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Sagittal abdominal diameter and waist circumference appear to be equally good as identifiers of cardiometabolic risk

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Abstract *Background and aims:* Body mass index (BMI) and waist circumference (WC) are commonly used markers of cardiometabolic risk. However, sagittal abdominal diameter (SAD) has been proposed as a possibly more sensitive marker of intra-abdominal obesity. We investigated differences in how SAD, WC, and BMI were correlated with cardiometabolic risk markers.
Methods and results: This cross-sectional study investigated anthropometric and metabolic baseline measurements of individuals from six trials. Multiple linear regression and (partial) correlation coefficients were used to investigate associations between SAD, WC, and BMI and cardiometabolic risk markers, including components of the metabolic syndrome as well as insulin resistance, blood lipids, and lowgrade inflammation.

In total 1516 mostly overweight or obese individuals were included in the study. SAD was significantly more correlated with TG than WC for all studies, and overall increase in correlation was 0.05 (95% CI (0.02; 0.08). SAD was significantly more correlated with the markers TG and DBP 0.11 (95% CI (0.08, 0.14)) and 0.04 (95% CI (0.006, 0.07), respectively compared to BMI across all or most studies.
Conclusion: This study showed that no single anthropometric indicator was consistently more strongly correlated across all markers of cardiometabolic risk. However, SAD was significantly more strongly correlated with TG than WC and significantly more strongly correlated with DBP and TG than BMI.

Abbreviations: BMI, body mass index; CT, computed tomography; FFA, free fatty acids; IDF, International Diabetes Federation; IL, interleukin; MRI, magnetic resonance imaging; ROC, Receiver Operating Characteristic; SAD, sagittal abdominal diameter; SAT, subcutaneous adipose tissue; TNF, tumor necrosis factor; VAT, visceral adipose tissue; WC, waist circumference.

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Introduction

Obesity is one of the most important risk factors for metabolic syndrome, cardiovascular disease (CVD) and type 2-diabetes (T2D) [1]. Body mass index (BMI) is often used to evaluate overweight and obesity, but BMI does not distinguish between lean and fat mass [2]. Furthermore, BMI does not provide information on fat distribution, and hence may not specifically reflect central obesity that is associated with an adverse metabolic phenotype [3].

When assessing abdominal obesity, it is important to distinguish between subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) as VAT is the most metabolically adverse type of adipose tissue [2–4]. Simple anthropometric indicators such as waist circumference (WC) and sagittal abdominal diameter (SAD, also referred to as "abdominal height") [5,6] have been used to examine abdominal obesity. SAD is measured as the height of the abdomen in a supine position, which increases with VAT accumulation as VAT is contained within the abdominal cavity, while SAT in the supine position will be distributed sideways, due to the force of gravity [7,8]. WC is a commonly used measure of abdominal obesity, but SAD has been proposed to be a more sensitive marker for VAT and therefore it may also be a better indicator of metabolic disturbances [2,9].

The aim of this study was to investigate whether SAD, WC and BMI correlate differently with cardiometabolic risk factors, including components of the metabolic syndrome. We hypothesized that SAD is more correlated with markers of cardiometabolic risk compared to WC and BMI.

Methods

Study design and participants

This cross-sectional study included baseline data from six human intervention trials: Gut, Grains and Greens (3G), Optimal well-being, development and health (OPUS), The Diet, Obesity and Genes Dietary Study (DIOGENES), Rye to Improve Gut Health (RIGHT), MyNewGut (MNG), and The Effect of Protein and Calcium on Weight Change and Blood Lipid Profile (PROKA) [10–15]. The studies were generally single-center randomized, controlled intervention trials conducted at the University of Copenhagen (Denmark). DIOGENES, however was a randomized, controlled multicenter intervention study involving eight different European centres: Maastricht (the Netherlands), Copenhagen (Denmark), Cambridge (UK), Heraklion (Greece), Potsdam (Germany), Pamplona (Spain), Sofia (Bulgaria) and Prague (the Czech Republic). The five other included studies were solely carried out at University of Copenhagen (Denmark). Therefore the methods used will be the same except for part of the data from DIOGENES.

The studies were registered at http://www.clinicaltrials.gov; 3G (NCT01719913 and NCT01731366); SHOPUS (NCT01195610); DIOGENES (NCT00390637); RIGHT (NCT02358122); MNG: (NCT02215343); PROKA (NCT01561131) and approved by the Research Ethics Committees of the Capital Region of Denmark in accordance with Helsinki Declaration 3G (H-2-2012-064 and H-2-2012-065); SHOPUS (H-3-2010-058); RIGHT (H-1-2014-062); MNG (H-4-2014-052); and PROKA (H-2-2011-145) or the local ethical committees in the respective countries [16].

Anthropometric, laboratory and analytical procedures

Body weight, height, WC, and SAD were measured by standard anthropometric procedures. The measurements were conducted by trained study personnel following standard operating procedures. SAD was measured twice to the closest 0.1 cm using a Holtain-Kahn Abdominal Caliper (Holtain Ltd, Crymych, United Kingdom) and we used the mean of the two measurements. The individuals were in supine position when measured and were asked to bend their knees to a 90° angle and keep their feet flat on the examination table. SAD was measured as the distance between the highest point of the abdomen and the back as assessed by the distance between the two blades of the caliper. A spirit level was used to ascertain that the caliper's shaft was at right angles. The measurement was made at the end of a normal exhalation. The upper blade of the caliper was then brought down to the abdomen without compressing it. This was done before the participant resumed breathing. WC was measured between the bottom of the ribs and the top of the iliac crest, while standing and with the measurement tape parallel to the floor, and at the end of a normal exhalation. The measurement tape was kept tight to the skin, but did not compress it when doing the measurement. WC was measured twice to the nearest 0.5 cm using a non-elastic flexible measuring tape and the mean of the two measurements was used. All cohorts used a similar standard operating procedure for the anthropometric measurements.

