Body Mass Index or Waist Circumference: Which Is the Better Predictor for Hypertension and Dyslipidemia in Overweight/Obese Children and Adolescents? Association of Cardiovascular Risk Related to Body Mass Index or Waist Circumference

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Key Words

Body mass index · Dyslipidemia · Hypertension · Obesity · Waist circumference

Abstract

Background: In order to assess the relationship between hypertension or dyslipidemia and obesity, the body mass index (BMI) is usually used. Unlike waist circumference (WC), BMI does not reflect body fat distribution. The aim of this study is to investigate whether BMI or WC is a better predictor of hypertension or dyslipidemia in overweight/obese children and adolescents. **Methods:** As of November 2012, the APV database contained data on 81,819 patients from 189 specialized pediatric obesity institutions in Germany, Austria and Switzerland. Logistic regression analysis was conducted using odds ratios (OR) with 95% CI. **Results:** The average age

of the youths ($n = 5.978$) was 13.9 ± 1.8 years. Mean BMI-SDS was 2.0 ± 0.5 , and mean WC-SDS was 2.2 ± 0.5 . Both BMI-SDS and WC-SDS are significant predictors of hypertension and dyslipidemia: BMI-SDS is a better predictor ($OR = 2.60$) for hypertension than WC-SDS ($OR = 1.85$), while WC-SDS ($OR = 1.90$) was slightly superior to BMI-SDS ($OR = 1.86$) in predicting adverse lipid profiles. Compared to normal-weight patients, obese patients ($BMI \geq 97$ th percentile) exhibited increased systolic ($+6.3$ mm Hg) and diastolic blood pressure ($+3.9$ mm Hg). However, this difference was only $+4.8$ mm Hg (systolic) and $+2.6$ mm Hg (diastolic) if WC >97 th percentile was used. **Conclusion:** BMI-SDS is more closely associated with hypertension, while WC-SDS is more closely associated with dyslipidemia. However, the additional measurement of WC has only a small benefit in obese youths.

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Introduction

Prevalence and severity of obesity have increased in childhood and adolescence during the last decades [1, 2]. However, a recent study reported stable or declining prevalence [3]. Obesity is a major risk factor for many chronic diseases and can lead to metabolic (dyslipidemia, diabetes mellitus type 2), cardiovascular and orthopedic diseases, as well as an increased cancer risk [4]. An obese child is at risk of becoming an obese adult with a high rate of severe comorbidities and premature death. It is known that the degree of obesity correlates with hypertension, carotid intima-media thickness and left ventricular hypertrophy [5, 6]. We recently reported that elevated blood pressure is the most prevalent risk factor in children and adolescents and exhibits the strongest association with body mass index (BMI) [7]. In addition, the prevalences of diabetes, dyslipidemia and metabolic syndrome increase with increasing BMI [8].

BMI determines the severity of obesity, but not the distribution of body fat. Adipose tissue is a dynamic endocrine organ secreting several inflammatory proteins that increase the risk of cardiovascular disease (CVD) [9]. Some studies indicate that body fat on hips and thighs is less detrimental to health than fat accumulating around the waist [10]. Metabolic and cardiovascular complications are closely associated with an increase in visceral fat for which waist circumference (WC) is an indicator [11].

Several studies have examined the predictive value of BMI and WC for hypertension, CVD and diabetes mellitus type 2. The Emerging Risk Factors Collaboration found in adults that BMI and WC, either alone or in combination, do not improve the prediction of CVD risk when additional information on systolic blood pressure, history of diabetes and lipids are available [12]. In contrast, Yusuf et al. [13] found in an international standardized case-control study of adults that waist- and hip circumference had a highly significant association with myocardial infarction.

Few studies in pediatric populations have reported contradictory findings for both measurements and their associations with comorbidities. An Australian study of adolescents by Denney-Wilson et al. [10] assessed the association between BMI, WC, risk factors for heart disease, type 2 diabetes and fatty liver disease. They found that WC is not a better predictor of metabolic risk than BMI. Results of a systematic review also found no evidence to support the assumption that WC is superior to BMI for the prediction of an adverse CVD risk profile, including blood pressure, in children [14]. However, Lee et al. [15]

reported in a small study with 167 youths that obesity-related health risk assessment can be improved by considering WC in addition to BMI percentiles. They concluded that WC should be included together with BMI in the evaluation of obesity in children to identify those at increased health risk. Recently, Bekkers et al. [16] reported that a high BMI and large WC were associated with higher blood pressure levels and adverse cholesterol concentrations.

