

Sagittal Abdominal Diameter does not Predict Metabolic Traits Better than Waist Circumference-Related Measures of Abdominal Obesity in Obese Subjects

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ABSTRACT

Background Recently, we showed that in subjects with a body mass index (BMI) > 35 kg/m² waist circumference (WC) is associated with metabolic traits but associations were weaker in men than in women.

Aims To confirm our previous observation that anthropometric measures of abdominal obesity are closer linked to metabolic traits in obese women than obese men. To test whether sagittal abdominal diameter (SAD) provides a better prediction of metabolic traits in obese subjects than WC related measures.

Methods SAD and WC along with metabolic traits were assessed in 204 women and 69 men (BMI 30.1–64.0 kg/m²).

Results In women, abdominal obesity measures were associated with glycated hemoglobin levels (HbA1c), fasting serum glucose, insulin, triglycerides (TG), total cholesterol (Chol), high-density lipoprotein (HDL), and uric acid levels as well as Chol/HDL ratio and homeostatic model assessment of insulin resistance (HOMA-IR) independently of age and BMI. SAD predicted serum insulin and Chol better than WC, whereas WC was superior to SAD in predicting HbA1c, glucose, HOMA-IR, TG, HDL, Chol/HDL, and uric acid. Of note, the combination of SAD and WC provided a better prediction of insulin, HOMA-IR, TG, and uric acid than each of these anthropometric alone. In men, only fasting glucose, Chol, and uric acid levels were associated with abdominal obesity markers.

Conclusion Data show various associations between anthropometric measures of abdominal obesity and metabolic traits in obese women but overall much less in obese men. Most metabolic traits are better predicted by WC than by SAD.

Introduction

Obesity is associated with a plethora of adverse metabolic traits such disturbed glucose metabolism, dyslipidemia, and hypertension often referred to as the metabolic syndrome. Apart from the overall degree of obesity, which is reflected by the body mass index (BMI), body fat distribution plays an important role in determining metabolic health and cardiovascular risk [1, 2]. In particular, abdominal obesity has been found to be associated with adverse metabolic traits and cardiovascular outcomes [3–6].

The most accurate methods to measure abdominal obesity and visceral adiposity in particular are computed tomography (CT) and magnetic resonance imaging (MRI). However, these methods are expensive and not widely available [7]. Therefore, several anthropometric measures such as waist circumference (WC) and related indices such as WC related to height (W/Ht ratio) or hip circumference (waist/hip ratio, WHR) have been established as surrogate markers of abdominal obesity [8]. Many studies have shown that these anthropometric measures, in fact, predict adverse metabolic traits and health outcomes much better than the BMI alone [4–6, 9–19].

In subjects with obesity, as defined by an BMI above 30 kg/m², the role of WC and related anthropometric measures of abdominal obesity is less clear since most of affected subjects already display a WC that is greater than the suggested cut-off points for the prediction of an increased health risk [8]. Putting this forward, we have previously performed a cross-sectional study in which we measured WC in 838 obese subjects (597 women) with a BMI of greater than 35 kg/m², i. e., grade 2 or higher obesity, along with cardio-metabolic risk markers such as blood pressure, glucose, insulin, lipid and uric acid levels [20]. Multivariate regression analyses of respective data revealed that WC as well as related anthropometric indices, in particular those accounting for subjects' height, were associated with many metabolic variables independently of body weight and BMI. Another interesting finding in this study was that WC-related indices were more closely associated with metabolic traits in women than in men. This suggests that abdominal fat accumulation, as indicated by increased WC, plays an important role in women displaying grade 2 or higher obesity.

The landmarks required for a proper measurement of WC, i. e., the lower margin of the least palpable rib and the top of the iliac crest [8], are often not easy to determine in obese subjects, which makes a reliable and accurate assessment of WC very difficult. The sagittal abdominal diameter (SAD) may represent a valuable alternative to WC since it appears to be much easier to assess with a higher reliability. Several studies have shown that SAD measurement can help to predict adverse metabolic traits and cardiovascular outcomes in distinct populations [21–30]. In obese subjects, SAD may even closer reflect the degree of visceral adiposity since it is measured in a supine position where accumulated subcutaneous abdominal fat layers, which are believed to be metabolically much less harmful, partly slide to the lateral sides and thus, do not impact the measure as much as WC [31]. However, to the best of our knowledge the value of SAD in predicting metabolic trait specifically in generally obese subjects has not been assessed so far.