Blood samples for all cohorts were drawn after overnight fasting. Standard clinical measurements of plasma glucose, insulin, total-, LDL- and HDL cholesterol, triglycerides, C-reactive protein (CRP), free fatty acids (FFA), and adiponectin were performed as well as measurements of serum inflammatory markers interleukin (IL)-6 and tumor necrosis factor (TNF)-α (Supplemental methods section). Blood pressure was measured using a digital blood pressure monitor using the same procedure across studies (Supplemental methods section).

Statistical analysis

The statistical analyses were carried out using R (R Core Team, Vienna, Austria) [17] and the R extension package "psych" [18]. Participant characteristics were summarized using mean and standard deviation (SD), median and interquartile range (IQR), or counts and percentages, as appropriate Associations between SAD, WC, and BMI and the markers of cardiometabolic health were estimated using simple linear regression (unadjusted analyses) and multiple linear regression that also included age and gender (adjusted analyses). Correlations between SAD,

Table 1 Characteristics of the participants at baseline (n = 1516) shown for each study and for all studies together.

Variables	n	3G	n	SHOPUS	n	DIOGENES	n	RIGHT	n	MNG	n	PROKA	n	Across studies	P-value
Age (years)	117	51.0(41.0; 57.0)^{b,c}	181	41.0(31.0; 52.0)^{a}	902	41.0(37.0; 45.0)^{a}	73	52.0(46.0; 58.0)^{c}	29	46.0(34.0; 53.0)^{a,b}	214	43.0(31.0; 48.0)^{a}	1516	42.0 (36.0; 48)	<0.001
Men % (M/F)	117	39.3 (46/71)	181	31.0 (53/128)	902	33.4 (301/601)	73	43.8 (32/41)	29	28.0 (8/21)	214	39.5 (45/169)	1516	32.0 (485/1031)	<0.001
Weight (kg)	117	85.9 ± 13.0^{a,b}	181	89.9 ± 17.1^{b}	902	99.6 ± 17.4^{d}	73	83.5 ± 9.1^{a}	29	88.0 ± 13.7^{a,b,c}	214	96.6 ± 13.6^{c,d}	1516	96.0 ± 17.0	<0.001
Sagittal abdominal diameter (cm)	117	22.9 ± 2.9^{a,b}	181	23.0 ± 3.2^{b}	902	25.2 ± 3.8^{d}	73	21.5 ± 2.1^{a}	29	22.0 ± 2.5^{b,c}	214	24.0 ± 2.5^{c}	1516	24.4 ± 3.6	<0.001
Waist circumference (cm)	117	100.0 ± 9.0^{a,b}	181	100.1 ± 12.4^{b,c}	902	107.5 ± 13.0^{c}	73	96.0 ± 8.0^{a}	29	96.5 ± 8.8^{a}	214	103.2 ± 10.6^{b}	1516	104.70 ± 12.60	<0.001
Body-mass index (kg/m^2)	117	28.7 ± 3.5^{a}	181	30.3 ± 4.9^{b}	902	34.5 ± 4.8^{d}	73	27.8 ± 1.9^{a}	29	30.1 ± 3.1^{a,b}	214	33.2 ± 3.3^{a}	1516	33.0 ± 5.0	<0.001
Fasting insulin (pmol/L)	114	57.9 (43.8; 78.2)^{b}	181	67.0 (42.0; 92.0)^{b,c}	799	69.4 (45.9; 102.5)^{c}	73	65.0 (52.7; 88.0)^{b,c}	28	41.3 (18.6; 61.6)^{a}	210	67.8 (42.9; 87.8)^{b,c}	1405	67.0 (44.9; 95.0)	<0.001
Fasting glucose (mmol/L)	117	5.7 ± 0.6^{c,d}	181	5.3 ± 0.5^{b}	817	5.0 ± 0.7^{a}	73	5.9 ± 0.6^{d}	28	5.5 ± 0.4^{b,c}	210	5.7 ± 0.7^{c,d}	1426	5.3 ± 0.7	<0.001
2-h glucose (mmol/L)		–	181	5.6 ± 1.4^{a}	794	6.7 ± 2.2^{b}		–		–		–	975	6.5 ± 2.1	<0.001
HOMA-IR	114	2.15(1.53; 2.85)^{a,b}	181	2.17(1.34; 3.12)^{b}	798	2.54(1.65; 3.82)^{c}	73	2.39(1.67; 3.37)^{b,c}	28	1.00(0.44; 1.52)^{a}	210	1.60(1.04; 2.24)^{a,b}	1404	2.24(1.45; 3.30)	<0.001
Matsuda index		–	180	5.24(3.45; 7.48)^{a}	783	4.45(2.95; 6.70)^{a}		–		–		–	963	4.56(3.02; 6.78)	0.104
TNF-α (pg/mL)	117	1.45(2.23; 1.70)^{b}	181	0.92(0.73; 1.23)^{a}		–		–		–		–	298	1.17(0.85; 1.46)	0.02
IL-6 (pg/mL)	116	1.20(0.84; 2.14)^{b}	180	1.09(0.77; 1.61)		–	73	1.78(1.43; 2.32)^{b}		–		–	369	1.24(0.84; 1.97)	<0.001
CRP (mg/L)	117	0.65(0.12; 2.37)^{a}	181	1.96(0.68; 3.97)^{b}	744	2.81(1.46; 4.72)^{c}	72	1.46(0.53; 2.15)^{a,b}	26	1.45(0.59; 2.36)^{a,b}		–	1113	2.25(1.09; 4.27)	<0.001
TC (mmol/L)	117	5.3 ± 1.0^{c}	180	4.6 ± 0.9^{a}	832	4.9 ± 1.0^{b}	73	5.2 ± 0.9^{b,c}	28	5.0 ± 0.9^{a,b,c}	210	5.3 ± 0.9^{c}	1440	5.0 ± 1.0	<0.001
HDL-C (mmol/L)	117	1.3 ± 0.3^{b}	180	1.2 ± 0.3^{a}	834	1.2 ± 0.3^{a}	73	1.4 ± 0.3^{b}	28	1.4 ± 0.4^{b}	210	1.4 ± 0.4^{b}	1442	1.2 ± 0.3	<0.001
LDL-C (mmol/L)	117	3.1 ± 0.7^{a}	180	3.0 ± 0.8^{a}	828	3.1 ± 0.9^{a}	73	3.3 ± 0.8^{a}	28	3.1 ± 0.9^{a}	210	3.2 ± 0.8^{a}	1430	3.1 ± 0.8	<0.001
TG (mmol/L)	117	1.17(0.93; 1.68)^{a,c}	180	0.99(0.76; 1.43)^{a}	822	1.34(0.89; 1.68)^{b,c}	73	0.93(0.71; 1.56)^{a,b}	28	2.70(2.03; 3.3)^{d}	210	1.26(0.88; 1.66)^{c}	1430	1.20(0.86; 1.67)	<0.001
FFA (mmol/L)	117	0.48 ± 0.16^{a}	159	–	735	0.65 ± 0.32^{b}		–		–	211	0.46 ± 0.16^{a}	1063	0.6 ± 03	<0.001
SBP (mmHg)	117	128 ± 12.6^{c}	181	122 ± 14^{b}	885	125 ± 15^{b,c}	73	129 ± 17^{c}	29	120 ± 15^{a,b,c}	214	118 ± 11^{a}	1499	124.0 ± 14.5	<0.001
DBP (mmHg)	117	81 ± 9^{b,c}	181	81 ± 10^{b,c}	885	77 ± 11^{a}	73	85 ± 12^{c}	29	78 ± 10^{a,b,c}	214	76 ± 9^{a}	1499	78.3 ± 10.8	<0.001

