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Waist Circumference and Related Anthropometric Indices Are Associated with Metabolic Traits in Severely Obese Subjects

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Abstract Increased waist circumference (WC) and related anthropometric indices have been shown to be, independently of body weight and body mass index (BMI), associated with adverse metabolic traits in many populations. It is unknown, however, whether WC also predicts adverse metabolic traits in severely obese subjects displaying a BMI greater than 35 kg/m^2 . To address this question, we analyzed a dataset including 838 severely obese patients (597 women, BMI $44.6 \pm 6.2 \text{ kg/m}^2$; 241 men, BMI $44.3 \pm 5.7 \text{ kg/m}^2$). Body weight, height, WC, hip circumference, and blood pressure were measured in all subjects along with the following metabolic blood markers: fasting glucose, insulin, glycolized hemoglobin levels, triglycerides, total cholesterol, low- and high-density cholesterol, and uric acid. Multivariate regression analyses indicated 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. In general, height-adjusted WC indices were more closely associated with metabolic traits in women than in men. Collectively, our findings suggest that body fat distribution also plays an important role in determining metabolic traits in severely obese subjects and that WC represents a valuable marker of abdominal/visceral obesity in this population.

Keyword Abdominal obesity · Insulin resistance · Uric acid · Sex differences · Anthropometry

Introduction

Obesity is a major risk factor for the development of many metabolic diseases and premature death [1, 2]. The body mass index (BMI, weight is in kilograms divided by height in meters squared) is commonly used to define normal-, over-, and underweight as well as different degrees of obesity [3]. However, the BMI is only a surrogate marker of a subject's degree of obesity since it does not account for distinct body composition components [4]. Also, the distribution of body fat plays an important role in determining a subject's metabolic health with visceral fat accumulation being associated with a particular high risk for metabolic and cardiovascular disease [5–7]. Accordingly, waist circumference (WC) as a surrogate marker of visceral obesity predicts morbidity and mortality on top of the BMI on population-based level [8–14]. To account for other anthropometric variables such as hip circumference and height, distinct anthropometric indices have been developed and tested for their predictive value concerning metabolic and cardiovascular outcomes. For instance, the waist-to-height ratio (W/Ht) has been shown to be more strongly associated with metabolic and cardiovascular risk factors than WC and also than the waist-to-hip ratio (WHR) [15–19]. Other WC-related indices accounting for height have been established, e.g., a height³-to-waist³ ratio (Ht^3/W^3), which might show an even closer relationship with metabolic traits [20]. However, whether such WC-related indices also predict metabolic traits in severely obese subjects displaying a BMI above 35 kg/m^2 is largely unknown. This question arises for two reasons, i.e., a biological one and a technical one. First, severely obese subjects frequently show such a great excess of body fat mass that its distribution may only have a minor

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impact, if any, on metabolic traits. Second, giving that the anatomical landmarks required for a proper WC measurement are often very difficult to identify in severely obese subjects, the reliability of respective measurements appears to be questionable.

In the present study, we used a large clinical dataset including 838 severely obese patients to investigate how WC and WC-related anthropometric indices relate to metabolic traits in subjects with a BMI greater than 35 kg/m^2 . If no association can be demonstrated, WC measurements will not be much value, and thus, they could be omitted in clinical practice.

Methods

Subjects

For this retrospective cross-sectional study, we extracted data from 567 obese women and 271 obese men from the prospectively maintained database of the Interdisciplinary Obesity Center (IOC), St. Gallen, Switzerland. All patients were examined between February 2006 and March 2011. Data were collected as part of the first visit at the IOC. Inclusion criteria for this study were a BMI greater than 35.0 kg/m^2 and an age of at least 18 years. 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 Measurements

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 was calculated by weight in kilograms divided by height in meters squared. WC was measured to the nearest 0.5 cm, whenever possible, midway between the lowest rib and the iliac crest while the patients were at minimal respiration according to the World Health Organization recommendations [21]. In cases in which the respective anatomical landmarks were not identifiable, the maximal WC was measured. Hip circumference (HC) was measured horizontally at the level of the largest lateral extension of the hip [21].