The aim of this study was to investigate whether BMI, WC or their combination is a better predictor for hypertension and dyslipidemia in a large multicenter survey of obese youths. We will also assess whether BMI and WC have the same predictive value for boys and girls.

Methods

Based on the German guidelines for diagnosis and treatment of overweight children and adolescents (www.a-g-a.de), computer software was developed for standardized, prospective documentation of anthropometric and metabolic parameters in overweight children and adolescents (APV, www.a-p-v.de). Twice a year, participating centers (inpatient rehabilitation or outpatient), specialized in obesity care for children and adolescents, transmit anonymized data to the University of Ulm for central analysis. Data are checked for completeness and plausibility. Implausible data are reported back twice yearly to the centers for correction. The APV database is used for clinical research, quality assurance, benchmarking and numerous evaluations in order to improve treatment, rehabilitation and prevention of overweight and obesity.

As of November 2012, the APV database contained data on 81,819 patients from 189 centers (28 inpatient rehabilitation and 161 outpatient) in Germany, Austria and Switzerland. The inclusion criterion for this analysis was an age between 11 and 17.9 years. The restriction to this age range was chosen because in the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) survey [17] measurements for WC were documented in this age group only. In order to achieve ethnic homogeneity of the study population, patients with a migration background were excluded from this analysis [18]. Youths using anti-hypertensive or lipid-lowering medications were also excluded.

Age- and gender-specific percentiles for children and adolescents were used for BMI [19] and WC [17] based on KiGGS. KiGGS data was chosen since reference data for both BMI and WC measurements were available. WC was measured at the narrowest point below the ribs or halfway between the lowest ribs and the highest point of the iliac crest. Hypertension was also evaluated based on German KiGGS reference data [20]. Hypertension was diagnosed if either systolic or diastolic blood pressure was elevated above the 95th percentile for age and gender, at more than 50% of individual blood pressure measurements. Examination and anthropometric parameters are documented routinely in specialized obesity centers according to the standardized specifications of AGA (www.a-g-a.de). Dyslipidemia was defined as at least one abnormal value for cholesterol, high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL) or triglycerides,

Table 1. Classification of the cohort in weight categories based on BMI and WC according to the KiGGS percentiles

	<90th percentile	90–97th percentile	97–99.5th percentile	>99.5th percentile
BMI all	6.3/374	33.2/1,982	49.8/2,974	10.8/648
BMI boys	5.9/166	30.8/862	51.2/1,433	12.1/336
BMI girls	6.5/208	35.2/1,120	48.4/1,541	9.8/312
WC all	4.0/236	17.3/1,032	55.4/3,311	23.4/1,399
WC boys	3.7/102	17.6/493	52.1/1,458	26.6/744
WC girls	4.2/134	16.9/539	58.3/1,853	20.6/655

Values are given as %/n.

based on the guidelines of the American Heart Association [21]. Cutoff levels were total cholesterol >200 mg/dl, HDL <35 mg/dl, LDL >130 mg/dl and triglycerides >150 mg/dl.

Statistical Analysis

All analyses were performed using SAS version 9.3 statistical software (SAS Institute Inc., Cary, N.C., USA). Values of $p < 0.05$ were regarded as significant. Continuous variables are given as means $\pm$ SD, and group differences were analyzed using a Wilcoxon test. Binary variables are presented as percentages, and group differences were analyzed using χ^2 tests. Values of p were corrected for multiple comparisons using the Holm method [22]. Correlations between BMI-SDS, WC-SDS and hypertension or dyslipidemia were tested using Spearman's rank correlation coefficient.

A logistic regression analysis was conducted to establish whether BMI-SDS or WC-SDS (the independent variable) is more predictive for hypertension or dyslipidemia (the dependent variable). Results are reported as odds ratios (OR) and 95% CI based on maximum-likelihood estimation. The area under the curve (AUC) was used to assess the effectiveness for both measurements to predict comorbidities. An AUC of 0.5 means that the test is no better than mere chance; values >0.5 are more predictive.

To evaluate the increase in risk for hypertension and dyslipidemia with elevated BMI and WC, the children were divided into two groups each, i.e. BMI or WC <97th percentile or $\geq$ 97th percentile according to age and gender. Logistic regression models with least square means were computed to quantify adjusted rates of hypertension or dyslipidemia for nonobese and obese patients.