The aim of our present study was 1) to confirm, in an independent sample, our previous observation that WC-related anthropometric measures of abdominal obesity are independently of body weight and BMI associated with metabolic traits in subjects with a wide range of obesity, 2) to confirm that abdominal obesity markers in generally obese subjects are stronger associated with metabolic traits in obese women than men, and 3) to test the hypothesis that SAD is superior to WC-related measures in predicting metabolic traits in obese subjects.

Materials and Methods

Subjects

This was a cross-sectional study for which we extracted data from 204 obese women and 69 obese men from our prospectively maintained database. All subjects were examined between March 2011 and April 2012 and were referred to our center specifically for obesity evaluation and treatment. Data were collected as a part of our standardized clinical evaluation protocol. Inclusion criteria for the study were a BMI greater than 30.0 kg/m² and an age of at least 18 years. Exclusion criteria was the inclusion of subject's data set in previously published data analyses on the association between anthropometric indices and metabolic traits [20]. All subjects gave written informed consent for scientific use of their clinical data and the study was carried out in accordance with the recommendations of the Swiss Federal Expert Commission for Physician Confidentiality.

Anthropometric measurement

Body weight was measured to the nearest 0.1 kg with subjects wearing light clothes and height was measured to the nearest 0.5 cm. BMI were calculated by weight in kilograms divided by height in meters squared. WC was measured to the nearest 0.5 cm midway between the lowest rib and the iliac crest while subject was at minimal respiration according to World Health Organization [8]. In cases in which the respective anatomic landmarks were not identifiable, the maximal WC was measured. Hip circumference (HC) was measured around the widest portion of the buttocks [8]. Upon these measurements waist to hip ratio (WHR) and Waist to height ratio (W/Ht) were calculated. SAD was measured by using a caliper (Holtain-Kahn Abdominal Caliper, Crosswell, UK) in supine position as the distance between the examining table and the apex of the abdominal girth or the largest anteroposterior diameter between the xiphoid process and the umbilicus.

Assessment of metabolic traits

Systolic and diastolic blood pressure was measured by using an electronic blood pressure meter (OSZ 5 easy, Welch Allyn, Jungingen, Germany) with the subject being in a seated position for at least 5 min. Blood samples for the determination of metabolic markers were drawn in all the patients in the morning between 08:00 and 11:00 h after an overnight fast. The following metabolic markers were determined: Serum concentrations of glucose, insulin, triglycerides (TG), total cholesterol (Chol), low- and high-density lipoprotein (LDL and HDL), and uric acid. The Chol/HDL ratio was calculated [32].

Insulin was measured by chemiluminescence immunoassay (Beckman Coulter International S.A., Nyon, Switzerland) with a CV of less than 10%. Glycolized hemoglobin levels (HbA1c) were assessed in whole blood samples by immunoassay (DCA Systems, Siemens Healthcare Diagnostics Inc., New York, USA). The remaining laboratory blood variables were assayed by clinical routine methods by the local hospital laboratory (Zentrum für Labormedizin, St. Gallen, Switzerland). Homeostasis model assessment (HOMA-IR) was taken as an estimate of insulin resistance [32] and was computed upon the formula: $HOMA-IR = (\text{fasting insulin (mU/l)} \times \text{fasting glucose (mmol/l)}) / 22.5$.

Statistical analysis

Data are presented as mean \pm SD and range. All values were tested for normal distribution by using the Kolmogorov-Smirnov test. In case of non-normal distribution respective data were logarithmized (log). For analysis of blood pressure data subjects taking antihypertensive drugs (n = 86) were excluded; for analysis of glucose metabolism related traits subjects taking anti-diabetic drugs (n = 21) were excluded; and for analysis of lipid levels patients taking lipid-lowering drugs (n = 25) were excluded.

