보건정보통계학회지 제39권 제2호
ISSN 2287-3708(Print) ISSN 2287-3716(Online)
Journal of Health Informatics and Statistics (JHIS)
2014; 39(2): 1-12

Measures of Adiposity in the Identification of Metabolic Abnormalities in Middle-aged and Older Korean Adults

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Abstract

Objectives: We investigated anthropometric measures of obesity, including body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) in their associations with metabolic abnormalities in Korean adults.

Methods: Study participants were 1,399 male and 2,325 female community dwellers aged 40-79 years. Assessed metabolic variables included blood pressure, fasting glucose, insulin resistance, triglycerides, HDL cholesterol, LDL cholesterol, alanine aminotransferase, and gamma-glutamyl transferase. Associations of anthropometric measures per 1-SD increase with each metabolic abnormality were assessed using logistic regression analysis.

Results: The adiposity measurements were significantly associated with all of the metabolic abnormalities, only except for with LDL cholesterol in men. In men, hypertension was more strongly associated withBMI (OR=1.58) than WC (OR=1.40) or WHtR (OR=1.44) or WHtR (OR=1.75); and hypertriglyceridemia was more closely associated with WC (OR=1.91) than BMI (OR=1.79) or WHtR (OR=1.87). In women, three adiposity measurements had similar association with metabolic abnormalities.

Conclusions: Simple anthropometric measurements can be used to screen high-risk individuals of metabolic abnormalities in Korean men and women, although certain obesity indicators are more strongly with a specific kind of metabolic abnormality in men.

Keywords: Metabolic abnormalities, Anthropometric measures, Body mass index, Waist circumference, Waist-to-height ratio

[접수일: 2014년 06월 11일, 수정일: 2014년 08월 12일, 게재확정일: 2014년 10월 06일]

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* This study was supported by grants from the Korean Health Technology R&D Project (HI13C0715).

Ⅰ. INTRODUCTION

The metabolic syndrome is defined by a clustering of multiple metabolic abnormalities including impaired glucose, insulin resistance, high blood pressure, dyslipidemia [1]. The syndrome frequently accompanies other metabolic abnormalities such as nonalcoholic fatty liver disease (NAFLD) or elevated liver enzyme or chronic inflammation [2-4]. The rapid socioeconomic growth in Korea has caused in lifestyle changes, such as Westernized diet and sedentary behavior, which have led to an increase in the prevalence of metabolic syndrome from 24.9% in 1998 to 31.3% in 2007 [5]. This increasing prevalence is of considerable concern because many studies show that people with the metabolic abnormalities are at increased risk for developing diabetes mellitus and cardiovascular disease [6,7].

Obesity is a strong risk factor for metabolic disorders. Body mass index (BMI) is the most commonly used measure of obesity, but its relation with abdominal visceral fat is dependent on age and gender [8]. Ageing is associated with increase in fat mass and decreases in fat-free mass even if body weight remains stable [9]. Moreover, BMI cannot measure the change of body fat distribution in the elderly. Therefore, BMI is a weak indicator of metabolic abnormalities [10,11]. Since many studies reported that abdominal obesity is more important to the metabolic abnormalities [12-14], waist circumference (WC) [15-17] and waist-to-height ratio (WHtR) [18-20] have been suggested to measure abdominal obesity. Several investigators have concluded that the WC and WHtR are more strongly associated with metabolic abnormalities than BMI is. Plenty of data are available on the relationship between obesity and adverse health outcomes in the Western populations. However there is only limited number of community-based studies which examined the association of anthropometric indices of obesity with metabolic abnormalities in Koreans. Therefore, we evaluated the associations between anthropometric indices of obesity and metabolic abnormalities among community-dwelling Korean adults. We additionally sought evidence as to identify the best anthropometric predictor of the metabolic abnormalities.

Ⅱ. METHODS

A. Participants

This is a cross-sectional investigation analyzing baseline data collected for a prospective community-based cohort study of the Korean genome epidemiology study (KoGES). Subjects of the current investigation were 4,828 people who were enrolled between 2008 and 2010, aged 40-79 years, and living in the community of Kangwha Island, Incheon, South Korea. Among them, we excluded 1,104 participants who were using antihypertensives, antidiabetics, or lipid lowering drugs and/or having a history of cardiovascular disease, cancer, or fatty liver disease. Finally, 3,724 participants (1,399 men and 2,325women) were eligible for the current analysis. All participants provided written informed consents, and the study protocol was approved by the Institutional Review Board.