Data shown as mean ± SD or median and IQR. ^{a,b,c} Values with different superscripts letters indicate statistically significant differences between studies, assessed by analysis of variance or chi-square tests, $p < 0.05$. Abbreviations: CRP, C-reactive protein; DBP, Diastolic blood pressure; FFA, Free fatty acids; HDL-C, HDL cholesterol; HOMA-IR, Homeostatic model assessment for insulin resistance; IL-6, Interleukin 6; LDL-C, LDL cholesterol; SAD, sagittal abdominal diameter; SBP, Systolic blood pressure; TC, Total cholesterol; TG, Triglycerides; TNF- α, Tumor necrosis factor alpha; WC, waist circumference.

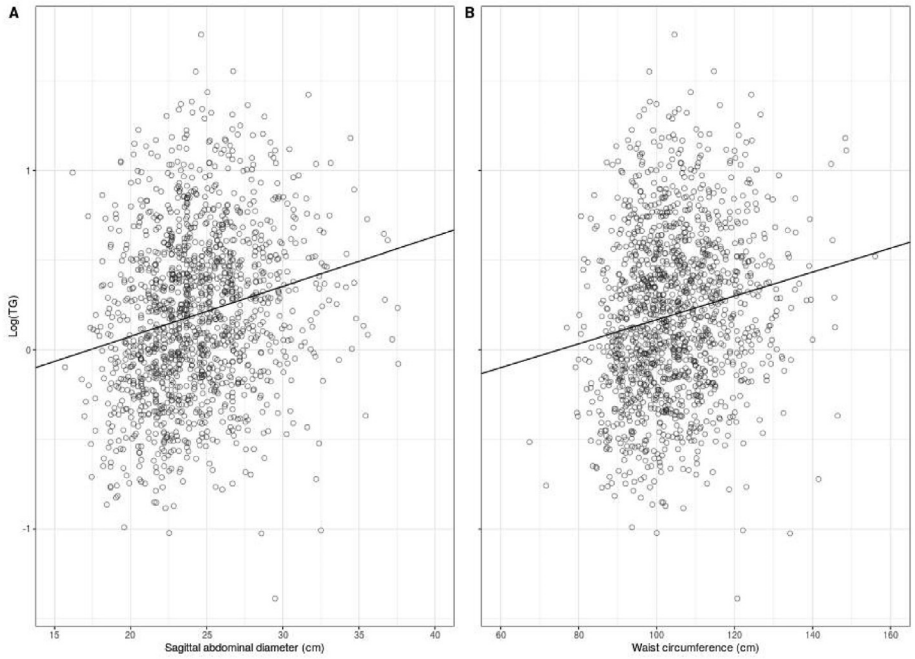

Figure 1 Scatter plots showing the associations between A) SAD and TG and B) WC and TG, respectively. Data points are obtained using residuals from models adjusting for age and gender (removing age and gender variation). Regression line is also based on models adjusted for age and gender.