Differences between women and men were assessed by using unpaired Student's t tests. Bivariate association between anthropometric variables and metabolic traits was evaluated by Pearson's correla-

tion analyses. Multiple stepwise linear regression analysis was performed to test for the independence of associations. R² values obtained from respective regression models were taken as measures of the amount of explained variance in the respective dependent variable (here metabolic traits) upon the considered independent variable (here anthropometric measures) and expressed as %. Multivariate models included age, body weight or BMI, SAD, WC, WHR and W/Ht ratio as independent variables, whereas variables of metabolic traits were set as dependent variables. Variables that include the same measures, e. g., BMI and W/Ht ratio or WC and WHR, were not computed in the same model. A P value of less than 0.05 was considered significant.

Results

Subjects' characteristics

Characteristics including anthropometric measures of the subjects are provided in ► **Table 1** and data on blood pressure and metabolic blood markers in ► **Table 2**. Of note, men were older, taller, heavier and had higher BMI, SAD, WC, WHR, W/Ht, systolic and diastolic blood pressure, insulin, HOMA-IR, TG, Chol/HDL ratio, and uric acid levels than women (all $p < 0.04$).

► **Table 1** Subjects' characteristics and anthropometric data.

	Women N = 204	Men N = 69	P
Age (years)	41.7 ± 12.8 (18–77)	46.2 ± 12.2 (18–75)	0.013
Height (cm)	164 ± 7 (148–188)	176 ± 7 (160–196)	<0.001
Weight (kg)	112 ± 19 (77–169)	140 ± 23 (97–208)	<0.001
BMI (kg/m ²)	41.5 ± 6.5 (30.1–62.1)	44.9 ± 6.7 (34.2–64.0)	<0.001
SAD (cm)	20.8 ± 5.3 (11.5–36.0)	25.8 ± 5.4 (17.5–36.0)	<0.001
Waist circumference (cm)	122 ± 13 (96–168)	140 ± 15 (110–184)	<0.001
Hip circumference (cm)	123 ± 14 (92–175)	133 ± 16 (104–189)	<0.001
WHR (cm/cm)	0.9 ± 0.1 (0.7–1.8)	1.1 ± 0.1 (0.9–1.2)	<0.001
W/Ht (cm/cm)	0.7 ± 0.1 (0.6–1.0)	0.8 ± 0.1 (0.7–1.0)	<0.001

All values are mean ± SD (range); P values derived by unpaired Student's t-tests. BMI = Body Mass Index; SAD = sagittal abdominal diameter; WHR = Waist to hip ratio; W/Ht = Waist to height ratio

► **Table 2** Metabolic traits assessed in the obese study population.

	N	Women	N	Men	P
¹ Systolic blood pressure (mmHg)	143	133 ± 17 (97–204)	44	147 ± 22 (89–192)	<0.001
¹ Diastolic blood pressure (mmHg)	143	86 ± 12 (60–127)	44	90 ± 11 (60–123)	0.029
² HbA1c (%)	135	5.7 ± 0.7 (4.8–10.3)	37	5.9 ± 0.9 (4.9–9.3)	0.219
² Glucose (mmol/l)	176	5.6 ± 1.4 (4.1–15.1)	50	6.1 ± 2.4 (3.9–18.4)	0.226
² Insulin (mU/l)	151	15.1 ± 11.6 (2.8–82.2)	42	21.5 ± 15.7 (4.7–74.3)	0.017
² HOMA-IR	151	3.9 ± 3.9 (0.6–29.2)	42	5.5 ± 4.6 (0.8–22.8)	0.023
³ TG (mmol/l)	159	1.7 ± 1.3 (0.4–6.8)	43	2.3 ± 1.4 (0.4–6.2)	0.006
³ Cholesterol (mmol/l)	190	5.2 ± 1.0 (2.8–9.1)	58	5.3 ± 0.9 (3.2–7.2)	0.54
³ LDL (mmol/l)	155	3.3 ± 0.9 (1.2–6.2)	40	3.1 ± 1.0 (0.4–5.0)	0.192
³ HDL (mmol/l)	160	1.3 ± 0.4 (0.7–3.2)	44	1.2 ± 0.8 (0.6–5.6)	0.256
³ Chol/HDL (mmol/l)	160	4.2 ± 1.3 (1.6–8.3)	43	5.0 ± 1.7 (0.8–8.6)	0.004
Uric acid (mmol/l)	165	336 ± 86 (149–662)	55	411 ± 92 (226–629)	<0.001

All values are mean ± SD (range); ¹Patients taking hypertensive-lowering drugs were excluded from analyses ²Patients taking antidiabetic-lowering drugs were excluded from analyses ³Patients taking lipid-lowering drugs were excluded from analyses. HOMA-IR: Homeostatic Model Assessment of insulin resistance; TG: Triglycerides; HDL and LDL: low and high density lipoprotein cholesterol

Correlation analyses

Results of correlation analyses between anthropometric variables and metabolic traits are provided in ► **Table 3** for women and in ► **Table 4** for men.

