ORIGINAL RESEARCH

MRI sagittal abdominal diameter is a stronger predictor of metabolic syndrome than visceral fat area or waist circumference in a high-risk vascular cohort

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Objective: To determine whether sagittal abdominal diameter (SAD) is associated with the metabolic syndrome independently of visceral fat area (VFA) and waist circumference (WC).

Methods: Forty-three high-risk vascular patients were evaluated for metabolic syndrome criteria and underwent magnetic resonance imaging (MRI) to quantify SAD and VFA at the L4–L5 disc.

Comparisons: 1. Baseline differences in patients with and without the metabolic syndrome 2. Forward binary logistic regression analysis of predictors of the metabolic syndrome with SAD, VFA and WC as independents 3. Correlates of SAD.

Results: Patients with metabolic syndrome had greater SAD, VFA and WC than patients without the metabolic syndrome ($P < 0.01$). Of SAD, VFA and WC, only SAD was associated with metabolic syndrome on forward binary logistic regression; beta 0.68, Wald's statistic 10.8 ($P = 0.001$) and c-statistic 0.89 ($P < 0.001$). A > 22.7 cm SAD threshold identified metabolic syndrome with a 91% sensitivity and 80% specificity. SAD correlated with waist circumference ($r = 0.918$), high-density lipoprotein-cholesterol ($r = -0.363$), triglyceride ($r = 0.401$), fasting glucose ($r = 0.428$) and the QUICK index of insulin sensitivity ($r = -0.667$) (all $P < 0.05$).

Conclusions: MRI-measured SAD is associated with the metabolic syndrome and renders the current gold standard of VFA redundant. This measure of obesity-related cardiovascular risk requires validation and evaluation in a prospective cohort.

Keywords: obesity, insulin resistance, waist circumference, metabolic syndrome, sagittal abdominal diameter, visceral fat area

Introduction

The increased risk of cardiovascular events associated with obesity is driven by the accumulation of visceral fat and insulin resistance.[1–5] Waist circumference (WC) is typically used in clinical practice to both quantify abdominal obesity and to make the diagnosis of the metabolic syndrome. In patients with established vascular disease, as in healthy patients, the diagnostic label of 'metabolic syndrome' portends an increased risk of cardiovascular events and therefore carries clinical significance.[6–9] While several reports have suggested that the anteroposterior diameter of the abdomen, the sagittal abdominal diameter (SAD), is a superior correlate of metabolic syndrome criteria and insulin resistance than waist circumference, there has been little incorporation of this measure into routine clinical practice.[10–13] SAD has recently been suggested to be a superior predictor of the metabolic syndrome than visceral fat area (VFA) in a single report.[14] VFA, measured at the umbilicus, is the current gold standard for the

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determination of obesity-related cardiovascular risk and is a determinant of metabolic risk factors and the metabolic syndrome after correction for body mass index (BMI) and WC.[4,15] Further, VFA has been independently linked to the development of coronary artery disease.[16] Hence, the finding that SAD is a superior predictor of the metabolic syndrome than VFA potentially carries important implications. Firstly, SAD may be measured with the Holtain–Kahn abdominal caliper without requiring any imaging, with its associated costs. Secondly, while commercial software is available to automate the process of quantifying fat areas from imaging, the process remains time-consuming and requires human input for analysis of appropriate images. Hence we sought to reproduce the finding that SAD is a superior predictor of the metabolic syndrome than VFA and to also compare this to WC. Further, we sought to investigate the correlation of SAD with the individual criteria of the metabolic syndrome and insulin sensitivity on a continuous scale.