WC, and BMI and the markers were estimated using Pearson correlation coefficients (unadjusted analyses) and partial (Pearson) correlation coefficients (analyses adjusted for age and gender) [19]. Differences in correlations were quantified with corresponding 95% confidence intervals and statistical tests were obtained using Fisher's z-transformation and Steiger's approximate t-test [6,20]. It was assumed that presence of missing values in the different studies were unrelated to the associations and correlations being investigated in this study. Therefore, missing values were assumed to occur completely at random, justifying the use of complete-case analysis.

Results

The six RCTs comprised a total of 1516 individuals. There were 485 men and 1031 women.The majority of the participants were Caucasian. The median age was 42 years (range 36–48 years). Average SAD, WC, and BMI were 24.4 ± 3.6 cm, 104.70 ± 12.60 cm, and 33.0 ± 5.0 kg/m2, respectively (Table 1).

Across all six studies, SAD, WC, and BMI were mostly positively associated (correlated) with all markers except for Matsuda index, TNF-α, and HDL-C where negative associations were seen (results from adjusted analyses in Tables S1–S3). There were slightly more significant associations for SAD than for WC and BMI.

SAD was significantly more correlated with TG than WC for all studies (Fig. 1), and overall increase in correlation was 0.05 (95% CI (0.02; 0.08) (results from adjusted analyses in Table 2). Likewise, SAD was more correlated with 2-h glucose and TNF-α (data only available for 2 studies) but not significantly so. For fasting insulin and HOMA-IR, SAD showed a stronger correlation than WC for all studies except for DIOGENES. For the remaining outcomes fasting glucose, Matsuda index, IL-6, CRP, TC, HDL-C, LDL-C, FFA, SBP, and DBP, there were no clear trends in differences in correlations between SAD and WC across the 6 studies.

SAD was significantly more correlated with TG and DBP than BMI for all studies and overall increases in correlation were 0.04 (95% CI (0.006, 0.07) and 0.11 (95% CI (0.08, 0.14)), respectively (results from adjusted analyses in Table 3). SAD was more correlated with 2-h glucose than BMI (data only available for 2 studies) but the increase was not significant. Likewise, SAD showed a higher correlation for fasting insulin, HOMA-IR, and CRP than BMI for all studies except for DIOGENES. For TNF-α and IL-6, BMI showed a higher correlation than SAD, but not significantly across studies. For fasting glucose, Matsuda index, FFA, SBP, HDL-C, and LDL-C, there were no clear trends in differences in correlations between SAD and BMI across studies.

Discussion

Across six studies, this study evaluated differences in correlations between SAD, WC and BMI. There were a few consistent findings across all six studies, but these findings, which all were increases in the strength of associations for SAD compared to WC or BMI, were not always significant. However, results were mostly inconsistent with no clear trends in terms of which measure correlated the most with the cardiometabolic risk markers.

In the past studies comparing SAD with WC and BMI have shown conflicting results. One study, in a French population, showed that SAD and WC were comparable as markers of cardiometabolic risk [1,21]. Another study, in a

Table 2 Correlations between markers of cardiometabolic health and SAD and differences in correlations between SAD and WC shown for each study separately and for all studies together.