In women, HbA1c levels, serum glucose and insulin concentrations, as well as HOMA-IR were correlated with all anthropometric measures except for WHR (all $p < 0.05$). TG levels were correlated with SAD, WC, WHR, and W/Ht (all $p < 0.02$). Total Chol was inversely correlated with SAD and BMI (all $p < 0.04$) while LDL was not correlated with any of the anthropometric variables (all $p > 0.24$). HDL was correlated inversely with WC and W/Ht (all $p < 0.05$) while Chol/HDL positively correlated with WC and WHR (both $p < 0.04$). Serum uric acid levels significantly correlated with all anthropometric parameters (all $p < 0.001$) except for WHR ($p = 0.14$).

In men, metabolic traits in general appeared to be much weaker correlated with anthropometric measures than in women. Serum glucose levels were only correlated with SAD ($p = 0.004$) and total Chol was correlated with WHR ($p = 0.02$). None of the other glucose or lipid metabolism markers correlated with any of the anthropometric measures (all $p > 0.19$). However, serum uric acid levels were correlated with WC, W/Ht, and BMI (all $p < 0.05$).

► **Table 3** Bivariate correlations between anthropometric variables and metabolic traits in women.

	SAD	Waist	WHR	W/Ht	BMI
¹ Systolic blood pressure	0.13	0.11	0.11	0.11	0.11
¹ Diastolic blood pressure	0.07	0.07	0.16	0.03	-0.04
² HbA1c	0.31 * * *	0.34 * * *	0.17 *	0.31 * * *	0.19 *
² Glucose	0.22 * *	0.28 * * *	0.05	0.25 * *	0.15 *
² Insulin	0.40 * * *	0.38 * * *	0.08	0.33 * * *	0.39 * * *
² HOMA-IR	0.29 * * *	0.40 * * *	0.12	0.36 * * *	0.34 * * *
³ TG	0.19 *	0.22 * *	0.31 * *	0.19 *	0.01
³ Cholesterol	-0.23 * *	-0.08	0.08	-0.03	-0.18 *
³ LDL	-0.09	0.001	0.01	0.02	-0.08
³ HDL	-0.15	-0.27 * *	-0.11	-0.17 *	-0.15
³ Chol/HDL	-0.002	0.20 *	0.17 *	0.14	0.02
Uric acid	0.39 * * *	0.40 * * *	0.12	0.36 * * *	0.34 * * *

* P<0.05 ** P<0.01 *** P<0.001; ¹Patients taking hypertensive-lowering drugs were excluded from analyses ²Patients taking antidiabetic-lowering drugs were excluded from analyses ³Patients taking lipid-lowering drugs were excluded from analyses. HOMA-IR: Homeostatic Model Assessment of insulin resistance; TG: Triglycerides; HDL and LDL: low and high density lipoprotein cholesterol

► **Table 4** Bivariate correlations between anthropometric variables and metabolic traits in men.

	SAD	Waist	WHR	W/Ht	BMI
¹ Systolic blood pressure	0.09	-0.10	0.01	-0.16	-0.03
¹ Diastolic blood pressure	0.12	-0.12	-0.05	-0.15	-0.05
² HbA1c	0.02	-0.17	0.23	-0.04	-0.12
² Glucose	0.39 * *	0.08	-0.04	0.17	0.13
² Insulin	0.12	0.22	0.22	0.25	0.28
² HOMA-IR	0.19	0.20	0.21	0.25	0.28
³ TG	0.13	-0.01	0.07	-0.06	-0.03
³ Cholesterol	-0.16	-0.03	-0.31 *	-0.04	-0.03
³ LDL	-0.14	-0.14	-0.16	-0.17	-0.16
³ HDL	0.17	-0.14	-0.008	-0.12	-0.09
³ Chol/HDL	-0.20	0.12	-0.18	0.07	0.08
Uric acid	0.26	0.39 * *	-0.04	0.32 *	0.27 *