Upon these measurements, the following additional anthropometric indices were calculated: WHR, W/Ht ratio, waist-to-height² (W/Ht^2) ratio, waist-to-height³ (W/Ht^3) ratio, and height³-to-waist³ (Ht^3/W^3) ratio.

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 patients 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 0800 and 1100 hours after an overnight fast. The following metabolic markers were determined and included in our analyses: fasting serum concentrations of glucose, insulin, triglycerides (TG), total cholesterol (Chol), low- and high-density lipoprotein (LDL and HDL), and uric acid. Glycolized hemoglobin levels (HbA1c) were assessed in whole blood samples. The Chol/HDL ratio was calculated. Also, the homeostatic model assessment (HOMA) was calculated as an index of insulin resistance [22].

Statistical Analysis

Data are presented as mean $\pm$ SD and ranges. 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 ($n=272$) were excluded; for analysis of glucose metabolism-related traits, subjects taking antidiabetic drugs ($n=112$) were excluded; and for analysis of lipid levels, patients taking lipid-lowering drugs ($n=67$) 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 correlation analyses. Subsequently, multiple stepwise linear regression analyses were performed to test for the independence of respective associations with analyses of HC, WC, and WC-related indices, taking into account age, height, and weight. For indices based on height, e.g., W/Ht, height was not included in respective models as an independent variable. Independent associations of metabolic traits with the BMI were assessed by only including sex and age in the respective multiple regression models. *p* values of less than 0.05 were considered significant.

Results

Subject's Characteristics

The subject's anthropometric data are provided in Table 1 and data on metabolic traits are in Table 2. Men were older, taller, and heavier and displayed a greater WC than women (all $p<0.001$), while the BMI did not differ between both sexes ($p=0.48$). In contrast, HC was greater in women than in men ($p<0.001$). Accordingly, the WHR as well as the WC-related measures W/Ht^2 and W/Ht^3 were significantly greater in men than in women (all $p<0.001$). The Ht^3/W^3 and the W/Ht did not differ between both sexes (all $p>0.12$).

Systolic as well as diastolic blood pressure showed no significant differences between both sexes (all $p>0.19$).

Table 1 Patient's characteristics and anthropometric data

	Women N=597	Men N=241	<i>p</i> value
Age (years)	41.5±12.2 (18–74)	43.7±12.4 (18–76)	0.019
Height (cm)	162±7.2 (141–181)	176±7.9 (152–197)	<0.001
Weight (kg)	117±18.6 (78–196)	137±21.5 (88–203)	<0.001
BMI (kg/m ²)	44.6±6.2 (35.0–70.2)	44.3±5.7 (35.1–65.1)	0.480
Waist circumference (cm)	125±13.2 (80–178)	137±13.7 (102–181)	<0.001
Hip circumference (cm)	135±13.5 (96–197)	131±13.8 (100–180)	<0.001
WHR (cm/cm)	0.9±0.1 (0.7–1.5)	1.1±0.1 (0.8–1.4)	<0.001
W/Ht (cm/cm)	0.8±0.1 (0.5–1.1)	0.8±0.1 (0.6–1.04)	0.201
W/Ht ² (cm/m ²)	47.9±5.9 (28.7–71.8)	44.5±5.4 (32.7–63.9)	<0.001
W/Ht ³ (cm/m ³)	29.7±4.5 (17.2–49.2)	25.4±3.9 (17.6–39.2)	<0.001
Ht ³ /W ³ (cm ³ /cm ³)	2.3±0.8 (0.8–9.1)	2.2±0.6 (0.9–5.1)	0.117

All values are mean ± SD (range); non-normal distributed variables were log-transformed (log). *p* values were derived by unpaired Student's *t* tests

BMI body mass index, WHR waist-to-hip ratio, W/Ht waist to height, W/Ht² waist to height², W/Ht³ waist to height³, Ht³/W³ height³ to waist³

Serum glucose, insulin, HOMA index, triglyceride, uric acid concentrations, and Chol/HDL ratio were higher in men than in women (all *p*<0.008), while HDL levels were higher in women than in men (all *p*<0.001).