Marker	3G		SHOPUS		DIOGENES		RIGHT		MNG		PROKA		All studies	
	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Cor (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference
Fasting insulin (pmol/L)														
Unadjusted	0.35	0.04(-0.04; 0.14)	0.49	0.02(-0.04; 0.07)	0.25	**−0.06(-0.11;-0.02)**	0.53	**0.25(0.12;0.37)**	0.62	**0.17(0.03;0.30)**	0.43	0.03(-0.04; 0.10)	0.31	**−0.04(-0.07;-0.006)**
Adjusted	0.34	0.05(-0.05; 0.15)	0.50	0.02(-0.04; 0.08)	0.21	**−0.07(-0.12;-0.02)**	0.56	**0.26(0.13;0.38)**	0.61	**0.17(0.05;0.29)**	0.42	0.02(-0.06; 0.10)	0.28	**−0.04(-0.07;-0.009)**
Fasting glucose (mmol/L)														
Unadjusted	0.40	0.05(-0.03; 0.14)	0.37	−0.004(-0.06; 0.06)	0.14	**−0.07(-0.12;-0.03)**	0.42	0.04(-0.10; 0.17)	0.40	−0.02(-0.18; 0.14)	0.28	−0.02(0.10; 0.05)	0.06	**−0.06(-0.09;0.03)**
Adjusted	0.28	0.08(-0.02; 0.18)	0.27	0.01(-0.06; 0.08)	0.09	**−0.07(-0.12;-0.02)**	0.33	0.07(-0.08; 0.22)	0.27	0.05(-0.11; 0.21)	0.19	−0.004(-0.09; 0.09)	0.02	**−0.04(-0.07;-0.007)**
2-h glucose (mmol/L)														
Unadjusted		–	0.26	0.03(-0.03; 0.09)	0.09	0.07(0.02; 0.11)		–		–		–	0.15	0.03(-0.01; 0.06)
Adjusted			0.25	0.03(-0.04; 0.10)	0.11	0.03(-0.02; 0.08)							0.16	0.03(-0.009; 0.07)
HOMA-IR (%)*														
Unadjusted	0.45	0.07(-0.01; 0.16)	0.54	0.02(-0.04; 0.07)	0.31	**−0.12(-0.16;-0.07)**	0.59	**0.23(0.11;0.36)**	0.61	**0.15(0.02;0.29)**	0.45	0.03(-0.04; 0.09)	0.39	**−0.06(-0.08; -0.03)**
Adjusted	0.41	0.08(-0.01; 0.18)	0.53	0.02(-0.04; 0.08)	0.25	**−0.12(-0.16;-0.07)**	0.59	**0.24(0.11;0.36)**	0.60	**0.14(0.009;0.27)**	0.44	0.01(-0.06; 0.09)	0.35	**−0.05(-0.08; -0.02)**
Matsuda index (%)*														
Unadjusted		–	−0.51	−0.02(-0.08; 0.03)	−0.31	**0.1(0.05;0.14)**		–		–		–	−0.35	**0.08(0.04;0.11)**
Adjusted			−0.49	−0.03(-0.09; 0.03)	−0.25	**0.1(0.05;0.14)**							−0.29	**0.08(0.04;0.11)**
TNF-α (%)*														
Unadjusted	0.05	0.02(-0.08; 0.11)	0.19	0.02(-0.04; 0.08)		–		–		–		–	0.12	0.00(-0.07; 0.07)
Adjusted	0.06	0.02(-0.09; 0.12)	0.18	0.02(-0.05; 0.08)									−0.07	0.001(-0.07; 0.07)
IL-6 (%)*														
Unadjusted	0.28	0.05(-0.04; 0.14)	0.32	0.01(-0.05; 0.07)		–	0.24	0.13(-0.02; 0.27)		–		–	0.22	0.03(-0.03; 0.09)
Adjusted	0.31	0.05(-0.05; 0.15)	0.39	−0.005(-0.07; 0.06)		–	0.19	0.14(-0.02; 0.29)					0.22	0.02(-0.04; 0.09)
CRP (%)*														
Unadjusted	0.31	0.02(-0.07; 0.11)	0.20	0.02(-0.05; 0.08)	0.25	−0.002(-0.05; 0.05)	0.35	0.01(-0.07; 0.22)	0.38	0.05(-0.13; 0.22)		–	0.29	0.002(-0.02; 0.05)
Adjusted	0.37	0.02(-0.08; 0.11)	0.32	0.009(-0.06; 0.08)	0.31	−0.03(-0.08; 0.02)	0.35	0.06(-0.09; 0.21)	0.34	0.04(-0.13; 0.20)			0.34	−0.004(-0.04; 0.03)
TC (mmol/L)														
Unadjusted	0.30	−0.08(-0.17; 0.003)	0.04	−0.01(-0.05; 0.03)	0.14	**0.09(0.04;0.13)**	−0.07	0.03(-0.12; 0.18)	0.07	0.03(-0.15; 0.21)	0.03	0.01(-0.06; 0.09)	0.09	**0.05(0.02;0.07)**

Adjusted	0.22	**−0.1(-0.20;-0.003)**	−0.04	−0.05(-0.12; 0.02)	0.12	**0.10(0.05;0.15)**	−0.08		0.09	0.03(-0.14; 0.20)	0.02	0.01(-0.07; 0.09)	0.09	**0.06(0.03;0.09)**
HDL-C (mmol/L)														
Unadjusted	−0.10	−0.04(-0.13; 0.05)	−0.36	**−0.03(0.04;0.01)**	−0.20	**0.11(0.07;0.15)**	−0.35	−0.04(-0.18; 0.10)	−0.56	0.04(-0.10; 0.18)	−0.37	0.04(-0.02; 0.11)	−0.26	**0.07(0.04;0.10)**
Adjusted	0.02	−0.06(-0.16; 0.04)	−0.29	−0.03(-0.10; 0.04)	−0.11	**0.11(0.06;0.16)**	−0.31	−0.09(-0.24; 0.06)	−0.32	−0.07(-0.23; 0.09)	−0.29	0.02(-0.06; 0.10)	−0.18	**0.06(0.03;0.09)**
LDL-C (mmol/L)														
Unadjusted	0.27	−0.06(-0.15; 0.02)	0.05	−0.01(-0.05; 0.03)	0.16	**0.05(0.007;0.10)**	−0.004	0.04(-0.11; 0.19)	0.31	−0.004(-0.17; 0.16)	0.13	0.002(-0.07; 0.08)	0.13	0.02(-0.007; 0.06)
Adjusted	0.17	−0.08(-0.18; 0.02)	−0.04	−0.06(-0.13; 0.007)	0.13	**0.07(0.02;0.12)**	−0.02	0.02(-0.14; 0.18)	0.20	0.05(-0.11; 0.21)	0.11	0.01(-0.07; 0.09)	0.12	0.04(0.004; 0.07)
TG (%)*														
Unadjusted	0.28	0.03(-0.06; 0.12)	0.39	0.06(-0.002; 0.12)	0.27	0.03(-0.02; 0.07)	0.23	0.002(-0.15; 0.15)	0.51	0.05(-0.09; 0.20)	0.29	0.02(-0.06; 0.09)	0.27	0.02(-0.01; 0.05)
Adjusted	0.21	0.04(-0.06; 0.14)	0.34	0.07(0.007; 0.13)	0.21	0.05(0.0; 0.10)	0.17	0.04(-0.12; 0.20)	0.34	**0.17(0.03;0.32)**	0.21	0.04(-0.04; 0.12)	0.22	**0.04(0.007;0.07)**
FFA (mmol/L)														
Unadjusted	0.10	−0.01(-0.11; 0.09)		−	0.08	**0.10(0.06;0.15)**		−		−	0.02	−0.01(-0.9; 0.06)	0.13	**0.09(0.05;0.12)**
Adjusted	0.14	−0.01(-0.11; 0.09)			0.17	**0.09(0.04;0.14)**					0.10	−0.05(-0.13; 0.03)	0.21	**0.07(0.03;0.11)**
SBP (mmHg)														
Unadjusted	0.32	0.05(-0.04; 0.14)	0.24	−0.07(-0.07; 0.06)	0.30	0.003(-0.04; 0.05)	0.24	0.07(-0.08; 0.22)	0.34	−0.08(-0.2; 0.07)	0.19	−0.04(-0.11; 0.03)	0.26	−0.001(-0.03; 0.03)
Adjusted	0.14	0.09(-0.01; 0.20)	0.12	0.01(-0.06; 0.08)	0.23	0.02(-0.03; 0.07)	0.15	0.01(-0.02; 0.28)	0.34	−0.03(-0.18; 0.12)	0.02	0.03(-0.05; 0.11)	0.20	**0.04(0.009;0.07)**
DBP (mmHg)														
Unadjusted	0.43	0.07(-0.02; 0.15)	0.32	0.01(-0.05; 0.07)	0.34	**0.11(0.06;0.15)**	0.23	0.14(-0.003; 0.29)	0.44	0.04(-0.11; 0.2)	0.34	−0.03(-0.10; 0.04)	0.26	**0.07(0.04;0.10)**
Adjusted	0.36	0.09(-0.006; 0.19)	0.27	0.02(-0.05; 0.09)	0.29	**0.13(0.09;0.18)**	0.20	0.13(-0.02; 0.28)	0.58	−0.01(-0.14; 0.12)	0.26	−0.01(-0.09; 0.07)	0.23	**0.09(0.06;0.12)**

