respectively, of BMI and anthropometric indices. The lowest quartile was the reference category. For other abbreviations, see Table 1.
[*] Significant level: $p < 0.05$.
[**] Significant level: $p < 0.01$.
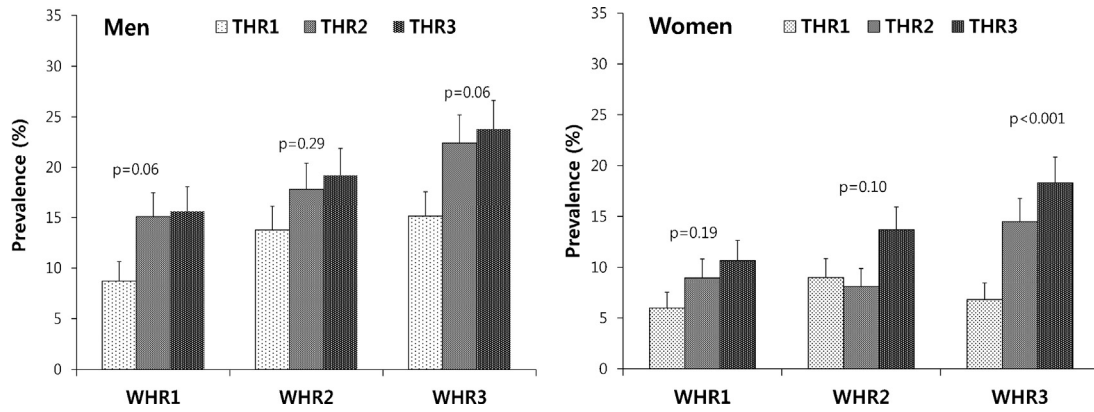[***] Significant level: $p < 0.001$.

Fig. 1 – Prevalence of type 2 diabetes of tertiles of THR across tertiles of WHR. THR, thoracic-to-hip ratio (THR1, THR2, and THR3 refers to tertiles of THR within each tertile of WHR); WHR, waist-to-hip ratio (WHR 1, WHR 2, and WHR 3 refer to tertiles of WHR).
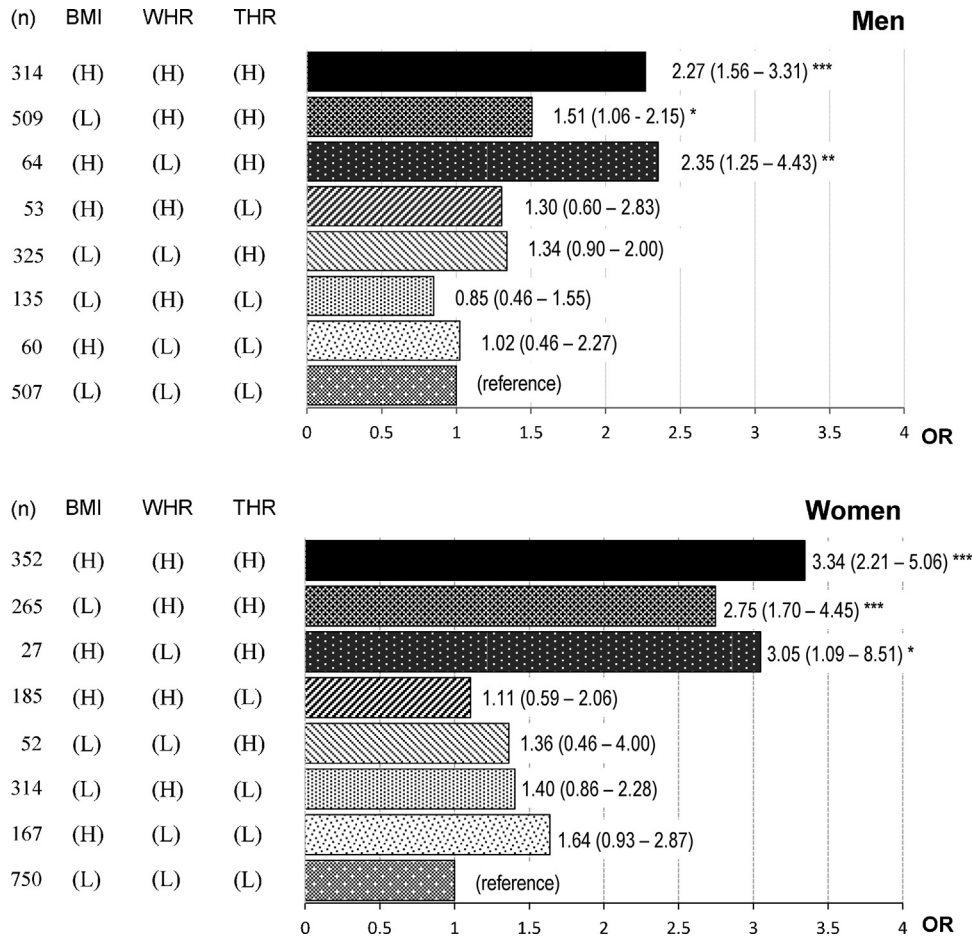