B. Definition of Metabolic Abnormalities

Metabolic abnormalities were defined as follows: 1)

high blood pressure (systolic blood pressure≥140 mmHg or diastolic blood pressure ≥90 mmHg) [21], 2) high fasting glucose (≥126 mg/dL) [22], 3) high insulin resistance (homeostasis model assessment of insulin resistance ≥2.5) [23], 4) high triglycerides (≥150 mg/dL) [24], 5) low high-density lipoprotein (HDL) cholesterol (〈40 mg/dL) [24], 6) high low-density lipoprotein (LDL) cholesterol (≥160 mg/dL) [24], 7) high alanine aminotransferase (ALT) (≥43 IU/L), 8) high gamma-glutamyl transferase (GGT) (〉50 IU/L) [25].

C. Measurements

Detailed methods for the measurements were previously reported elsewhere [26,27]. Participants were individually interviewed using standardized questionnaires to obtain information about their general characteristics, medical history, medication use, and lifestyle behaviors, such as smoking (current smokers or nonsmokers), alcohol intake (current alcohol drinkers or nondrinkers), and level of exercise (regular exercise or no exercise). The anthropometric measurements included height, weight, and waist circumference. We measured height and weight with subjects in light clothing and calculated BMI by dividing weight by height (kg/m^2). Waist circumference was measured mid-level between the inferior margin of the ribs and the superior border of iliac crest using a tape measure (SECA-200; SECA, Hamburg, Germany). The WHtR was calculated as the ratio of waist circumference and height. Resting blood pressure was measured twice by an automatic sphygmomanometer (Dinamap 1846 SX/P; GE Healthcare, Waukesha, WI, USA) with the participant in the sitting position at least 5 minute intervals. If the difference between the first and second measurement was more than 10 mmHg, a third measurement was performed. The average of the last two measurements was used for the analysis. Blood samples were collected from the antecubital vein after at least an 8 hour fast. Enzymatic methods were applied to measure fasting plasma glucose, triglycerides, total cholesterol, HDL cholesterol, hemoglobin A1c (HbA1c), insulin, C-reactive protein (CRP), ALT and GGT (ADVIA 1650; Siemens Healthcare Diagnostics Inc., Deerfield, IL, USA). LDL cholesterol was calculated using the Friedewald' method [28]. The measure for insulin resistance, the homeostasis model assessment of insulin resistance (HOMA-IR), was calculated as fasting insulin (U/mL)×fasting glucose (mg/dL)/405 [29].

D. Statistical Analyses

Comparison between men and women was made using independent t-test and chi-square test. Since some variables included in the analysis were markedly skewed, Spearman correlation coefficients were used to determine correlation between obesity indices and metabolic risk factors. Multiple logistic regression analysis was used to assess the odds ratio for the individual metabolic abnormalities per one unit increase in the measures of adiposity. Furthermore, the receiver operating characteristic (ROC) analysis was used to compare the discriminative power of BMI, WC, and WHtR. All statistical analyses were performed using SAS version 9.2 (SAS Inc., Cary, NC, USA).

Ⅲ. RESULTS

General characteristics for men and women participants were shown in Table 1. The variables were significantly different between men and women, with the exception of HbA1c and CRP.

Men had higher blood pressure, triglycerides, fasting glucose and liver enzyme than women. Women had higher BMI, WC, WHtR, total cholesterol, HDL cholesterol, LDL cholesterol, insulin and HOMA-IR than men.