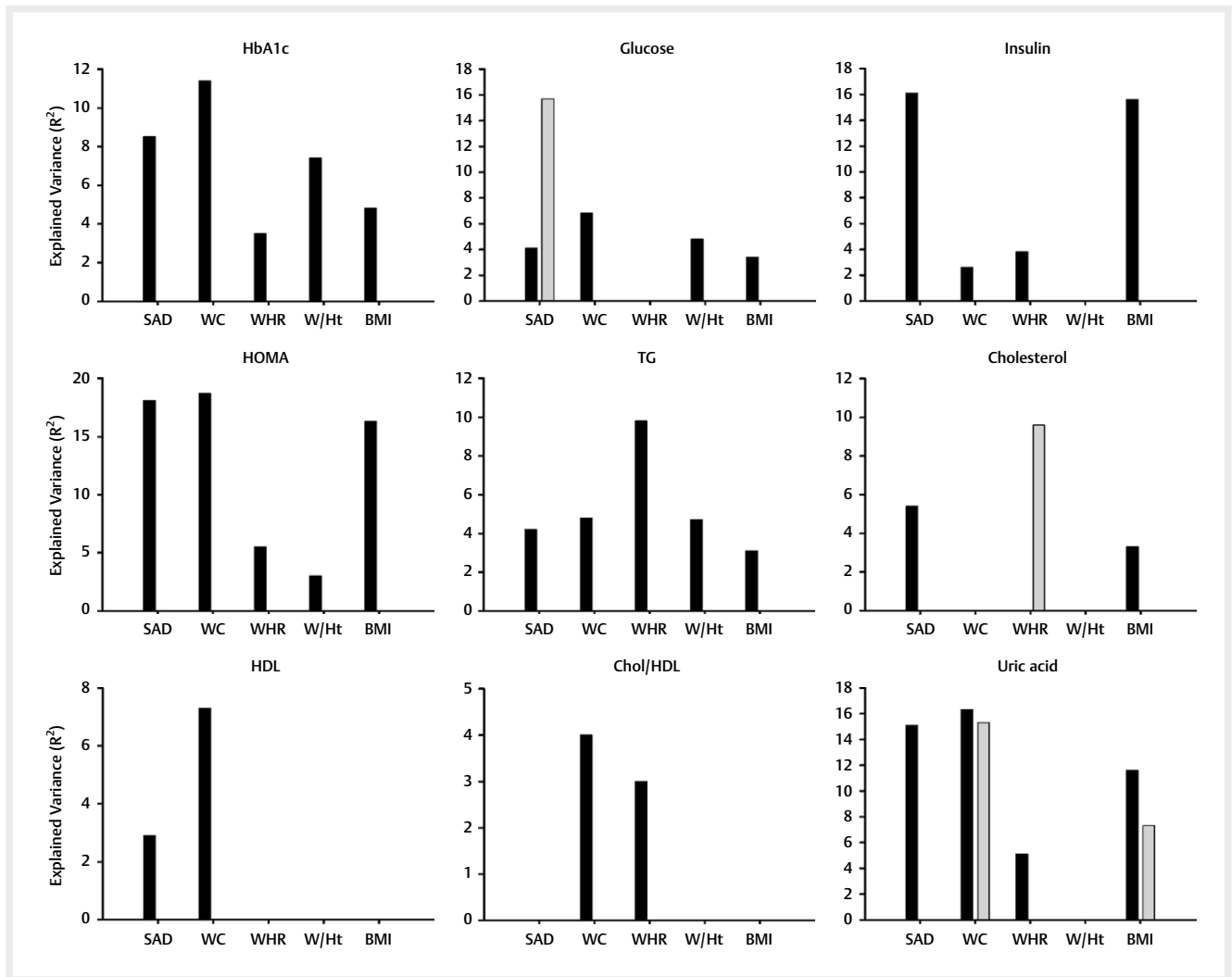
* P<0.05 ** P<0.01; ¹Patients taking hypertensive-lowering drugs were excluded from analyses ²Patients taking antidiabetic-lowering drugs were excluded from analyses ³Patients taking lipid-lowering drugs were excluded from analyses. HOMA-IR: Homeostatic Model Assessment of insulin resistance; TG: Triglycerides; HDL and LDL: low and high density cholesterol