Methods
Study population
We recruited patients with coronary artery disease (CAD), ischemic stroke, or CAD risk-equivalents. Eligible patients had to have at least one of the following: 1. CAD (positive angiogram or history of myocardial infarction) 2. Peripheral vascular disease (ABI < 0.9 or history of lower limb revascularization for atherosclerosis) 3. Abdominal aortic aneurysm 4. carotid atherosclerosis with >50% narrowing 5. type II diabetes with age > 50 and 3 additional risk factors (male sex, albuminuria, hypertension, high-density lipoprotein-cholesterol [HDL-C] < 40 mg/dL, triglycerides [TG] > 150 mg/dL, low-density lipoprotein-cholesterol [LDL-C] > 100 mg/dL, current smoking, diabetes duration >20 years), or 6. Ischemic stroke. Eligible patients were not taking lipid-modifying drugs. Study participants were in a clinically stable condition and were recruited from the vascular surgery outpatient department at the Royal Brisbane and Women's Hospital.

Patient data
Patient demographic information was collected including age, sex, qualifying criterion, self-reported race, current medications, cigarette smoking, blood pressure, anti-hypertensive medication use, height, weight, and waist circumference. Metabolic syndrome was defined as per the Adult Treatment Panel III (ATP III) criteria.[17] Fasting blood samples were analyzed for baseline lipids, glucose, and insulin. Fasting lipid profile and glucose were determined using standard hospital

methods. Insulins were measured by chemilumnescent immunoassay on a Beckman Coulter DxI800 (Beckman Coulter UK Ltd, London, UK) as per the manufacturer's instructions. To determine insulin sensitivity, we used the quantitative insulin sensitivity check index (QUICK index) since this a superior linear correlate (r~0.8–0.9) of the reference standard glucose clamp than the homeostasis model assessment (HOMA) model.[18,19]

MRI measurement of abdominal fat areas
MR imaging was performed with a Siemens Trio 3 T MRI system (Siemens AG, Erlangen, Germany) using standard array coils with the subject supine. Breath-hold FISP images were centered on the L4–L5 intervertebral disc using standard localizer images with the following parameters: TR = 4 ms, TE = 2 ms, number of slices = 12, slice thickness = 8 mm, image matrix 256×256, field-of-view = 500×500 mm. The 4 slices that were best aligned with the L4–L5 disc (19, 20), were analyzed using the polygon region of interest in Escape medical viewer v3.2 to define visceral fat area (VFA) as described previously.[20] Briefly, VFA was measured by fitting a spline curve to points on the border of the subcutaneous and visceral regions. Nonfat regions within the visceral region were also outlined with a spline fit and subtracted from the total visceral region. The SAD was measured at the L4–L5 disc by measuring the distance from the anterior part of the body to the posterior portion of the body using the caliper function on the software package. However, SAD can be measured using the Holtain–Kahn abdominal caliper without imaging.

Statistical methods
The baseline characteristics of the included patients were summarized and the diagnosis of the metabolic syndrome as per ATP III criteria[17] was determined for each patient. We compared patients with and without the metabolic syndrome for various metabolic parameters and imaging parameters. We compared the means of continuous variables with a two-tailed Student's t-test for normally distributed variables, and with the Mann–Whitney U test for non-normally distributed variables. Categorical variables were analyzed with the Chi-square test or Fisher's exact test. We then used forward LR binary logistic regression to identify independent predictors of patients having the diagnosis of the metabolic syndrome. Candidate variables selected for logistic regression were three measures of obesity: VFA, SAD, and WC. Variables were only entered into the model if the P-value of the score statistic was less than the entry value of 0.05. Wald statistics and odds ratios were reported for

variables in the final model and the overall model was assessed with the c-statistic for predicting the metabolic syndrome. ROC curves were used to identify an optimal SAD cut-off for predicting the metabolic syndrome with acceptable sensitivity and specificity. In order to determine correlates of SAD, we undertook univariate correlation with the metabolic syndrome criteria and insulin sensitivity (the QUICK index) as independents and SAD as the dependent variable. The QUICK index of insulin sensitivity for each subject with insulin and glucose data was calculated as 1/[log (fasting insulin, µU/mL) + log (fasting glucose, mg/dL)].[18] Variables that correlated with SAD with a Spearman's $P < 0.05$ were subjected to stepwise multivariate linear regression and the R2 change calculated with the addition of any variable to the model. To remove the influence of multicollinearity from the multiple regression model, variance-inflation factors (VIFs) were determined, and variables with a VIF > 4.0 were removed from the model. Residuals from the regression model were graphically examined. All analyses were done with statistics software (V. 16 SPSS Inc., Chicago, IL, USA).