Correlation Analyses

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

In women, systolic blood pressure was significantly correlated with WC, WHR, W/Ht, W/Ht², and Ht³/W³ (all *p*<0.02). Diastolic blood pressure was only significantly correlated with WHR (*p*<0.005). Serum glucose and insulin

concentrations as well as HbA1c levels and the HOMA index were correlated with all anthropometric measures (all *p*<0.04) except for HC which did not significantly correlate with glucose and HbA1c levels (both *p*>0.37) and WHR which did not significantly correlate with insulin levels (*p*=0.06). TG levels were correlated with WHR, W/Ht, W/Ht², W/Ht³, and Ht³/W³ (all *p*<0.015). Total Chol was correlated with HC, W/Ht², and W/Ht³ (all *p*<0.035) and LDL only with W/Ht³ (*p*=0.025). HDL was correlated with BMI and WC (both *p*<0.02), while serum uric acid levels were significantly correlated with BMI, WC, WHR, W/Ht, W/Ht², and Ht³/W³ (all *p*<0.04).

In men, metabolic traits in general appeared to be much weaker correlated with anthropometric measures than in

Table 2 Metabolic traits assessed in the severely obese study population

	Number	Women	Number	Men	<i>p</i> value
Systolic blood pressure (mmHg) ^a	412	134±17.5 (92–197)	142	137±16.8 (97–198)	0.189
Diastolic blood pressure (mmHg)	412	86±10.9 (60–141)	142	87±10.2 (65–116)	0.682
Glucose (mmol/l) ^b	533	5.5±1.2 (3.6–13.9)	193	5.8±1.5 (3.5–16.0)	0.008
Insulin (mU/l)	372	13.3±8.1 (2.1–91.6)	124	19.2±12.8 (4.8–98.7)	<0.001
HOMA	372	3.3±2.4 (0.5–30.9)	124	4.9±3.7 (1.0–28.9)	<0.001
HbA1c (%)	442	5.8±0.7 (4.5–12.3)	158	5.9±0.7 (5.0–9.7)	0.0057
TG (mmol/l)	548	1.7±1.0 (0.3–10.5)	202	2.1±1.1 (0.5–6.7)	<0.001
Cholesterol (mmol/l) ^c	549	5.2±1.1 (2.0–9.0)	204	5.1±1.1 (3.0–9.0)	0.141
LDL (mmol/l)	544	3.1±0.9 (0.6–6.3)	205	3.1±0.9 (0.6–6.4)	0.38
HDL (mmol/l)	547	1.4±0.5 (0.6–7.2)	205	1.2±0.4 (0.6–4.8)	<0.001
Chol/HDL (mmol/l) ^c	545	3.9±1.2 (0.9–9.7)	204	4.5±1.2 (1.0–7.4)	<0.001
Uric acid	446	333±72.2 (30–761)	179	398±70.3 (219–590)	<0.001

All values are mean ± SD (range)

HOMA homeostatic model assessment, TG triglycerides, HDL high-density lipoprotein, LDL low-density lipoprotein

^a Patients taking hypertensive-lowering drugs were excluded from analyses

^b Patients taking antidiabetic-lowering drugs were excluded from analyses

^c Patients taking lipid-lowering drugs were excluded from analyses

Table 3 Correlations between metabolic risk factors and anthropometric parameters in women