Data shown as estimated (partial) Pearson correlation coefficients and differences in estimated partial correlation coefficients with 95% confidence intervals (CI), derived from simple linear regression models (unadjusted analysis) and multiple linear regression models (adjusted analysis including age and gender). Significant differences shown in bold. *HOMA-IR, Matsuda index, TNF-α, IL-6, CRP and TG were logarithm-transformed prior to estimation of correlation coefficients. Abbreviations: CRP, C-reactive protein; DBP, Diastolic blood pressure; FFA, Free fatty acids; HDL-C, HDL cholesterol; HOMA-IR, Homeostatic model assessment for insulin resistance; IL-6, Interleukin 6; LDL-C, LDL cholesterol; SAD, sagittal abdominal diameter; SBP, Systolic blood pressure; TC, Total cholesterol; TG, Triglycerides; TNF- α, Tumor necrosis factor alpha; WC, waist circumference.

Table 3 Correlations between markers of cardiometabolic health and SAD and differences in correlations between SAD and BMI shown for each study separately and for all studies together.

Marker	3G		SHOPUS		DIOGENES		RIGHT		MNG		PROKA		All studies	
	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference	Cor (SAD)	Difference	Corr. (SAD)	Difference	Corr. (SAD)	Difference
Fasting insulin (pmol/L)														
Unadjusted	0.35	0.08(-0.05; 0.20)	0.49	0.05(-0.02; 0.11)	0.25	0.03(-0.02; 0.08)	0.53	**0.29(0.11;0.47)**	0.62	**0.27(0.05;0.49)**	0.43	0.09(-0.001; 0.17)	0.31	**0.05(0.009;0.08)**
Adjusted	0.34	0.08(-0.04; 0.20)	0.50	0.06(0.0; 0.12)	0.21	−0.01(-0.06; 0.04)	0.56	**0.3(0.14;0.46)**	0.61	**0.32(0.08;0.56)**	0.42	0.07(-0.02; 0.15)	0.28	0.02(-0.01; 0.05)
Fasting glucose (mmol/L)														
Unadjusted	0.40	0.10(-0.02; 0.22)	0.37	**0.17(0.10;0.24)**	0.14	0.04(-0.01; 0.10)	0.42	**0.31(0.12;0.49)**	0.40	0.25(-0.003; 0.50)	0.28	0.09(-0.001; 0.18)	0.06	**0.10(0.06;0.14)**
Adjusted	0.28	−0.009(-0.13; 0.11)	0.27	**0.08(0.01;0.15)**	0.09	−0.03(-0.08; 0.02)	0.33	0.17(-0.1; 0.35)	0.27	0.26(-0.02; 0.54)	0.19	0.07(-0.02; 0.16)	0.02	0.02(-0.01; 0.05)
2-h glucose (mmol/L)														
Unadjusted		–	0.26	0.03(-0.05; 0.10)	0.09	0.02(-0.03; 0.08)		–		–		–	0.15	0.004(-0.04; 0.05)
Adjusted			0.25	0.02(-0.05; 0.09)	0.11	0.03(-0.02; 0.24)							0.16	0.01(-0.03; 0.05)
HOMA-IR (%)*														
Unadjusted	0.45	0.10(-0.03; 0.22)	0.54	0.07(0.004; 0.14)	0.31	0.01(-0.04; 0.06)	0.59	**0.27(0.10;0.44)**	0.61	**0.28(0.07;0.50)**	0.45	0.06(-0.002; 0.15)	0.39	**0.06(0.02; 0.09)**
Adjusted	0.41	0.08(-0.04; 0.19)	0.53	**0.07(0.008;0.13)**	0.25	**−0.06(-0.11;-0.009)**	0.59	**0.26(0.11;0.42)**	0.60	**0.31(0.07;0.55)**	0.44	0.05(-0.03; 0.13)	0.35	0.07(-0.03; 0.04)
Matsuda index (%)*														
Unadjusted		–	−0.51	**−0.08(-0.14;-0.001)**	−0.31	**−0.07(-0.12;-0.01)**		–		–		–	−0.35	**−0.06(-0.11;0.02)**
Adjusted			−0.49	**−0.06(-0.13;-0.003**)	−0.25	0.01(-0.04; 0.06)							−0.30	−0.01(-0.05; 0.03)
TNF-α (%)*														
Unadjusted	0.05	−0.09(-0.22; 0.04)	0.19	−0.02(-0.10; 0.05)		–		–		–		–	0.12	0.03(-0.06; 0.11)
Adjusted	0.06	−0.08(-0.20; 0.04)	0.18	−0.03(-0.10; 0.03)									0.07	−0.02(-0.09; 0.06)
IL-6 (%)*														
Unadjusted	0.28	−0.08(-0.21;-0.04)	0.32	−0.05(-0.12; 0.03)		–	0.24	0.18(-0.03; 0.38)		–		–	0.22	−0.02(-0.09; 0.06)
Adjusted	0.31	−0.05(-0.17;-0.06)	0.39	−0.002(-0.07; 0.06)		–	0.19	0.13(-0.06; 0.32)					0.22	−0.02(-0.09; 0.04)
CRP (%)*														
Unadjusted	0.31	0.02(-0.11; 0.15)	0.20	**−0.08(-0.16;0.003)**	0.25	**−0.12(-0.17;-0.06)**	0.36	0.10(-0.10; 0.30)	0.38	−0.04(-0.31; 0.22)		–	0.29	**−0.10(-0.14;-0.06)**
Adjusted	0.37	0.06(-0.05; 0.18)	0.32	0.01(-0.06; 0.08)	0.31	**−0.06(-0.11;-0.02)**	0.34	0.08(-0.1; 0.26)	0.34	−0.05(-0.35; 0.24)			0.34	**−0.05(-0.09;-0.02)**
TC (mmol/L)														
Unadjusted	0.30	0.1(-0.03; 0.23)	0.04	0.03(-0.05; 0.11)	0.14	**0.09(0.03;0.14)**	−0.07	−0.02(-0.23; 0.19)	0.07	−0.009(-0.29; 0.27)	0.03	0.03(-0.07; 0.12)	0.09	**0.07(0.03;0.11)**
Adjusted	0.22	0.04(-0.08; 0.16)	−0.04	−0.04(-0.11; 0.03)	0.12	**0.06(0.01;0.11)**	−0.08	0.01(-0.18; 0.20)	0.09	0.001(-0.30; 0.31)	0.02	0.07(-0.02; 0.16)	0.09	**0.04(0.006;0.07)**