Table 1. General characteristics and anthropometric measurements

Variables	Men (n=1,399)	Women (n=2,325)	*p*-value
Age (year)	57.3±8.8	55.2±8.6	<0.001
Height (cm)	165.8±5.9	153.4±5.5	<0.001
Weight (kg)	66.1±9.3	57.9±8.4	<0.001
Measures of adiposity			
BMI (kg/m²)	24.0±2.8	24.6±3.2	<0.001
WC (cm)	85.8±7.5	87.0±8.5	<0.001
WHtR (%)	51.8±4.4	56.8±5.8	<0.001
Lifestyle characteristics			
Current smoker (%)	441(31.6)	58(2.5)	<0.001
Drinker (%)	1019(72.8)	734(31.6)	<0.001
Physical inactivity (%)	908(64.9)	1538(66.2)	0.427
Metabolic risk factors			
Systolic BP (mmHg)	121.1±17.2	118.4±18.2	<0.001
Diastolic BP (mmHg)	77.3±10.2	71.7±10.4	<0.001
Total cholesterol (mg/dL)	189.5±32.1	201.0±35.1	<0.001
HDL cholesterol (mg/dL)	42.4±10.4	45.9±10.9	<0.001
LDL cholesterol (mg/dL)	117±30.2	129±31.1	<0.001
Triglycerides (mg/dL)	124[88-185]	114[82-160]	<0.001
Fasting glucose (mg/dL)	93[87-102]	90[85-97]	<0.001
HbA1c (%)	5.7±0.8	5.7±0.8	0.991
Insulin (uIU/L)	6.2[5.0-7.8]	7[5.6-8.7]	<0.001
CRP (mg/L)	0.7[0.4-1.6]	0.7[0.3-1.4]	0.080
HOMA-IR	1.5[1.1-1.9]	1.6[1.2-2.1]	<0.001
ALT (IU/L)	23[18-30]	18[15-23]	<0.001
GGT (IU/L)	27[18-48]	14[11-20]	<0.001

Data are expressed as means ±standard deviation, median [inter quartile range]

BMI: body mass index, WC: waist circumference, WHtR: waist to height ratio,BP: bloodpressure, HDL: high density lipoprotein, LDL: low density lipoprotein, CRP: C-reactive protein, HOMA-IR: homeostasis model for insulin resistance, ALT: alanine aminotransferase, GGT: gamma-glutamyl transferase

Table 2 shows correlation coefficients between obesity indices and metabolic variables, after adjusting for age, smoking, physical activity, and alcohol intake. BMI, WC and WHtR are all significantly correlated with blood pressure, fasting glucose, HbA1c, insulin, HOMA-IR, triglycerides, HDL cholesterol, CRP, ALT and GGT in both sexes. However, the correlation between obesity indices and LDL cholesterol, was significantonly in women ($p<0.001$), but not in men ($p=0.435$).

Table 2. Correlation between anthropometric obesity indices and metabolic variables

Variables	BMI		WC		WHtR	
	r*	*p*-value	r*	*p*-value	r*	*p*-value
Men (n=1,399)						
Systolic BP (mmHg)	0.22	<0.001	0.22	<0.001	0.23	<0.001
Diastolic BP(mmHg)	0.18	<0.001	0.20	<0.001	0.19	<0.001
Fasting glucose (mg/dL)	0.22	<0.001	0.23	<0.001	0.24	<0.001
HbA1c (%)	0.21	<0.001	0.19	<0.001	0.21	<0.001
Insulin (uIU/L)	0.47	<0.001	0.47	<0.001	0.46	<0.001
HOMA-IR	0.47	<0.001	0.48	<0.001	0.47	<0.001
Triglycerides (mg/dL)	0.34	<0.001	0.37	<0.001	0.36	<0.001
HDL cholesterol (mg/dL)	-0.29	<0.001	-0.27	<0.001	-0.27	<0.001
LDL cholesterol (mg/dL)	0.02	0.435	0.02	0.414	0.02	0.414
CRP (mg/L)	0.23	<0.001	0.26	<0.001	0.27	<0.001
ALT (IU/L)	0.26	<0.001	0.26	<0.001	0.27	<0.001
GGT (IU/L)	0.26	<0.001	0.28	<0.001	0.29	<0.001
Women (n=2,325)						
Systolic BP (mmHg)	0.26	<0.001	0.23	<0.001	0.24	<0.001
Diastolic BP (mmHg)	0.22	<0.001	0.18	<0.001	0.18	<0.001
Fasting glucose (mg/dL)	0.20	<0.001	0.19	<0.001	0.19	<0.001
HbA1c (%)	0.22	<0.001	0.24	<0.001	0.25	<0.001
Insulin (uIU/L)	0.37	<0.001	0.33	<0.001	0.32	<0.001
HOMA-IR	0.38	<0.001	0.34	<0.001	0.33	<0.001
Triglycerides (mg/dL)	0.24	<0.001	0.23	<0.001	0.23	<0.001
HDL cholesterol (mg/dL)	-0.13	<0.001	-0.11	<0.001	-0.10	<0.001
LDL cholesterol (mg/dL)	0.09	<0.001	0.10	<0.001	0.10	<0.001
CRP (mg/L)	0.35	<0.001	0.33	<0.001	0.34	<0.001
ALT (IU/L)	0.25	<0.001	0.22	<0.001	0.24	<0.001
GGT (IU/L)	0.29	<0.001	0.26	<0.001	0.28	<0.001