Fig. 2 – Joint and independent effects of BMI, WHR, and THR in predicting type 2 diabetes for men and women. The cutoff point for BMI was 25.7 kg/m^2 for men and 25.0 kg/m^2 for women (see Table 2); cutoff points for WHR (see Table 2) were 0.93 for men and 0.90 for women; cutoff points for THR (Table 2) were 0.93 for men and 0.88 for women. (H) means high category of independent variables (e.g., BMI (H) means BMI $\geq$ 25.7 kg/m^2 for men and $\geq$25.0 kg/m^2 for women); (L) means low category of independent variable (e.g., BMI (L) means BMI < 25.7 kg/m^2 for men and <25.0 kg/m^2 for women). The sample was stratified into 8 categorizes with 7 dummies. The group of subjects with low BMI, low WHR, and low THR was setup as the reference group. [*]$p < 0.05$; [**]$p < 0.01$; [***]$p < 0.001$, assessed by multivariable logistic regression analysis adjusted for age, smoking, drinking, and study center. Bars represent the adjusted odds ratio of type 2 diabetes; numbers are odds ratio (95% confident interval).

Thus, participants were categorized into 8 groups coded as 7 dummy variables (Fig. 2). The group that did not have high BMI, high WHR, or high THR was used as the reference category in the multiple logistic regression analysis adjusted for potential confounders. As shown in Fig. 2, those who had only a high BMI or high WHR or high THR did not have a significantly higher risk of type 2 diabetes than the reference group for both men and women. The adjusted ORs for individuals who had high BMI and high THR were 2.35 (1.25–4.43) for men ($p < 0.01$) and 3.05 (1.09–8.51) for women ($p < 0.05$). The adjusted ORs for individuals with high BMI and high WHR were 1.30 (0.60–2.83) for men ($p = 0.50$) and 1.11 (0.59–2.06) for women ($p = 0.75$). Additionally, the risk increase for individuals with high BMI, high THR, and high WHR (ORs were 2.27 in men and 3.34 in women) was not remarkably higher than that of individuals who had only high BMI and high THR.

4. Discussion

Many previous studies stressed the link between overall (assessed by BMI) and central (assessed by WC and WHR) obesity and increased risk of metabolic complications, including type 2 diabetes [21–24]. Debate continues about the best anthropometric indices for diabetes. Recent studies have focused on the cardiometabolic correlates of upper trunk fat and upper trunk-related anthropometric indices, such as NC [9,10], and the ''protective'' effect of hip size [24,25]. However, no studies have compared upper trunk-related anthropometric indices and indicators of overall and central obesity for predicting type 2 diabetes. The present study is the first attempt to compare the effects of upper trunk-related anthropometric indices and indicators of overall and central obesity in predicting type 2 diabetes in Korean adults. We found that (i) THR is the upper-trunk-related anthropometric index that is most closely related to type 2 diabetes among the upper-trunk-related anthropometric indices; (ii) THR appears to be an independent determinant of type 2 diabetes to BMI and WHR and its effect may be better than that of WHR in women; and (iii) BMI and THR can predict type 2 diabetes better than BMI and WHR.