Results

Data on BMI, WC, blood pressure and lipids were available for 5,978 adolescents 11–17.9 years of age (average: 13.8 ± 1.8). There were fewer boys (46.8%) than girls (53.2%). The mean BMI-SDS was 2.0 ± 0.5 and the average WC-SDS was 2.2 ± 0.5 . Table 1 lists the weight categories for BMI and WC.

42.4% of the population had hypertension and 33.0% had one or more abnormal lipid value. Girls were more likely to have hypertension than boys ($p = 0.04$). Boys had a higher percentage of abnormal lipid levels ($p = 0.001$). 50.7% of the children had either hypertension or dyslipidemia. The characteristics of the population are presented in table 2.

Correlation between BMI-SDS and WC-SDS

BMI-SDS and WC-SDS correlated closely ($r = 0.74$; $p < 0.0001$). In the boys this correlation between BMI-SDS and WC-SDS was $r = 0.77$ ($p < 0.0001$), and in the girls it was $r = 0.71$ ($p < 0.0001$).

Descriptive characteristics of youths with blood pressure <97th percentile or $\geq$ 97th percentile as well as youths with and without dyslipidemia are presented in table 3.

Compared to nonobese (BMI <97th percentile) subjects, systolic blood pressure was increased by +6.3 mm Hg and diastolic blood pressure by +3.9 mm Hg in obese patients (BMI $\geq$ 97th percentile). For patients with a WC $\geq$ 97th percentile, increases of systolic blood pressure of +4.9 mm Hg and diastolic blood pressure of +2.6 mm Hg were registered. Compared to subjects with a WC <97th percentile, youths with a WC $\geq$ 97th percentile had higher cholesterol and triglyceride values, but lower HDL values. After stratifying by sex, girls with a BMI $\geq$ 97th percentile showed higher systolic blood pressure and LDL values compared to boys. Boys with a WC $\geq$ 97th percentile showed higher systolic blood pressure values compared to girls. The differences between the girls and boys are shown in table 4.

Both BMI-SDS and WC-SDS were significant predictors of hypertension and dyslipidemia. BMI-SDS turned out to be a better predictor (OR = 2.60) for hypertension than WC-SDS (OR = 1.85). This difference was similar for boys and girls. WC-SDS was a slightly better predictor (OR = 1.90) for dyslipidemia than BMI-SDS (OR = 1.86). The differences between the boys and girls are listed in table 5.

Based on logistic regression analysis, the AUC confirmed that BMI-SDS was a better predictor (AUC = 0.62) for hypertension than WC-SDS (AUC = 0.58; $p < 0.0001$). There were no differences between BMI-SDS (AUC = 0.58) and WC-SDS (AUC = 0.58; $p = 0.87$) for dyslipidemia. Combining the two measurements increased the prediction probability for both comorbidities only marginally, resulting in an AUC of 0.62 for hypertension and an AUC of 0.59 for dyslipidemia (fig. 1). For the prediction of hypertension, there was only a small difference between sexes (fig. 2).

Table 2. Characteristics of study population and p values for differences between boys and girls (adjusted for multiple comparisons)

	All (n = 5,978)		Boys (n = 2,797)		Girls (n = 3,181)		Difference between boys/girls p value
	mean	SD	mean	SD	mean	SD	
Age, years	13.9	1.8	13.7	1.7	14.0	1.8	<0.0001
Weight, kg	87.3	21.8	89.3	24.3	85.5	19.0	0.003
BMI, kg/m ²	31.8	5.8	31.6	5.8	31.9	5.7	0.04
BMI-SDS (KiGGS)	2.0	0.5	2.0	0.5	2.0	0.5	0.006
WC, cm	100.3	15.0	102.2	15.4	98.6	14.5	<0.0001
WC-SDS (KiGGS)	2.2	0.5	2.2	0.5	2.2	0.5	0.05
Height, cm	164.9	9.7	166.9	11.1	163.1	7.9	<0.0001
Height-SDS (KiGGS)	0.5	1.0	0.5	1.1	0.4	1.0	0.02
Systolic blood pressure, mm Hg	123.2	14.0	124.3	14.2	122.2	13.7	n.s.
Diastolic blood pressure, mm Hg	74.3	10.6	74.2	10.7	74.3	10.5	n.s.
Hypertension, %	42.4		41.4		43.2		n.s.
Elevated systolic blood pressure, %	32.4		31.1		33.2		n.s.
Elevated diastolic blood pressure, %	32.0		31.5		32.8		n.s.
Dyslipidemia, %	33.0		35.2		31.1		0.03
Cholesterol >200 mg/dl, %	11.5		12.4		10.8		n.s.
HDL <35 mg/dl, %	11.9		13.6		10.3		0.006
LDL >130 mg/dl, %	13.6		15.4		12.0		0.001
Triglycerides >150 mg/dl, %	16.0		15.8		16.1		n.s.