*Partial Spearman coefficient adjusted for age, smoking, physical activity, and alcohol intake.

BMI: body mass index, WC: waist circumference, WHtR: waist to height ratio, BP: blood pressure, HDL: high density lipoprotein, LDL: low density lipoprotein, HOMA-IR: homeostasis model for insulin resistance, CRP: C-reactive protein, ALT: alanine aminotransferase, GGT: gamma-glutamyl transferase

Table 3 shows the odds ratio for each metabolic abnormality associated with one unit increase in the adiposity measurements, after adjusting for age, smoking, physical activity, and alcohol intake. The adiposity measurements were associated with all of the metabolic abnormalities. Exceptionally, high LDL cholesterol level in men was not associated with any of obesity measures. In male subjects, among the three adiposity measurements, BMI was most strongly associated with high blood pressure (OR: 1.58, 95% CI: 1.29-1.93) WC was most strongly associated with high fasting glucose (OR: 1.79, 95% CI: 1.40-2.30) and high triglycerides (OR: 1.91, 95% CI: 1.68-2.17). However, in women, all three adiposity measures showed similar magnitude of associations with metabolic abnormalities.

Table 3. Association with anthropometric obesity indices and metabolic abnormalities

Metabolic abnormalities	Odds ratio (95% confidence interval) per 1-SD increase in		
	BMI	WC	WHtR
Men (n=1,399)			
High blood pressure[1)]	1.58 (1.29, 1.93)	1.40 (1.14, 1.71)	1.44 (1.17, 1.76)
High glucose[2)]	1.44 (1.14, 1.84)	1.79 (1.40, 2.30)	1.75 (1.37, 2.24)
High HOMA-IR[3)]	2.54 (2.10, 3.07)	2.55 (2.11, 3.08)	2.44 (2.02, 2.95)
High triglycerides[4)]	1.79 (1.58, 2.03)	1.91 (1.68, 2.17)	1.87 (1.64, 2.12)
Low HDL cholesterol[5)]	1.68 (1.50, 1.90)	1.64 (1.46, 1.84)	1.63 (1.45, 1.83)
High LDL cholesterol[6)]	1.03 (0.85, 1.26)	1.15 (0.95, 1.39)	1.17 (0.97, 1.42)
High ALT[7)]	1.70 (1.41, 2.07)	1.64 (1.35, 1.99)	1.74 (1.43, 2.12)
High GGT[8)]	1.43 (1.24, 1.63)	1.48 (1.29, 1.70)	1.51 (1.31, 1.73)
Women (n=2,325)			
High blood pressure[1)]	1.32 (1.09, 1.61)	1.34 (1.08, 1.68)	1.29 (1.02, 1.62)
High glucose[2)]	1.98 (1.65, 2.38)	2.01 (1.61, 2.51)	1.92 (1.52, 2.42)
High HOMA-IR[3)]	2.25 (1.99, 2.55)	2.28 (1.99, 2.60)	2.20 (1.92, 2.52)
High triglycerides[4)]	1.47 (1.34, 1.61)	1.55 (1.40, 1.70)	1.56 (1.41, 1.72)
Low HDL cholesterol[5)]	1.24 (1.13, 1.35)	1.19 (1.09, 1.30)	1.17 (1.06, 1.28)
High LDL cholesterol[6)]	1.17 (1.05, 1.30)	1.23 (1.09, 1.37)	1.23 (1.09, 1.39)
High ALT[7)]	1.82 (1.51, 2.18)	1.89 (1.52, 2.36)	2.01 (1.60, 2.53)
High GGT[8)]	1.72 (1.46, 2.04)	1.74 (1.42, 2.12)	1.86 (1.51, 2.30)

Adjustment for age, smoking, physical activity, and alcohol intake.

