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Original Article

Equation to estimate visceral adipose tissue volume based on anthropometry for workplace health checkup in Japanese abdominally obese men

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Abstract: The purpose of this study was to develop a new equation model for predicting abdominal visceral adipose tissue (VAT) volume using anthropometric values for workplace health checkup and to clarify the association between metabolic risk factors and measured and predicted VAT volumes. Two hundred sixty male workers (200 for derivation group and 60 for validation group) participated in the cross-sectional study. The anthropometric variables and VAT volume were measured with 24 consecutive magnetic resonance images. Measurements in the validation group also included metabolic risk factors, i.e. blood pressure, HDL cholesterol, triglyceride, fasting glucose and HbA1c. Using multiple regression analyses for the derivation group, we determined the best prediction equation for abdominal VAT volume with a variance of 47% as follows: 47.03 age + 117.79 BMI + 74.18 waist circumference −8,792.7. In our validation group, the correlation coefficient between the measured and predicted VAT volumes was 0.74 ($p < 0.01$). Furthermore, blood pressure, fasting glucose and HbA1c correlated with both measured and predicted VAT volumes. This study suggests that the equation model has potential to assess VAT accumulation levels in workers health checkup where CT and MRI are not available.

Key words: Health checkup, Visceral adipose tissue, Prediction equation, Waist circumference, Metabolic syndrome

Introduction

Metabolic syndrome (MS) is defined as a condition with central obesity (excess abdominal visceral adiposity), elevated blood pressure, fasting glucose (FG), high serum triglyceride (TG) and low HDL cholesterol (HDLC), and it is characterized by inter-related risk factors that increase the incidence of cardiovascular disease[1, 2] and type 2 diabetes[3, 4]. In recent years, the prevalence of MS continues to increase in many countries[5]. Therefore, establishing countermeasures against MS has become an important worldwide issue.

Although some of the MS criteria may vary in different parts of the world, a major criterion is central obesity which the International Diabetes Federation (IDF)[6] regards as an essential component, as does Japan's evaluative body for metabolic syndrome[7]. In Japan, the government has started to apply its 2008 MS criteria for use in the workplace health checkup, a program aimed at reducing MS in people 40 yr and older. The Japanese definitions for

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pre-MS and MS include central obesity as an essential condition plus one (pre-MS) or more (MS) of the following three components: 1) dyslipidemia (TG ≥150 mg/dl and/or HDLC <40 mg/dl, or specific treatment for these lipid abnormalities); 2) hypertension (systolic blood pressure (SBP) ≥130 mmHg and/or diastolic blood pressure (DBP) ≥85 mmHg, or treatment of diagnosed hypertension); or 3) hyperglycemia (FG ≥110 mg/dl). One important characteristic of the Japanese MS definition is the concept of central obesity as an essential condition for MS, that is, a waist circumference (WC) cut-point of ≥85 cm for men and ≥90 cm for women at the umbilicus. Thus, the definition of MS focuses on abdominal visceral adipose tissue (VAT) as the most important risk factor for MS.

Currently, the methods of choice for directly measuring VAT are computed tomography (CT) and magnetic resonance imaging (MRI). With these imaging methods, a single-slice at the umbilicus or the fourth and fifth lumbar vertebrae (L4–L5) generally is used for calculating the VAT area (cm^2)[8, 9]. For instance, the Japanese WC definition for MS was defined as ≥85 cm for men and ≥90 cm for women because epidemiological studies indicated that the risk of cardiovascular disease and type 2 diabetes increased when the VAT at the umbilicus exceeded 100 cm^2, and a WC of 85 cm for men and 90 cm for women are equivalent to 100 cm^2 of VAT area[10].

However, recent studies[11, 12] indicate that using only a single-slice image to determine an individual's VAT may be inaccurate. Abdominal adipose tissue is divided into two main regions, VAT and subcutaneous abdominal tissue (SAT), and the distribution of those two components within the abdominal cavity can vary significantly different between individuals[13]. Therefore, a cross-sectional image of a single-specific abdominal point at the umbilicus or L4–L5 may inaccurately portray the distribution of VAT and SAT in the abdominal cavity. This suggests that volumetric measurements may more accurately characterize the differences in VAT distribution between individuals. In addition, other studies[14, 15] reported a significantly greater correlation of the MS risk factors of blood pressure, FG and lipids with VAT volume than with VAT area at L4–L5. Therefore, we believe it is more helpful to discuss VAT based on total volume rather than a cross-sectional area of the abdominal cavity.