Our findings suggested that the strength of the association between diabetes and ThC is slightly stronger than that of NC and WC. Moreover, THR is the strongest marker of type 2 diabetes among all investigated indices, particularly in women. ThC reflects the size of thoracic cavity and the body segment where android fat is measured by dual-energy X-ray absorptiometry [14]. Evidence suggests that android fat components, such as pericardial, hepatic, and intra-thoracic fats, are associated with metabolic disturbances independent of total and abdominal fatness [11–13], and the metabolic correlates of android fat are stronger than those of VAT [14]. It has been indicated that hepatic fatness plays a unique important role in determination of type 2 diabetes [26,27]. Although WC is a widely recommended index for determining central obesity and can be a strong determinant of diabetes, there is no consensus on the standard measurement site for this index. WC measured at the upper abdomen (just below the lowest rib) has a stronger relation with VAT than WC

measured at the lower abdomen (umbilicus or iliac crest) [28]. The VAT measured at the upper abdomen is additionally associated more closely with obesity-related health risks than VAT measured at the lower abdomen [29]. Furthermore, WC is more related to abdominal sc fat than abdominal VAT [30], and VAT more strongly correlates with insulin resistance than abdominal sc fat [31]. In this study, ThC measured at the prominence of the 7th–8th costochondral junctions (approximately 5 cm above the lowest rib) may be more related with android fat/VAT than abdominal sc fat. Although ThC and WC are highly correlated, they may reflect different aspects of body fat (android/VAT versus abdominal sc fat). Further studies should focus on the different relationships between ThC and WC with abdominal sc fat and VAT.

We additionally found that THR and WHR, which are the ratios that include information on upper/central trunk measurements and hip size, had a stronger relationship with diabetes than BMI and other anthropometric indices; the effect of THR was slightly stronger than WHR (Table 3). WC and HC have independent and opposite associations with diabetes risk. A larger HC is inversely associated with cardiovascular risk, including diabetes. The protective effect is most likely a result of the increase in gluteofemoral fat and muscle mass [25]. The combination of WC and HC in a ratio reflects not only the size of body segments and local body fats but also the pattern of fat distribution. Several studies have reported a stronger correlation between diabetes and WHR than WC, which may be a result of the integrative effects of both waist and hip size [24,32,33]. THR can be considered as the ratio of android fat, a harmful factor, to gluteofemoral (gynoid) fat, a protective factor. Evidence showed that the ratio of android to gynoid fat was associated with insulin resistance [34], and the trunk-to-hip ratio was more related to baseline insulin and QUICKI levels than abdominal-to-hip ratios [35]. Although THR and WHR were relatively correlated (the Pearson's correlation coefficients were 0.62 in men and 0.73 in women) in the current study, the correlation between diabetes and THR was slightly stronger than that of WHR in all models, even after adjusting for BMI. Interestingly, the correlation between diabetes and THR remained within each tertile of WHR (Fig. 1 and S1). Furthermore, the combination of a high BMI and a high THR resulted in a higher risk of type 2 diabetes than a combination of a high BMI and a high WHR, possibly because of the stronger correlation between diabetes and android fat versus abdominal sc fat. Taken together, body measurements at the upper trunk, such as ThC and THR, provide more accurate information on the risk of diabetes than BMI and other anthropometric measurements, and they should be considered in clinical and epidemiological studies.

This study has certain limitations. Although there may be advantages of THR over BMI and WHR, THR is more difficult to measure because it is not easy to identify the prominences of the 7th–8th costochondral junctions in some circumstances, such as serious obesity. The operators must be trained thoroughly. We were unable to measure body fat composition to examine the relationship between ThC and THR with abdominal fat and VAT. In this study, WC was measured at the umbilicus level that may cause measurement bias, particularly in obese individuals. These findings originated from a cross-sectional study and are unable to confirm any causal

relationship. Because those who are forty or older are at a higher risk of type 2 diabetes with a higher demand of diabetes screening than those are at younger age, the present study therefore focused on middle-aged and elderly Korean individuals. Thus, the results may not be generalizable to populations of other ages and races.