Ethics approval

This study is approved by the RBWH research ethics committee (2005/006A) and all study participants gave informed consent.

Results

We enrolled 43 patients in this MRI study. Baseline characteristics, including components of the metabolic syndrome, baseline lipid panel, insulin and QUICK index of insulin sensitivity are shown in Table 1. The differences between the patients with and without the metabolic syndrome are summarized in Table 2 and show expected differences in various metabolic parameters. Patients with metabolic syndrome had greater WC, SAD, and VFA compared to patients without the metabolic syndrome ($P < 0.01$). In order to determine which of these measures of obesity is most strongly associated with the metabolic syndrome, we subjected the outcome of metabolic syndrome to binary logistic regression analysis with WC, SAD, and VFA as independents. On forward logistic regression, only SAD entered the model with no independent contribution from waist circumference or VFA; beta 0.68, Wald's statistic 10.8, $P = 0.001$. The overall c-statistic for SAD in identifying the metabolic syndrome was 0.89 ($P < 0.001$) and, in this sample, an SAD of > 22.7 cm identified the metabolic syndrome with 91% sensitivity and 80% specificity.

Table 1 Characteristics of patients included in the analysis

	Mean ± SD or n (%)
Age	70 ± 8
Males	35 (81)
Females	8 (19)
Race	
White	42 (98)
Non-White	1 (2)
Height (cm)	172 ± 10
Weight (kg)	79 ± 19
Body mass index	26 ± 5
Diabetic, n (%)	10 (23)
Metabolic syndrome (ATP III), n (%)	22 (53)
Waist (cm)	101 ± 16
Visceral fat area (cm²)	203 ± 111
Sagittal abdominal diameter (cm)	23.2 ± 4.0
Fasting glucose (mg/dl)	112 ± 40
HDL cholesterol (mg/dl)	44 ± 17
Triglycerides (mg/dl)	142 ± 74
Systolic blood pressure (mmHg)	142 ± 19
Diastolic blood pressure (mmHg)	72 ± 9
Average number of ATP III criteria	2.7 ± 1.5
Fasting insulin (mU/L)	7 ± 4
QUICK index	0.25 ± 0.03
Qualifying criterion[a]	
Coronary artery disease	10 (24)
Peripheral vascular disease	23 (55)
Carotid atherosclerosis >50%	12 (29)
Abdominal aortic aneurysm	10 (24)
Ischemic stroke	8 (19)
Diabetes	10 (24)

Notes: [a]Patients frequently had >1 inclusion criterion.
Abbreviations: ATP, Adult Treatment Panel; HDL, high-density lipoprotein; SD, standard deivation.

Despite the criticism of the label of metabolic syndrome as being no greater than a sum of risk factors, it remains a clinically-useful label denoting an increased cardiovascular risk.[21] However, given evidence that insulin resistance drives the increased risk of cardiovascular events in obese individuals,[22] we assessed the utility of an SAD of >22.7 cm in identifying insulin-resistant patients. We compared the QUICK index of insulin sensitivity in patients with an SAD of >22.7 cm and <22.7 cm and found that patients with SAD >22.7 cm were significantly more insulin resistant (lower QUICK index score) than those with an SAD <22.7 cm, $P = 0.01$. Next, we sought to confirm the association between SAD and metabolic indicators of risk by correlating the SAD to each of the metabolic syndrome criteria and the QUICK index. The QUICK index and all the metabolic syndrome criteria, except for the hypertension criterion, were significant correlates of SAD as shown in Table 3. On stepwise multivariate analysis of the significant univariate correlates as independents and SAD as the

Table 2 Characteristics of the patients with and without the metabolic syndrome (Met Syn)