Since MRI and CT imaging can be costly and time-consuming, health professionals do not commonly employ those methods to measure VAT in health checkup for the workers. Instead, WC has been used as an alternative measurement. However, as pointed out above, using only WC to evaluate the accumulation of VAT may not be accurate because the WC measurement is based on the single-slice method of determining VAT area.

In this study, we measured VAT volume using a MRI multiple-slice method. We then tried to develop an equation using simple anthropometric values to predict VAT volume. Some studies[16, 17] have proposed VAT-estimate equation models, but these studies used the single-slice VAT area as a criterion value which still included the problematic issue of determining VAT area using a single-specific abdominal point. Therefore, the purpose of this study is twofold: 1) to develop a new equation model for predicting VAT volume using anthropometric values, and 2) to clarify the association between MS risk factors and the measured and predicted VAT.

Methods

Participants

We used data who participated for weight-loss studies or health check event conducted in 2009–2014. The participants were recruited through advertisements in local newspapers and the distribution of flyers. The participants were selected for this study based on the following eligibility criteria: 1) aged 30–59 yr 2) WC greater than 85 cm according to the MS criteria in the workplace health checkup[7]. We initially collected 288 workers for this study but excluded 22 men because we were unable to measure adequately their MRI images. The final derivation group comprised 200 men for the first year of the study and a validation group of 60 men in which we validated our best-fit model of the anthropometric values to predict VAT volume for the second year of the study. We determined the VAT volume by MRI and anthropometric values in all participants. We also included MS risk factor values in the validation group. This study conformed to the principles outlined in the Helsinki Declaration and was approved by the Institutional Ethical Review Board. All participants gave their informed consent to participate after a full explanation of the study.

Measurements

Anthropometric measurements

We measured body weight to the nearest 0.1 kg using a digital scale (WB-150; Tanita, Tokyo, Japan) and measured height once to the nearest 0.1 cm using a wall-mounted stadiometer (YG-200; Yagami, Nagoya, Japan). Body mass index (BMI) was calculated as the weight (in kilograms) divided by height (in meters) squared. We measured WC

in the standing position directly on the skin surface at the level of the umbilicus, chest circumference in normal expansion at the level of the nipple, and hip circumference at the greater curvature. We made all circumference measurements in duplicate to the nearest 0.1 cm with the mean value used for the analysis.

Magnetic resonance imaging

We used a 1.5-T system to obtain abdominal, multiple-slice MRI scans with the image location defined relative to the common anatomical landmark of the L4–L5 intervertebral space. Detail protocol of the MRI scan is fully described elsewhere[18]. Briefly, the slice thickness was 10 mm with images spanning from the ninth thoracic vertebra (T9) to the first sacral vertebra (S1). We segmented and quantified each image using image analysis software (SliceOmatic, Tomovision Inc., Montreal, Canada). The model and method employed to segment the various tissues is fully described and illustrated elsewhere[14]. We used the single-slice image at the level of L4–L5 to assess VAT and SAT areas and analyzed VAT and SAT volumes with reference to the L4–L5 image. A total of 24 MRI images were collected: the reference point at L4–L5, 20 points toward the head at 1-cm intervals and 3 points toward the feet at 1-cm intervals. An individual's VAT and SAT volumes were calculated as their sums of slice thickness and interslice distance. Also, the technical errors for 2 readings of the same scan by the same observer for SAT and VAT volumes in our laboratory were 1.23% and 2.27%, respectively (n=82)[15].

Blood pressure and biochemical assays of blood

One trained nurse measured the SBP and DBP of subjects via the right arm using a mercury manometer and a standard protocol after the subjects had rested for at least 20 min in a seated position. Blood samples were collected from the antecubital vein of each participant after an overnight (≥8 h) fast for analysis of HDLC, TG and FG. We determined HbA1c with a latex agglutination method (Kyowa Medex, Tokyo, Japan). The inter- and intra-assay CV were <5% for all blood parameters.

Statistical analysis

We performed all statistical analyses using SPSS version 22.0 for Windows package. Participants medication status is reported as mean (%), other values are expressed as the mean ± SD. The Mann-Whitney U test was used to compare differences between the derivation group and validation group. The Pearson`s correlation coefficients were used to examine relationships between MRI measurements of VAT and SAT with age and anthropometric measurements. Also, The Spearman's correlation coefficients were used to examine relationships between body fat-related variables and metabolic variable in validation group. Multiple, stepwise, linear regressions were developed with VAT volume as a dependent variable and anthropometric parameters as independent variables. We applied the final prediction equation to the validation group as a means of cross-validation and then assessed the accuracy of our VAT volume prediction with Bland-Altman plots.