Table 3. Comparison between blood pressure <97th percentile and hypertension ≥97th percentile and children with and without dyslipidemia (mean ± SD)

	Blood pressure			Lipid measurements		
	normal (n = 3,674)	elevated (n = 2,304)	p value	normal (n = 4,005)	elevated (n = 1,973)	p value
Age, years	14.0±1.8	13.7±1.7	<0.0001	13.8±1.7	14.1±1.9	<0.001
Boys, %	47.0	46.0	n.s.	0.45	0.50	0.002
BMI-SDS	1.9±0.5	2.1±0.5	<0.0001	2.0±0.5	2.1±0.5	<0.0001
BMI, kg/m ²	31.0±5.4	33.0±6.2	<0.0001	31.2±5.5	32.8±6.1	<0.0001
WC-SDS	2.2±0.5	2.3±0.5	<0.0001	2.2±0.5	2.3±0.4	<0.0001
WC, cm	99.1±14.4	102.1±15.8	<0.0001	98.9±14.5	103.1±15.6	<0.0001
Systolic BP, mm Hg	116.3±9.0	134.3±13.4	<0.0001	122.4±13.6	124.9±14.5	<0.0001
Diastolic BP, mm Hg	69.5±7.5	81.9±10.4	<0.0001	73.7±10.3	75.5±11.0	<0.0001
Cholesterol, mg/dl	158.9±39.6	164.6±44.4	<0.0001	151.9±25.2	179.9±58.6	<0.0001
HDL, mg/dl	46.8±14.8	46.5±17.4	n.s.	48.7±11.9	42.6±21.2	<0.0001
LDL, mg/dl	109.1±123.1	107.6±99.2	<0.0005	88.5±21.0	148.3±189.4	<0.0001
Triglyceride, mg/dl	102.7±83.6	111.3±86.5	<0.0001	78.4±27.5	162.3±124.7	<0.0001

BP = Blood pressure.

Discussion

In the present study we compared BMI and WC with respect to their association with cardiovascular risk factors. Our results demonstrated that both BMI-SDS and WC-SDS were significant predictors of hypertension and dyslipidemia. We could detect that BMI-SDS

is a better predictor for hypertension compared to WC-SDS. After stratifying by sex, BMI-SDS had a closer relation with hypertension in girls. On the other hand, WC-SDS showed a closer association with dyslipidemia in boys. Combining BMI and WC had only a small additional benefit for the prediction of either comorbidity.

Table 4. Comparison of systolic/diastolic blood pressure and lipid profiles between non-obese patients (BMI/WC <97th percentile) and obese (BMI/WC ≥97th percentile) patients adjusted for age, sex and height

	All (≥97th percentile)		Boys (≥97th percentile)		Girls (≥97th percentile)	
<i>BMI</i>						
Patients, n	2,998		1,411		1,587	
Systolic BP, mm Hg	+6.0	p < 0.0001	+5.4	p < 0.0001	+6.4	p < 0.0001
Diastolic BP, mm Hg	+3.9	p < 0.0001	+3.9	p < 0.0001	+3.8	p < 0.0001
Cholesterol, mg/dl	-0.2	p = 0.83	+0.7	p = 0.69	-0.8	p = 0.55
HDL, mg/dl	-4.0	p < 0.0001	-3.8	p < 0.0001	+4.0	p < 0.0001
LDL, mg/dl	-1.4	p = 0.67	-2.2	p = 0.68	-0.8	p = 0.60
Triglyceride, mg/dl	+15.2	p < 0.0001	+15.6	p < 0.0001	+14.8	p < 0.0001
<i>WC</i>						
Patients, n	4,710		2,202		2,508	
Systolic BP, mm Hg	+4.3	p < 0.0001	+4.8	p < 0.0001	+3.8	p < 0.0001
Diastolic BP, mm Hg	+2.4	p < 0.0001	+2.5	p < 0.0001	+2.2	p < 0.0001
Cholesterol, mg/dl	+2.5	p = 0.06	+5.6	p = 0.007	+0.1	p = 0.94
HDL, mg/dl	-5.0	p < 0.0001	-4.3	p < 0.0001	-5.4	p < 0.0001
LDL, mg/dl	-1.7	p = 0.67	-2.1	p = 0.74	-1.2	p = 0.78
Triglyceride, mg/dl	+17.5	p < 0.0001	+20.8	p < 0.0001	14.6	p < 0.0001