	BMI	Waist	Hip	WHR	W/Ht	W/Ht ²	W/Ht ³	Ht ³ /W ³
RR_sys	0.03	0.12*	−0.01	0.15*	0.12*	0.10*	0.09	−0.12*
RR_dias	0.01	0.06	−0.06	0.14**	0.06	0.04	0.03	−0.06
Glucose	0.14**	0.12**	0.01	0.12**	0.16**	0.17**	0.16**	−0.16**
Insulin	0.29**	0.24**	0.15**	0.09	0.23**	0.19**	0.15**	−0.23**
HOMA	0.30**	0.26**	0.14**	0.12*	0.26**	0.22**	0.19**	−0.26**
HbA1c	0.11*	0.18**	−0.02	0.22**	0.22**	0.23**	0.21**	−0.22**
TG	0.03	0.05	−0.07	0.12**	0.11*	0.14**	0.16**	−0.11*
Chol	−0.07	−0.06	−0.09*	0.04	0.02	0.09*	0.12**	−0.02
LDL	−0.04	−0.04	−0.07	0.04	0.02	0.07	0.09*	−0.02
HDL	−0.12**	−0.09*	−0.06	−0.05	−0.05	−0.01	0.02	0.05
Chol/HDL	0.06	0.05	−0.01	0.07	0.07	0.07	0.07	−0.07
Uric acid	0.09*	0.17**	−0.02	0.19**	0.15**	0.11*	0.07	−0.15**

* $p < 0.05$; ** $p < 0.01$

women. Systolic blood pressure was only correlated with WHR ($p = 0.036$). Serum glucose levels did not correlate with any anthropometric measure (all $p > 0.05$), while HbA1c, serum insulin, and HOMA index levels were significantly correlated with BMI, WC, HC, WHR, W/Ht, W/Ht², and Ht³/W³ (all $p < 0.038$) except for the correlation between HbA1c and HC ($p = 0.81$) as well as the correlation between insulin and HOMA index with WHR (both $p > 0.06$). None of the lipid metabolism-related measures correlated with the anthropometric variables, while serum uric levels were significantly correlated with WC and HC (both $p < 0.01$).

Multivariate Regression Analyses

Figure 1 illustrated the strength of independent association (i.e., R^2 =explained variance) between anthropometric

measures and metabolic traits as revealed by multiple linear regression analysis. Overall, much more independent associations were found in women than in men.

In women, systolic blood pressure was independently associated with WC, HC, WHR, W/Ht, W/Ht², and Ht³/W³, while in men, only an independent association with WHR was found. Diastolic blood pressure was only associated with WHR in women but not in men.

Serum glucose levels were independently associated with BMI, WC, HC, WHR, W/Ht, W/Ht², and Ht³/W³ in women, while in men, no such associations with anthropometric parameters were found. Serum insulin levels were independently associated with BMI, WC, HC, WHR, W/Ht, W/Ht², W/Ht³, and Ht³/W³ in women and with BMI and WC in men. HOMA index as well as HbA1c levels was independently associated with BMI, WC, HC, WHR, W/Ht, W/Ht², W/Ht³, and Ht³/W³

Table 4 Correlations between metabolic risk factors and anthropometric parameters in men

	BMI	Waist	Hip	WHR	W/Ht	W/Ht ²	W/Ht ³	Ht ³ /W ³
RR_sys	−0.11	−0.02	−0.16	0.18*	−0.06	−0.07	−0.08	0.04
RR_dias	−0.09	−0.03	−0.10	0.09	−0.07	−0.09	−0.09	0.04
Glucose	0.08	0.04	−0.01	0.07	0.06	0.07	0.06	−0.01
Insulin	0.31**	0.34**	0.22*	0.16	0.28**	0.18*	0.09	−0.24**
HOMA	0.31**	0.31**	0.19*	0.17	0.27**	0.19*	0.11	−0.21*
HbA1c	0.17*	0.19*	0.02	0.22**	0.19*	0.17*	0.13	−0.18*
TG	−0.01	−0.06	−0.12	0.08	−0.01	0.03	0.05	0.02
Chol	−0.08	−0.12	−0.13	0.02	−0.06	−0.01	0.03	0.05
LDL	−0.03	−0.08	−0.09	0.02	−0.03	0.003	0.03	0.02
HDL	0.03	0.02	0.03	−0.01	0.02	0.02	0.02	−0.02
Chol/HDL	−0.05	−0.08	−0.09	0.03	−0.04	−0.001	0.02	0.03
Uric acid	0.11	0.20**	0.19**	0.01	0.13	0.04	−0.03	−0.12