Table 1. Characteristics of men in the derivation and validation group

	Derivation group	Validation group
n	200	60
Age, yr	48.9 ± 8.6	49.1 ± 9.4
Height, cm	170.7 ± 6.1	172.5 ± 5.4
Weight, kg	85.2 ± 11.7	87.2 ± 12.3
BMI, kg/m^2	29.2 ± 3.3	29.3 ± 3.8
Chest circumference, cm	103.6 ± 6.9	104.2 ± 8.2
Waist circumference, cm	99.6 ± 8.1	99.8 ± 9.2
Hip circumference, cm	101.5 ± 6.8	102.9 ± 7.7
VAT volume, cm^3	4,330 ± 1,426	4,339 ± 1,382
SAT volume, cm^3	4,125 ± 1,357	4,276 ± 1,413
VAT area, cm^2	162.4 ± 67.0	165.4 ± 58.1
SAT area, cm^2	239.1 ± 77.0	244.3 ± 83.7
Metabolic variables		
SBP, mmHg		130.4 ± 18.1
DBP, mmHg		87.0 ± 12.5
HDL cholesterol, mg/dl		48.1 ± 9.3
Triglyceride, mg/dl		164.3 ± 110.2
Fasting glucose, mg/dl		107.2 ± 37.7
HbA1c, %		5.7 ± 1.3

Data are given as mean ± SD. Abbreviations: BMI: body mass index; VAT: visceral adipose tissue; SAT: subcutaneous adipose tissue; SBP: systolic blood pressure; DBP: diastolic blood pressure; HDL: high-density lipoprotein.

Table 2. Pearson's correlation coefficients between VAT, SAT and traditional anthropometric measurements in the derivation group (n=200)

	Volume	
	VAT	SAT
Age	0.17*	−0.42**
Height	0.13	0.11
Weight	0.58**	0.64**
BMI	0.61**	0.69**
Chest circumference	0.55**	0.64**
Waist circumference	0.62**	0.76**
Hip circumference	0.42**	0.64**

*Correlation is significant at 0.05 level.
**Correlation is significant at 0.01 level.

Table 3. Regression coefficients for predicting abdominal VAT volume using traditional anthropometrics in the derivation group (n=200)

	Eq	intercept	Independent variables					R^2 (%)	SEE
			Age	BMI	Chest circumference	Waist circumference	Hip circumference		
VAT volume	1	−6,562.6				109.39		38.0	1,120.3
	2	−9,661.8	46.51			117.69		45.6	1,051.3
	3	−8,792.7	47.03	117.79		74.18		46.9	1,039.1

Abbreviations: VAT: visceral adipose tissue; Eq: equation; BMI: body mass index.
Multiple, stepwise, linear regressions were developed with VAT volume as a dependent variable and age and anthropometric parameters (BMI, chest circumference, waist circumference, hip circumference) as independent variables. The 3 equation models were determined by the analysis.

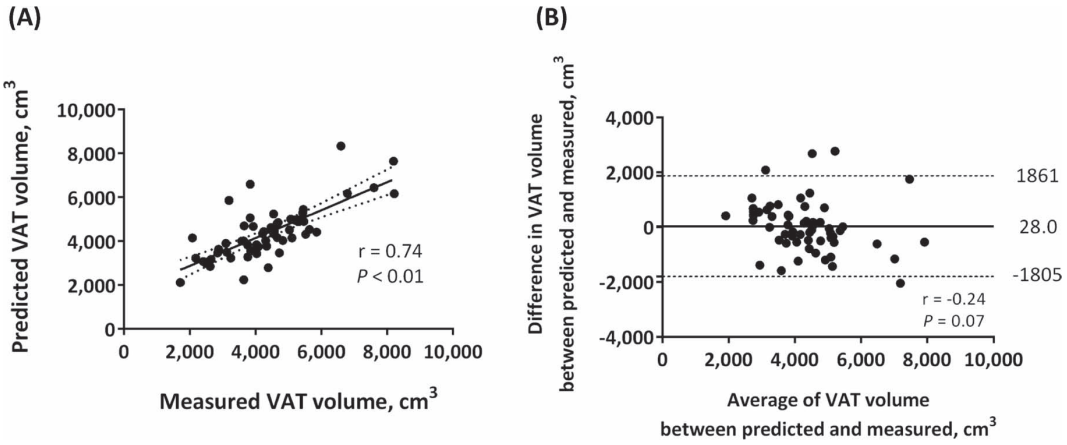

Fig. 1. (A) Correlations between measured VAT volume by MRI and predicted by anthropometrics. (B) Bland-Altman plot of VAT volume measured by MRI and the prediction equation based on anthropometric variables. The middle solid line indicates the mean between measured value and estimated value. The upper and lower dashed lines represent limits of agreement (±1.96 SD from the mean).