Multivariate regression analyses on each abdominal obesity marker

► **Fig. 1** illustrated the strength of association (i. e., R^2 = explained variance) between metabolic variables and each anthropometric abdominal obesity marker adjusted for age and BMI (SAD, WC, WHR) or body weight (W/Ht) as revealed by multiple linear regression analysis. For comparison, the association of metabolic variables with BMI adjusted for age is also provided. As can be seen, women overall showed much more associations than men. Systolic and diastolic blood pressure as well as LDL values were not associated with any anthropometric parameters in both sexes and thus, are not illustrated.

In women, serum glucose levels were, independently of age and BMI/body weight, associated with SAD (R^2 = 4.1%), WC (R^2 = 6.8%), W/Ht (R^2 = 4.8%), and also with BMI independently of age (R^2 = 3.4%). In men, glucose levels were only associated with SAD (R^2 = 15.7%). Serum insulin levels were independently associated

with SAD (R^2 = 16.1%), WC (R^2 = 2.6%), WHR (R^2 = 3.8%), and BMI (R^2 = 15.6%) in women but not with any anthropometric measures in men. HbA1c, HOMA-IR, and TG levels were associated with all anthropometric markers of abdominal obesity (SAD: R^2 = 8.5%; 18.1%; 5.4%; respectively, WC: R^2 = 11.4%; 18.7%; 4.8%; respectively, WHR: R^2 = 3.5%; 5.5%; 9.8%; respectively, W/Ht: R^2 = 7.4%; 3.0%; 4.7%; respectively) as well as with BMI (R^2 = 4.8%; 16.3%; 3.1%; respectively) in women whereas in men no such associations were found. Total Chol levels were associated with SAD (R^2 = 5.4%) and BMI (R^2 = 3.3%) in women and with WHR (R^2 = 9.6%) in men. In women, HDL was associated with SAD (R^2 = 2.9%) and WC (R^2 = 7.3%) and Chol/HDL with WC (R^2 = 4.0%) and WHR (R^2 = 3.0%). In men, no such associations were found. Serum uric acid levels were independently associated with SAD (R^2 = 15.1%), WC (R^2 = 16.3%), WHR (R^2 = 5.1%), and BMI (R^2 = 11.6%) in women and with WC (R^2 = 15.3%) and BMI (R^2 = 7.3%) in men.



► **Fig. 1** Explained variance (R^2) of the metabolic traits upon distinct anthropometric indices. Men are grey, women are black columns; SAD, WC, WHR – related models included age and BMI as independent variables; W/Ht related models included age and weight as independent variables; BMI related models included only age as independent variables. HOMA: Homeostatic Model Assessment of insulin resistance; TG: Triglycerides; HDL: high density lipoprotein cholesterol.

Comparison of strength of associations between different abdominal obesity markers

To compare the strength of associations of distinct abdominal obesity markers with each metabolic variable all independent anthropometric variables were included in the respective multiple stepwise regression model at the same time. For women, results of these analyses are provided in ► **Table 5**.

In women, age was the only predictor of systolic blood pressure and the same was true for serum LDL levels. While age was also a strong predictor of HbA1c and serum glucose levels, measures of abdominal obesity additionally explained some of the variance of these glucose metabolism parameters. For both, fasting glucose and HbA1c, WC was a stronger predictor than SAD. Serum insulin levels were best predicted by SAD but, of note, their prediction was improved further when WC or WHR were additionally included in the respective model. HOMA-IR values were best predicted by WC followed by SAD. Again, prediction of HOMA-IR was even improved

when SAD and WC or WHR were included in the same model. Serum TG levels were best predicted by WHR followed by WC and W/Ht. However, inclusion of SAD in the respective WC and WHR model further improved the prediction. SAD was the only anthropometric measure to predict total Chol levels and the association was inverse. Serum HDL levels were best predicted by WC followed by SAD. The Chol/HDL ratio was only predicted by WC and, to a slightly weaker extent, by WHR. Serum uric acid levels were best predicted by WC followed by SAD and then W/Ht. Again, the combination of WC with SAD further improved the prediction of serum uric acid levels.