[1)]high blood pressure (a systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg [21], [2)]high fasting glucose (≥126 mg/dL) [22], [3)]high insulin resistance (defined as HOMA-IR ≥2.5) [23], [4)]high triglycerides (≥150 mg/dL) [24], [5)]low HDL cholesterol (〈40 mg/dL) [24], [6)]high LDL cholesterol (≥160 mg/dL) [24], [7)]high ALT (≥43 IU/L), [8)]high GGT (〉50 IU/L) [25]

BMI: body mass index, WC: waist circumference, WHtR: waist to height ratio, HDL: high density lipoprotein, LDL: low density lipoprotein, HOMA-IR: homeostasis model for insulin resistance, ALT: alanine aminotransferase, GGT: gamma-glutamyl transferase

The area under the curve (AUC) of the three anthropometric indices in the prediction of metabolic abnormalities are shown in Table 4. In men, the AUC of WC was greater than that of BMI or WHtR in the prediction of high fasting glucose, high HOMA-IR, low HDL cholesterol, high LDL cholesterol, high ALT, and high GGT. In women, the AUC of BMI was greater than that of WC or WHtR in the prediction of high blood pressure, high fasting glucose, high HOMA-IR, low HDL cholesterol, and high GGT the AUC of WHtR was greater than that of BMI or WC in the prediction of high triglycerides, high LDL cholesterol, and high ALT.

Table 4. Receiver operating characteristic curve of anthropometric obesity indices and metabolic abnormalities

Metabolic abnormalities	BMI	WC	WHtR
	AUC (95% CI)	AUC (95% CI)	AUC (95% CI)
Men (n=1,399)			
High blood pressure[1)]	0.633 (0.58, 0.69)	0.608 (0.55, 0.67)	0.603 (0.55, 0.66)
High glucose[2)]	0.603 (0.54, 0.67)	0.654 (0.59, 0.72)	0.654 (0.59, 0.72)
High HOMA-IR[3)]	0.735 (0.69, 0.78)	0.736 (0.70, 0.78)	0.715 (0.67, 0.76)
High triglycerides[4)]	0.642 (0.61, 0.67)	0.627 (0.60, 0.66)	0.624 (0.60, 0.65)
Low HDL cholesterol[5)]	0.655 (0.63, 0.68)	0.669 (0.64, 0.70)	0.651 (0.62, 0.68)
High LDL cholesterol[6)]	0.507 (0.45, 0.56)	0.533 (0.48, 0.59)	0.530 (0.48, 0.59)
High ALT[7)]	0.643 (0.59, 0.70)	0.653 (0.60, 0.71)	0.642 (0.59, 0.69)
High GGT[8)]	0.598 (0.56, 0.63)	0.617 (0.58, 0.65)	0.601 (0.57, 0.64)
Women (n=2,325)			
High blood pressure[1)]	0.583 (0.51, 0.66)	0.572 (0.50, 0.65)	0.543 (0.49, 0.60)
High glucose[2)]	0.692 (0.60, 0.78)	0.679 (0.60, 0.76)	0.675 (0.61, 0.74)
High HOMA-IR[3)]	0.722 (0.67, 0.78)	0.710 (0.66, 0.76)	0.697 (0.67, 0.73)
High triglycerides[4)]	0.619 (0.58, 0.66)	0.634 (0.60, 0.67)	0.643 (0.62, 0.67)
Low HDL cholesterol[5)]	0.566 (0.53, 0.60)	0.562 (0.53, 0.60)	0.562 (0.54, 0.59)
High LDL cholesterol[6)]	0.552 (0.48, 0.63)	0.571 (0.51, 0.63)	0.573 (0.54, 0.61)
High ALT[7)]	0.655 (0.59, 0.73)	0.664 (0.60, 0.73)	0.672 (0.61, 0.73)
High GGT[8)]	0.656 (0.61, 0.70)	0.646 (0.60, 0.69)	0.654 (0.60, 0.71)