Results

Table 1 presents the participants' characteristics in the derivation group (hypertension: 20.5%, hyperlipidemia: 17.0%, diabetes: 13.5%) and validation group (hypertension: 13.3%, hyperlipidemia: 21.7%, diabetes: 11.7%). The measurement values were not significantly different between groups (data not shown). Table 2 shows the Pearson correlation coefficients (*r*) between VAT and SAT volume and anthropometric measurements. In both VAT and SAT volumes, all independent variables other than height were statistically significant. All correlation coefficients of anthropometric measures were greater with SAT (range of r=−0.42~0.76) than with VAT (range of r=0.17~0.62).

In multiple regression analyses, the independent variables of WC only accounted for 38% of VAT volume variance. The best prediction equation for abdominal VAT volume used anthropometric measurements, namely, VAT volume (cm^3)=47.03×age (yr)+117.79×BMI (kg/m^2)+74.18×WC (cm)−8,792.7 (Table 3). The model explained 47% of VAT variance with the SEE of 1,039.1 cm^3.

Figure 1(A) illustrates the strong agreement (r=0.74, $p<0.01$) between the measured and predicted VAT volumes for the validation group, and Bland-Altman plots show the accuracy of our selected equation in Fig. 1(B). The mean bias for VAT volume was 28.0 cm^3 (95% limits of agreement: −1,805 to 1,861 cm^3), and the proportional bias was not noted (r=−0.24, $p=0.07$). Table 4 shows the correlation between body fat-related variables and MS risk factors in the validation group. The measured and predicted VAT volumes correlated significantly with SBP, DBP, FG and HbA1c. On the other hand, WC and BMI only correlated to HbA1c with a similar magnitude. Also, these correlations between MS risk factors and VAT volume were greater than measured VAT area.

Discussion

In this study, we developed a simple and accurate equa-

Table 4. Spearman's correlation coefficients between body fat-related variables and metabolic variables in the validation group (n=60)

	SBP	DBP	HDLC	Triglyceride	Fasting glucose	HbA1c
Predicted VAT volume	**0.41****	**0.36****	−0.03	0.08	**0.40****	**0.47****
Measured VAT volume	**0.41****	**0.35***	−0.02	0.15	**0.33***	**0.44****
Measured VAT area	**0.33***	0.13	−0.01	0.25	**0.30***	**0.26***
Waist circumference	0.19	0.21	−0.14	0.07	0.25	**0.40****
Body mass index	0.21	0.22	−0.23	0.08	0.25	**0.42****

*Correlation is significant at 0.05 level. **Correlation is significant at 0.01 level.

tion model using anthropometric variables to predict VAT volume and suggested a candidate equation we thought most useful. Using only WC in the model explained 38% of VAT variance, but adding BMI and age into the model increases 9% of the contribution ratio. In our validation group, the correlation coefficient between the measured and the predicted VAT volumes was 0.74 ($p<0.01$), and the equation predicted the VAT volume with a fair degree of accuracy (Fig. 1(B)). Further analyses in the validation group showed no significant correlation between single anthropometric values (WC and BMI) and MS risk factors except HbA1c. However, in this study both the measured and the predicted VAT volumes correlate significantly with some MS risk variables, and the important thing is that these correlation coefficients were stronger than the correlations between VAT area and MS risk factors. Taken together, our equation can be used to calculate VAT accumulation for defining MS in the workplace health checkup when appropriate imaging methods are not available.