* $p < 0.05$; ** $p < 0.01$

Fig. 1 Illustration of the explained variance (R^2) of the distinct glucose and lipid metabolism markers related by the different anthropometric indices. Men are *black columns*, women are *gray columns*. BMI was

adjusted for sex, age. WC, HC, and WHR were adjusted for sex, age, weight, and height. W/Ht, W/Ht², W/Ht³, and Ht³/W³ were adjusted for sex, age, and weight

in women. In men, the HOMA index was independently associated with BMI and WC, and HbA1c levels were associated with BMI.

Serum TG levels were independently associated with WHR, W/Ht, W/Ht², W/Ht³, and Ht³/W³ in women but not with any anthropometric measure in men. Serum HDL levels showed an independent association with BMI and HC in women. Serum total Chol and LDL levels were not associated with any anthropometric parameter in both sexes, and HDL levels show no associations in men.

Serum uric acid levels were independently associated with BMI, WC, HC, WHR, W/Ht, and Ht³/W³ in women and with WC in men.

Conclusion

The present data for the first time demonstrate that WC and WC-related indices are, independently of body weight,

associated with metabolic traits such as systolic blood pressure, markers of glucose and lipid metabolism, as well as uric acid levels in severely obese subjects. The association between WC-related indices and metabolic traits appears to be stronger in women than in men. In women, height-adjusted WC-related indices show closer associations with metabolic risk factors than WC per se, which is not the case in severely obese men. Overall, our data suggest that body fat distribution plays an important role in determining metabolic traits in severely obese subjects. Furthermore, the data show that assessment of WC and WC-related indices as surrogate markers of visceral obesity can help to predict the metabolic state in this population.

The overall closer association of WC-related indices with metabolic traits in women than in men is an interesting finding. In men, excess body fat frequently accumulates at the abdominal area, while in women, excessive fat mass often shows a much wider distribution with accumulation in distinct subcutaneous fat layers all over the body. Therefore,

anthropometric indices indicating an abdominal/visceral fat accumulation may be particularly important in obese women since they may explain more of the variance in metabolic traits in women than in men. The finding that the adjustment for height increases the strength of WC-related indices in predicting metabolic traits in women is also of relevance in this context. Based on our finding, one may conclude that measuring WC and relating it to height might be more important in severely obese women than in severely obese men.

Several limitations of our study need to be mentioned. First, the cross-sectional nature of our study leaves it unknown whether WC-related indices can help to prospectively predict health-related outcomes such as cardiovascular events in severely obese subjects. Second, overall, the found associations between WC-related indices and metabolic risk markers were rather weak. Therefore, respective indices might not be useful to stratify severely obese subjects to distinct risk groups without directly measuring metabolic risk markers, e.g., blood analyses, in the clinical setting. Putting this forward, the value of measuring WC in severely obese patients as a clinical routine in our view remains questionable. For epidemiological studies and public health approaches, however, the assessment of WC-related indices might be important measures to identify subjects who display high metabolic health-related risks.

In conclusion, our data for the first time show that WC and related anthropometric indices are associated with metabolic traits, independently of body weight in severely obese subjects. This finding suggests that abdominal/visceral fat accumulation is associated with an adverse metabolic state in severely obese subjects and that WC also represents a useful anthropometric measure in this population.

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Conflict of Interest None of the authors has a conflict of interest to the study.

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