In conclusion, these data indicate that THR is associated with type 2 diabetes beyond the effects of overall (assessed by BMI) and central obesity (assessed by WHR) indicators in a middle-aged and elderly Korean population. These findings underline the importance of upper trunk measurements, particularly ThC and THR, in epidemiological and clinical studies.

Conflict of interest statement

The authors declare that they have no conflict of interest.

Acknowledgements

REFERENCES

[1] WHO. The global burden of disease 2004 update. Geneva, Switzerland: WHO; 2004.

[2] WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet 2004;363(9403):157–63.

[3] Jensen MD. Role of body fat distribution and the metabolic complications of obesity. J Clin Endocrinol Metab 2008;93(11 Suppl. 1):S57–63.

[4] Garg A. Regional adiposity and insulin resistance. J Clin Endocrinol Metab 2004;89(9):4206–10.

[5] Vague J. The degree of masculine differentiation of obesities: a factor determining predisposition to diabetes, atherosclerosis, gout, and uric calculous disease. Am J Clin Nutr 1956;4(1):20–34.

[6] Park SH, Choi SJ, Lee KS, Park HY. Waist circumference and waist-to-height ratio as predictors of cardiovascular disease risk in Korean adults. Circ J 2009;73(9):1643–50.

[7] de Koning L, Merchant AT, Pogue J, Anand SS. Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies. Eur Heart J 2007;28(7):850–6.

[8] Freedman DS, Rimm AA. The relation of body fat distribution, as assessed by six girth measurements, to diabetes mellitus in women. Am J Public Health 1989;79(6):715–20.

[9] Preis SR, Massaro JM, Hoffmann U, D'Agostino Sr RB, Levy D, Robins SJ, et al. Neck circumference as a novel measure of cardiometabolic risk: the Framingham Heart study. J Clin Endocrinol Metab 2010;95(8):3701–10.

[10] Ben-Noun LL, Laor A. Relationship between changes in neck circumference and cardiovascular risk factors. Exp Clin Cardiol 2006;11(1):14–20.

[11] Thanassoulis G, Massaro JM, Hoffmann U, Mahabadi AA, Vasan RS, O'Donnell CJ, et al. Prevalence, distribution, and risk factor correlates of high pericardial and intrathoracic fat depots in the Framingham heart study. Circ Cardiovasc Imaging 2010;3(5):559–66.

[12] Fabbrini E, Magkos F, Mohammed BS, Pietka T, Abumrad NA, Patterson BW, et al. Intrahepatic fat, not visceral fat, is linked with metabolic complications of obesity. Proc Natl Acad Sci U S A 2009;106(36):15430–5.

[13] Rabkin SW. Epicardial fat: properties, function and relationship to obesity. Obes Rev 2007;8(May (3)): 253–61.

[14] Kang SM, Yoon JW, Ahn HY, Kim SY, Lee KH, Shin H, et al. Android fat depot is more closely associated with metabolic syndrome than abdominal visceral fat in elderly people. PLoS ONE 2011;6(11):e27694.

[15] Meisinger C, Döring A, Thorand B, Heier M, Löwel H. Body fat distribution and risk of type 2 diabetes in the general population: are there differences between men and women? The MONICA/KORA Augsburg cohort study. Am J Clin Nutr 2006;84(3):483–9.

[16] Yoo KY, Shin HR, Chang SH, Choi BY, Hong YC, Kim HD, et al. Genomic epidemiology cohorts in Korea: present and the future. Asian Pac J Cancer Prev 2005;6(3):238–43.

[17] Jang E, Kim JY, Lee H, Kim H, Baek Y, Lee S. A study on the reliability of sasang constitutional body trunk measurement. Evid Based Complement Alternat Med 2012. http://dx.doi.org/10.1155/2012/604842.

[18] Shin C, Abbott RD, Lee H, Kim J, Kimm K. Prevalence and correlates of orthostatic hypotension in middle-aged men and women in Korea: the Korean Health and Genome Study. J Hum Hypertens 2004;18(10):717–23.