We determined in this study that, statistically, the best prediction equation for VAT volume involves three variables–age, BMI and WC. Interestingly, BMI (r=0.61), as well as WC (r=0.62), showed a similar degree of association with VAT volume. These results indicate that either WC or BMI may be used for estimating VAT volume. However, our stepwise analysis showed that using both variables together increased the explanatory power over using either variable alone (WC: 38%; BMI: 37%). Therefore, using a combination of WC and BMI is advantageous for predicting VAT volume. Nazare *et al.*[19] proposed that the strong correlation between WC and BMI at the population level does not necessarily imply good concordance at the individual level. Namely, they suggested that the combined use of WC and BMI allows for stratification of individuals according to their level of VAT at a given BMI level. Others have reported similar findings when WC and BMI are included as predictor values. Goel *et al.*[20] produced an intra-abdominal adipose tissue predictive equation combining WC, hip circumference, age, sex and BMI in Asian Indians. Their equation explained 52% of variability. Similarly, Janssen *et al.*[21], who suggested a VAT prediction equation with BMI and WC as independent variables and a 57% variability for men, showed that combining WC with BMI has 6% more explanatory power for abdominal obesity than BMI alone. Brundavani *et al.*[17] developed prediction equations for VAT that included weight, WC and BMI as independent variables. Their equation had 74% variability in men and 63% variability for women. However, the aforementioned studies may be limited by using VAT area as a dependent variable. In our study, we determined our equation with multi-slice measurements, which improved the accuracy of our VAT measurement, yet we also found that BMI and WC together emerged as the best predictors of VAT volume. Furthermore, in this study, we used Bland-Altman analysis to assess the accuracy of our VAT volume prediction equation. Only one study by Schaudinn *et al.*[22] investigated a prediction equation for VAT volume in obese patients. They showed a mean VAT bias between −55~232 ml for males and −61~161 ml for females. It is impossible to compare the mean bias between the previous and the present studies directly because the two studies used different methods: Schaudinn's study used the VAT area (single- and five-slice MRI), whereas our study used anthropometry as explanatory variables. Taking this into consideration, the mean bias for VAT volume in the current study (28 cm^3) is not excessive.

Recently, the Framingham Heart Study[8] and the Jackson Heart Study[23] showed a significant correlation between measured VAT volume and metabolic risk factors such as TG, HDLC, FG, SBP and DBP. Correlations from both studies had similar ranges: r=−0.33~0.37 in the Framingham Heart Study and r=−0.33~0.29 in the Jackson Heart Study. Our results also showed significant correlation between measured VAT volume and MS risk factors except for HDLC and TG, and the correlation coefficient's range was similar (r=0.31~0.42). Furthermore, our predicted VAT volume correlated significantly with MS risk factors with a similar range (r=0.30~0.37). On the other hand, an

important result of this study is the difference correlations we found between VAT area/volume and MS risk factors. There were significant correlations between SBP (r=0.33), fasting glucose (r=0.30) and HbA1c (r=0.26) and the VAT area at L4–L5, but these correlation coefficients were weaker than the correlations between the VAT volume and MS risk factors. Although the reason for this trend on VAT area remains unclear, it may be due to individual differences in VAT distribution. Previous studies[11, 12] indicated that using only a single-slice image to determine an individual's VAT may be inaccurate, and conceivably, this may diminish the correlation. Those studies suggested that once the anatomic regions that define the depots are established, multiple-slice imaging would be the recommended method to measure VAT volumes accurately. These results suggest that our equation model based on VAT volume can be a useful tool for predicting cardiovascular disease in large populations during health checkup.

Developing an equation and investigating the association between MS risk factors using a highly reproducible volumetric method of VAT assessment is a marked strength of this study. Furthermore, we derived equations from easily and commonly measured anthropometrics in workplace health checkup currently. Other studies[16, 24, 25] have included sagittal diameters or skinfold thickness, types of measurements that may not be readily available in the majority of workplace situations. However, our results and equation are not generalizable over different races and sexes, and several reports have indicated that VAT and its relationship to MS risk factors is different depending on sex[26, 27] and race[13, 28]. Also, since this equation was derived from data acquired from middle-aged and abdominally obese male subject, use for people with normal weight or female is not appropriate.

In summary, this is the first volumetric method-based study to develop a VAT prediction equation using routine anthropometrics including WC and BMI. Our equation model was reasonable and the estimated VAT volume calculated from our candidate equation significantly related to MS risk factors. Future studies should expand these findings to different ethnic and sex groups. Where CT or MRI is not available, this equation model can assess VAT accumulation levels in the workplace health checkup for workers health care.

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Disclosure

The authors declare no conflict of interest.

Author Contributions

Substantial contributions to study conception and design: Rina So and Tomoaki Matsuo; MRI data acquisition: Kousaku Saotome; Data analysis and interpretation: Rina So, Tomoaki Matsuo; Contribution to manuscript revisions and developing study concept and design: Kiyoji Tanaka.

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