In men, serum glucose levels were predicted only by SAD (R^2 : 15.7%; β = 0.37; p = 0.005) while total Chol levels were predicted by WHR (R^2 : 9.6%; β = -0.31; p = 0.02). Serum uric acid levels were most strongly associated with WC (R^2 : 15.3%; β = 0.39; p = 0.003) followed by BMI (R^2 : 7.3%; β = 0.27; p = 0.05).

► **Table 5** Multiple stepwise regression analyses in women; explained variance (R²) of the distinct glucose and lipid metabolism markers as well as uric acid by the different anthropometric indices.

Dependent variable	Model 1			Model 2			Model 3			
	Total R ² (%)	Independent variable	B	P	R ² (%)	Total R ² (%)	Independent variable	B	P	R ² (%)
Systolic blood pressure	13	age	0.36	<0.001	13	13	age	0.36	<0.001	13
Glucose	16.6	age	0.29	<0.001	9.8	14.9	age	0.30	<0.001	9.8
		WC	0.26	<0.001	6.8		SAD	0.20	0.004	4.1
Insulin	19.5	SAD	0.28	0.002	16.1	21.7	BMI	0.30	0.004	2.9
		WC	0.22	0.01	3.4		SAD	0.21	0.04	16.1
HOMA-IR	23.7	WC	0.28	<0.001	18.7	24.6	WHR	0.18	0.02	2.7
		SAD	0.27	0.002	5.0		BMI	0.31	0.003	2.6
HbA1c	19.7	age	0.29	<0.001	8.3	18.2	age	0.29	<0.001	9.7
		WC	0.32	<0.001	11.4		SAD	0.29	<0.001	8.5
Chol	5.4	SAD	-0.23	0.001	5.4	5.4	SAD	-0.23	0.001	5.4
		BMI	-0.38	0.001	3.1	14.4	SAD	0.22	0.004	4.6
TG	12.4	SAD	0.29	0.005	4.5		WHR	0.32	<0.001	9.8
		WC	0.31	0.002	4.8					
HDL	10.7	age	0.19	0.02	3.4	5.7	age	0.18	0.02	2.8
		WC	-0.28	<0.001	7.3		SAD	-0.17	0.03	2.9
LDL	5.4	age	0.23	0.004	5.4	5.4	age	0.23	0.004	5.4
		WC	0.20	0.01	4.0	3.0	WHR	0.17	0.03	3.0
Uric Acid	22.4	age	0.14	0.04	2.0	17.5	age	0.16	0.03	2.4
		SAD	0.23	0.005	4.1		SAD	0.38	<0.001	15.1
		WC	0.26	0.002	16.3					

Model 1: Independent variables: age, BMI, SAD, WC; Model 2: Independent variables: age, BMI, SAD, WHR; Model 3: Independent variables: age, weight, SAD, W/Ht. HOMA-IR: Homeostatic Model Assessment of insulin resistance; TG: Triglycerides; HDL and LDL: high and low density lipoprotein cholesterol. WC: Waist circumference; SAD: sagittal abdominal diameter; BMI: Body mass Index; WHR: waist/hip ratio; W/Ht: Waist to height ratio

Discussion and Conclusions

Data of our study confirm the previously observed [15–20] association of WC-related measures of abdominal obesity with metabolic traits in obese subjects independently of BMI as an estimate of general obesity. Our hypothesis that SAD provides a better prediction of metabolic traits in obese subjects than WC-related measures was not confirmed since competitive inclusion of respective variables in multivariate regression analysis revealed an inconsistent picture where in most models WC predicted metabolic traits better than SAD. Overall, the association between anthropometric measures of abdominal obesity and metabolic traits appeared to be stronger in obese women than men. While this finding confirms our previous observations in a larger, independent sample of obese subjects [20] the direct comparison of the association of SAD and WC-related measures with metabolic traits represents the novel and thus, most important aspect of our present study.