HDL-C (mmol/L)													
Unadjusted	−0.10	−0.12(-0.25; 0.008)	−0.36	**−0.11(-0.18;-0.03)**	−0.20	**−0.07(-0.12;-0.014)**	−0.35	−0.28(-0.48;-0.09)	−0.56	−0.07(-0.30; 0.16)	−0.37	**−0.13(0.22;0.04)**	−0.26	**−0.08(-0.12;-0.05)**
Adjusted	0.02	−0.03(-0.15; 0.09)	−0.29	−0.04(-0.11; 0.03)	−0.11	0.04(-0.009; 0.09)	−0.31	−0.18(-0.36; 0.002)	−0.32	0.04(-0.24; 0.32)	−0.29	−0.02(-0.11,0.07)	−0.18	0.01(-0.2; 0.04)
LDL-C (mmol/L)													
Unadjusted	0.27	0.12(-0.002; 0.25)	0.05	0.03(-0.06; 0.10)	0.16	**0.08(0.03;0.13)**	−0.004	−0.01(-0.22; 0.2)	0.31	0.004(-0.26; 0.27)	0.13	0.06(-0.03; 0.16)	0.13	**0.07(0.03;0.11)**
Adjusted	0.17	0.04(-0.08; 0.16)	−0.04	−0.05(-0.12; 0.02)	0.13	0.04(-0.01; 0.09)	−0.02	0.01(-0.18; 0.20)	0.20	−0.04(-0.34; 0.26)	0.11	0.08(-0.008; 0.17)	0.12	0.03(-0.004; 0.06)
TG (%)*													
Unadjusted	0.28	**0.13(0.004;0.26)**	0.39	**0.11(0.04;0.18)**	0.27	**0.14(0.09;0.19)**	0.24	**0.31(0.11;0.5)**	0.51	**0.29(0.05;0.52)**	0.29	**0.13(0.04;0.22)**	0.27	**0.11(0.08;0.15)**
Adjusted	0.21	0.07(-0.05; 0.19)	0.34	**0.07(0.005;0.14)**	0.21	**0.07(0.02;0.12)**	0.17	**0.21(0.02;0.40)**	0.34	0.28(-0.002; 0.56)	0.21	0.06(-0.03; 0.14)	0.22	**0.05(0.02;0.08)**
FFA (mmol/L)													
Unadjusted	0.10	**−0.13(-0.26;0.002)**		–	0.08	**−0.06(-0.12;-0.001)**		–		–	0.02	**−0.12(-0.22;0.03)**	0.13	**−0.07(-0.11;-0.03)**
Adjusted	0.14	**−0.1(-0.22;0.02)**			0.17	0.04(-0.01; 0.09)					0.10	−0.05(-0.14; 0.04)	0.21	0.002(-0.04; 0.04)
SBP (mmHg)													
Unadjusted	0.32	0.15(0.03; 0.28)	0.24	**0.17(0.10;0.25)**	0.30	**0.11(0.06;0.16)**	0.24	0.20(-0.001; 0.41)	0.34	0.19(-0.07; 0.44)	0.19	0.08(-0.01; 0.17)	0.26	**0.14(0.10;0.17)**
Adjusted	0.14	−0.001(-0.12; 0.12)	0.12	**0.08(0.01;0.15)**	0.23	0.005(-0.04; 0.05)	0.15	0.09(-0.1; 0.28)	0.34	0.27(-0.003; 0.54)	0.02	−0.03(-0.12; 0.06)	0.20	0.03(-0.003; 0.06)
DBP (mmHg)													
Unadjusted	0.43	0.08(-0.04; 0.20)	0.32	**0.10(0.03;0.17)**	0.34	**0.18(0.13;0.22)**	0.23	0.07(-0.13; 0.28)	0.44	0.20(-0.05; 0.44)	0.34	0.06(-0.03; 0.15)	0.26	**0.18(0.14;0.21)**
Adjusted	0.36	0.01(-0.10; 0.12)	0.27	0.05(-0.02; 0.12)	0.29	**0.11(0.06;0.16)**	0.20	0.05(-0.14; 0.24)	0.58	**0.30(0.06;0.54)**	0.26	0.03(0.14; 0.46)	0.23	**0.11(0.08;0.14)**