Variable	Mean ± SD or n (%) of patients		P value MetSyn vs without MetSyn
	With MetSyn (n = 23)	Without MetSyn (n = 20)	
Waist (cm)	110 ± 10	91 ± 15	<0.001
Sagittal abdominal diameter (cm)	25.6 ± 3.3	20.4 ± 2.6	<0.001
Visceral fat area (cm^2)	263 ± 113	134 ± 53	<0.001
Number of ATP III criteria	3.9 ± 0.7	1.3 ± 0.7	<0.001
HDL-C (mg/dL)	39 ± 18	50 ± 15	0.007
TG (mg/dL)	177 ± 81	102 ± 38	<0.001
Fasting glucose (mg/dL)	127 ± 50	96 ± 8	0.001
Hypertension, n (%)	17 (74)	10 (50)	0.065
Diabetic, n (%)	10 (43)	0 (0)	0.001
Male, n (%)	19 (83)	16 (80)	0.83
Age	69 ± 7	69 ± 10	0.75
Fasting insulin (mU/L)	9.3 ± 4.9	4.9 ± 2.7	0.001
QUICK index of insulin sensitivity	0.242 ± 0.031	0.263 ± 0.26	0.001

Abbreviations: ATP, Adult Treatment Panel; HDL-C, high-density lipoprotein cholesterol; SD, standard deviation; TG, triglycerides.

dependent variable, only waist circumference is retained in the model with an R2 of 0.79, $P < 0.001$. Hence, waist circumference is an important determinant of SAD but does not explain all the variation in SAD.

Discussion

This report is the second report to show that SAD is a stronger predictor of the metabolic syndrome than the current gold standard for assessing obesity-related cardiovascular risk, the VFA. Unlike VFA, SAD does not require imaging to be measured. An SAD value of >22.7 cm identified patients with the metabolic syndrome with a 91% sensitivity and 80% specificity. Patients with an SAD > 22.7 cm had significantly lower QUICK insulin sensitivity indices than patients with an SAD < 22.7 cm which is consistent with this threshold being able to identify insulin-resistant patients. SAD correlates with insulin sensitivity and all components of the metabolic syndrome except for hypertension. On multivariate regression, waist circumference is the only significant determinant of SAD (R2 of 0.79, $P < 0.001$).

The association of SAD with the metabolic syndrome is a clinically-significant one since the clinical label of 'metabolic syndrome' in patients with established vascular disease identifies a cohort at an increased risk of cardiovascular events.[6–9] Hence, this measure of obesity can potentially identify a higher-risk cohort. While our data are encouraging in showing that SAD may better identify the higher-risk patient than VFA, our data set is small and cross-sectional. A large prospective cohort is required to determine if SAD is independently associated with cardiovascular events. From a pragmatic perspective, such a measure would be preferable to VFA for quantifying obesity-related cardiovascular risk since SAD can theoretically be measured in the office without requiring an imaging modality. However, clinic measurements of SAD using Holtain-Kahn calipers typically result in larger values than the MRI-measured SAD and would therefore require independent validation and adjustment for a predictive cut-off value. Nevertheless, the conclusions reached from the MRI-derived SAD cannot be extended to caliper-derived measurements without validation. In summary, we have shown MRI-measured SAD to be associated with the metabolic syndrome independently of VFA. SAD requires further validation as a maker of obesity-related cardiovascular risk and assessment in prospective cohort studies. This measure could potentially replace waist circumference as the preferred office-based method of assessing obesity-related cardiovascular risk.

Table 3 Univariate correlates of sagittal abdominal diameter

	Waist circumference	HDL cholesterol	Fasting triglyceride	Fasting glucose	ATP III hypertension criterion	QUICK index
Spearman's coefficient	0.918	−0.363	0.401	0.428	0.198	−0.667
P value	<0.001	0.017	0.008	0.004	0.204	<0.001

Abbreviations: ATP, Adult Treatment Panel; HDL, high-density lipoprotein.

Acknowledgments

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