In obese women, anthropometric measures of abdominal obesity explained about 4.2 to 15.6% of the variability in circulating serum insulin, TG, and uric acid levels as well as about 18.7% of variability in HOMA-IR independently of BMI. This finding supports the previous notion that abdominal obesity is a major driver for insulin resistance and associated metabolic features [33, 34] and suggests that this is also true in women who already display a general obesity as indicated by an BMI above 30 kg/m².

In obese men, the prediction of metabolic traits upon abdominal obesity measures on top of BMI did not appear to improve as much as in women. It might be argued that this finding was biased by the lower number of men than women included in our study which clearly limited the statistical power to detect significant associations. However, a similar sexual dimorphism in associations was found in our foregoing study that included an independent sample of 241 men with grade 2 or higher obesity [20]. It is well known that men predominantly deposit excess energy in visceral fat stores whereas women usually show a wider distribution of fat accumulation [35]. On this background, we speculate that the greater variability in visceral fat accumulation in obese women than in obese men explains the closer association of abdominal obesity measures with metabolic traits in women.

SAD was not superior in predicting metabolic traits in obese women as compared with WC-related measures in our sample of subjects with a wide range of obesity. This finding contrasts previous findings in overweight and moderately obese men where SAD explained the largest degree of variation in insulin sensitivity compared with other anthropometric measures [36]. Also, analyses on data of the National Health and Nutrition Examination Survey revealed SAD to better predict dysglycemia than WC [37] and a similar observation in regard of the prediction of insulin resistance was made in a Brazilian, mainly non-obese, female study population [38]. Taken together, our present and previous findings speak against our initial assumption that SAD is - in particular obese subjects - superior to WC-related measures in predicting metabolic traits.

It is noteworthy, that for some metabolic variables, i. e., insulin, HOMA-IR, TG, and uric acid, the concurrent inclusion of both, SAD

and WC-related measures, increased the predictive value of the respective regression model. This finding suggests that the combination of SAD and WC-related measures may provide a more accurate estimate of visceral adiposity which promotes the associated metabolic alterations. This notion is supported by a previous study in which the combination SAD and WC showed the most accurate prediction of abdominal fat distribution as assessed by MRI [39]. Of note, other anthropometric measures like the neck circumference, not reflecting abdominal obesity, might further improve the prediction of metabolic alterations as has recently been shown in obese women and men [40]. SAD on the other hand has previously been shown to predict the risk of cancer incidence in a non-obese population [41] and also in subjects with severe obesity [42]. Taking together, it appears likely that the combination of distinct anthropometric measures including SAD will provide the most accurate prediction of advance healthy outcomes in obese subjects.

It should be kept in mind that the metabolic consequences of abdominal obesity do not only depend on the extent of visceral fat accumulation but also on specific biological characteristics of visceral fat tissue such as adipocyte sizes and macrophages infiltration [43, 44]. Also, other factors like cardio-respiratory fitness are well known to modulated the metabolic health state of obese subjects [45]. Therefore, it can be assumed that even the best measure of abdominal obesity will not provide sufficient information on the metabolic health state of a given individual obese subject which makes, in clinical practice, the measurement of relevant metabolic variables in blood samples necessary. However, for epidemiological studies and public health approaches the concurrent assessment of WC and SAD might provide valuable information for metabolic and cardiovascular risk prediction.

Among the tested metabolic traits, uric acid levels showed the most consistent associations with anthropometric measures of abdominal obesity and this was true in both obese women and men. This finding might be of particular interest since it is still not clear whether or not uric acid is causally linked to adverse alteration metabolic traits and cardiovascular disease [46]. A recent study [47] showed that the associations between elevated uric acid levels and markers of altered glucose and lipid metabolism get lost when adjusting for visceral adipose tissue mass as measured by dual-energy X-ray absorptiometry. This finding suggests that visceral obesity represents the link between uric acid and cardio-metabolic disease and our findings may provide further support for this notion.

In summary, our results show that body fat distribution and abdominal obesity in particular play an important role in determining metabolic health in subjects with global obesity. This notion might be particularly true in obese women. While SAD is not superior to WC, the combination of both anthropometric may even increase their predictive value for metabolic traits in obese subjects.

Conflict of Interest

No conflict of interest has been declared by the authors.

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