Data shown as estimated (partial) Pearson correlation coefficients and differences in estimated partial correlation coefficients with 95% confidence intervals (CI), derived from simple linear regression models (unadjusted analysis) and multiple linear regression models (adjusted analysis including age and gender). Significant differences shown in bold. *HOMA-IR, Matsuda index, TNF-α, IL-6, CRP and TG were logarithm-transformed prior to estimation of correlation coefficients. Abbreviations: CRP, C-reactive protein; DBP, Diastolic blood pressure; FFA, Free fatty acids; HDL-C, HDL cholesterol; HOMA-IR, Homeostatic model assessment for insulin resistance; IL-6, Interleukin 6; LDL-C, LDL cholesterol; SAD, sagittal abdominal diameter; SBP, Systolic blood pressure; TC, Total cholesterol; TG, Triglycerides; TNF- α, Tumor necrosis factor alpha; WC, waist circumference.

Dutch population (aged 56–83 yrs), reported some differences in correlations with markers of insulin resistance, dyslipidaemia, and blood pressure between SAD and WC and BMI but found no consistent results with respect to which anthropometric measure was the most sensitive [1]. In two Swedish studies, SAD was found to be more correlated with metabolic risk factors than both WC and BMI [22,23]. Similarly, SAD was found to be a stronger indicator of insulin resistance than WC in a Swedish high-risk population [24]. More recently, in a US National Health and Nutrition Examination Survey (NHANES) study, Firouzi et al. [6] found that SAD was in general a better predictor compared to WC [6]. BMI as an anthropometric indicator of cardiometabolic risk compared to SAD has previously been criticized for not taking the proportion of lean and fat mass, including the body fat distribution into account and thus being of less predictive value in obesity related diseases [1]. Our results showed no clear trends in differences in correlations between SAD and BMI, but for a few outcomes we found SAD to be significantly more correlated than BMI. Öhrvall et al. [23] found similar results (SAD was more strongely correlated with and DBP and TG than was BMI).

One of the methodological differences that may lead to discrepancies in the results between studies is the measurement site for SAD [9]. In this study the highest point of the abdomen was used. This may have resulted in lower correlation with cardiometabolic measures [9,25,26] and it may have weakened our ability to detect differences between SAD and WC, e.g., compared to the protocol described in the US NHANES [9]. It has also been argued that when using the highest point of the abdomen the SAD measurement could be influenced by SAT expansion as well as by VAT [9]. This methodological difference may explain the discrepancies between our inconsistent findings and the more pronounced differences found in the NHANES study by Firouzi et al. [6].

Limitations of the present study are 1) the cross-sectional study design, residual confounding due to unmeasured life style markers such as alcohol consumption and smoking cannot be ruled out, and 2) the use of biomarkers compared to studies with a prospective design and hard endpoints such as CVD, T2D, and mortality. Moreover, the majority of the included individuals (98%) were overweight or obese whereas other studies included both normal weight and overweight individuals [27,28]. One strength of the present study is the use of a clinically relevant population group, which is at risk of developing T2D and CVD and which would benefit from establishing a highly predictable anthropometric measure. Another strength is the fact that many different cardiometabolic outcomes, including markers of insulin resistance, dyslipidemia, lowgrade inflammation and blood pressure, were investigated. To our knowledge none of the previous studies did include all these markers. Therefore, the present study provides an extensive evaluation of how well SAD, WC, and BMI predict overall cardiometabolic risk.

Conclusions

In this study of high risk individuals, we found that SAD was significantly more correlated with a few markers of cardiometabolic risk factors compared to WC and BMI, but no single anthropometric indicator was consistently superior in predicting markers of cardiometabolic risk.

Author contributions

GM, CR, and MVL were involved in conception and design of the study. MVL, LK, SV, SKK, OP, LL, TML, WS, AA and MK were involved in the collection of data and biological samples. CR did the statistical analysis. GM, CR, and MVL drafted the manuscript. All authors were involved in the interpretation of the data and all authors read, revised and approved the final manuscript.

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Declaration of competing interest

None of the authors has any conflict of interest in regards to this work.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2020.09.032.

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