[1)]high blood pressure (a systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg [21], [2)]high fasting glucose (≥126 mg/dL) [22], [3)]high insulin resistance (defined as HOMA-IR ≥2.5) [23], [4)]high triglycerides (≥150 mg/dL) [24], [5)]low HDL cholesterol (<40 mg/dL) [24], [6)]high LDL cholesterol (≥160 mg/dL) [24], [7)]high ALT (≥43 IU/L), [8)]high GGT (>50 IU/L) [25]

AUC: area under the receiver operating characteristic curve, CI: confidence interval, BMI: body mass index, WC: waist circumference, WHtR: waist to height ratio, HDL: high density lipoprotein, LDL: low density lipoprotein, HOMA-IR: homeostasis model for insulin resistance, ALT: alanine aminotransferase, GGT: gamma-glutamyl transferase

Ⅳ. DISCUSSION

This study showed strong associations between anthropometric measures and metabolic abnormalities in apparently healthy Korean adults. In male adults, BMI was more closely association with high blood pressure, while WC was more closely associated with high glucose and triglycerides. On the basis of discriminative power, BMI and WHtR were better predictors of metabolic abnormalities than WC in female, whereas WC is the best predictor in male. Among various measurements of obesity, BMI is the most frequently used in epidemiologic and clinical studies. However, BMI is not a good measure of visceral fat, the key determinant of metabolic abnormalities. Some authors have reported that WC and WHtR are better at predicting metabolic risk factors [30-32]. Compared to BMI, WC is more sensitive because increase of muscle mass might lead to little change of BMI but apparent changes in WC and WHtR. In the practice, WC can be a more convenient measure than WHtR, since ratios generally have larger measurement error than both their numerators and denominators [33-35]. On the other hand, WHtR can be used widely from children to adults with support of consumer-friendly conversion charts, but WC may not suit all groups and does not reflect body stature [36]. Some studies reported that WHtR correlates better with body fat mass than WC does [37]. These results suggest that BMI, WC, and WHtR may have different associations with metabolic abnormalities.

In our analysis, all of BMI, WC and WHtR showed strong associations with metabolic abnormalities, although certain obesity indicators are more strongly with a specific kind of metabolic abnormality in male adults. More specifically, high blood pressure was more strongly associated with BMI, and high fasting glucose and triglycerides levels were more closely associated with WC. In addition, we used ROC analysis to address the issue of discriminative performance. WC seems to be a better predictor of metabolic abnormality in men, while BMI and WHtR seem to be better than BMI in women. However, the difference in the magnitude of association and discriminative power was not big enough to choose the single best index. Our findings are only in partial agreement with the observation that specific simple anthropometric index is helpful for predicting the metabolic abnormalities in Korean adults [38,39]. We would like to recommend measuring BMI, WC and WHtR in health screenings, because all the three indices can be easily measured together and we can predict better a specific component of metabolic abnormalities by measuring three indices.

This study has the following limitations. First, the current study had no data directly assessing deposition of central fat such as dual X-ray absorptiometry body composition analysis. Thus, we could not address the relationship between direct measures of regional fat distribution and metabolic abnormalities. Second, our analysis was based on a cohort study from one rural area and limited to relatively healthy individuals. Thus, these results cannot be generalized for the entire Korean adult population. Third, this is a cross-sectional analysis. We could not determine whether the anthropometric measures predict change in metabolic profile or onset of new

metabolic abnormalities.

Since metabolic syndrome or its individual metabolic abnormalities predict future risk of cardiovascular disease [40,41], our study underscores the potential importance of reduction of adiposity for prevention of metabolic abnormalities and cardiovascular disease. In addition we support that anthropometric obesity measures, which are simple, inexpensive, reliable, and suitable for various settings, can predict metabolic abnormalities instead of using restricted mobility and expensive equipment.

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