[19] World Health Organization. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO Consultation. Part 1: diagnosis and classification of diabetes mellitus. Geneva, Switzerland: World Health Organization; 1999, Available at: http://whqlibdoc.who.int/hq/1999/WHO_NCD_NCS_99.2.pdf [accessed 05.12.12].

[20] Fluss R, Faraggi D, Reiser B. Estimation of the Youden index and its associated cutoff point. Biom J 2005;47(4):458–72.

[21] Wang Y, Rimm EB, Stampfer MJ, Willett WC, Hu FB. Comparison of abdominal adiposity and overall obesity in predicting risk of type 2 diabetes among men. Am J Clin Nutr 2005;81(3):555–63.

[22] Rexrode KM, Buring JE, Manson JE. Abdominal and total adiposity and risk of coronary heart disease in men. Int J Obes Relat Metab Disord 2001;25(7):1047–56.

[23] Taylor AE, Ebrahim S, Ben-Shlomo Y, Martin RM, Whincup PH, Yarnell JW, et al. Comparison of the associations of body mass index and measures of central adiposity and fat mass with coronary heart disease, diabetes, and all-cause mortality: a study using data from 4 UK cohorts. Am J Clin Nutr 2010;91(3):547–56.

[24] Snijder MB, Zimmet PZ, Visser M, Dekker JM, Seidell JC, Shaw JE. Independent and opposite associations of waist and hip circumferences with diabetes, hypertension and dyslipidemia: the AusDiab Study. Int J Obes Relat Metab Disord 2004;28(March (3)):402–9.

[25] Heitmann BL, Lissner L. Hip Hip Hurrah! Hip size inversely related to heart disease and total mortality. Obes Rev 2011;12(6):478–81.

[26] Stefan N, Kantartzis K, Machann J, Schick F, Thamer C, Rittig K, et al. Identification and characterization of metabolically benign obesity in humans. Arch Intern Med 2008;168(15):1609–16.

[27] Kantartzis K, Machann J, Schick F, Fritsche A, Häring HU, Stefan N. The impact of liver fat vs visceral fat in determining categories of prediabetes. Diabetologia 2010;53(5):882–9.

[28] Bosy-Westphal A, Booke CA, Blöcker T, Kossel E, Goele K, Later W, 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(5):954–61.

[29] Shen W, Punyanitya M, Chen J, Gallagher D, Albu J, Pi-Sunyer X, et al. Visceral adipose tissue: relationships between single slice areas at different locations and obesity-related health risks. Int J Obes (Lond) 2007;31(5):763–9.

[30] Oka R, Miura K, Sakurai M, Nakamura K, Yagi K, Miyamoto S, et al. Comparison of waist circumference with body mass index for predicting abdominal adipose tissue. Diabetes Res Clin Pract 2009;83(1):100–5.

[31] Preis SR, Massaro JM, Robins SJ, Hoffmann U, Vasan RS, Irlbeck T, et al. Abdominal subcutaneous and visceral adipose tissue and insulin resistance in the Framingham heart study. Obesity (Silver Spring) 2010;18(11):2191–8.

[32] Lissner L, Bjorkelund C, Heitmann BL, Seidell JC, Bengtsson C. Larger hip circumference independently predicts health and longevity in a Swedish female cohort. Obes Res 2001;9:644–6.

[33] Seidell JC, Han TS, Feskens EJ, Lean ME. Narrow hips and broad waist circumferences independently contribute to increased risk of noninsulin-dependent diabetes mellitus. J Intern Med 1997;242:401–6.

[34] Aucouturier J, Meyer M, Thivel D, Taillardat M, Duché P. Effect of android to gynoid fat ratio on insulin resistance in obese youth. Arch Pediatr Adolesc Med 2009;163(9):826–31.

[35] Penaforte FR, Japur CC, Diez-Garcia RW, Chiarello PG. Upper trunk fat assessment and its relationship with metabolic and biochemical variables and body fat in polycystic ovary syndrome. J Hum Nutr Diet 2011;24(1):39–46.