BP = Blood pressure.

Table 5. Effect of BMI-SDS and WC-SDS in logistic regression as predictors for hypertension and dyslipidemia

	All		Boys		Girls		p value
	OR	95% CI	OR	95% CI	OR	95% CI	
Elevated systolic BP							
BMI-SDS	2.74	2.40–3.13	2.54	2.10–3.09	2.92	2.44–3.52	0.001
WC-SDS	2.02	1.76–2.31	2.14	1.76–2.60	1.91	1.59–2.31	0.003
Elevated diastolic BP							
BMI-SDS	2.36	2.07–2.69	2.26	1.87–2.74	2.45	2.04–2.94	0.010
WC-SDS	1.66	1.46–1.90	1.84	1.53–2.23	1.51	1.26–1.81	0.026
Low HDL							
BMI-SDS	3.57	2.97–4.30	3.84	2.30–4.97	3.27	2.50–4.30	0.002
WC-SDS	4.29	3.48–5.32	5.10	3.85–6.81	3.42	2.50–4.72	0.005
Elevated triglyceride							
BMI-SDS	1.80	1.54–2.10	2.24	1.79–2.81	1.48	1.20–1.83	0.42
WC-SDS	1.57	1.34–1.84	1.96	1.56–2.48	1.27	1.02–1.58	0.49

p value differences between boys and girls. BP = Blood pressure.

These results concur with previous findings from the APV study with 26,008 overweight and obese children and adolescents. The study found that the degree of overweight is strongly associated with decreased HDL-cholesterol. Obesity leads to increased triglycerides, high blood pressure and impaired glucose metabolism [8]. Similar findings were reported by the Kiel Obesity Prevention

Study. The authors compared associations of BMI, triiceps skinfold, WC and percent fat mass with blood pressure and blood lipids in children and adolescents. They concluded that both BMI and WC are appropriate to estimate CVD risk [23]. In contrast, Meng et al. [24], who examined 1,452 school-age children between 7 and 17 years in Beijing found that WC showed a significantly

Fig. 1. AUC with SD for BMI-SDS, WC-SDS and the combination of BMI-SDS and WC-SDS as predictors for hypertension and dyslipidemia.

Fig. 2. AUC with SD for BMI-SDS, WC-SDS and the combination of BMI-SDS and WC-SDS as predictors for hypertension and dyslipidemia separately for boys and girls.

stronger relationship with dyslipidemia and fatty liver than BMI.

WC reflects abdominal fat and visceral tissue [25, 26], which seems to be a good predictor of metabolic syndrome in children [27]. Multiple screening tools are available to identify the body fat distribution in children. Computed tomography (CT), magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DXA) are accurate techniques for assessing central fat distribution [28]. However, their high cost and the radiation exposure (CT, DXA) make them unsuitable for children and large-scale studies [26]. Bioelectrical impedance analysis (BIA) is a common method for rapid and noninvasive quantification of body fat. Variations in body fat

distribution, including the relationship between subcutaneous and intra-abdominal fat, can be assessed. Simple anthropometric measurements such as BMI, waist-to-hip ratio and WC are cheaper and less time consuming. Browning et al. [29] compared in a cross-sectional study the relationship between visceral and total abdominal adipose tissue measurements obtained with MRI, BMI, WC, BIA and DXA. They found that men have more visceral abdominal fat than women. None of the simpler techniques like BMI or WC measurements showed strong correlations with visceral abdominal fat measured by MRI. Nevertheless, measurements of WC, BIA or DXA showed similar and strong correlations with total abdominal tissue and may be useful in large-scale surveys. Reine-

hr and Wunsch [30] detected in their study with 29 obese children that WC, ultrasonographic measurement of intra-abdominal fat mass and BMI-SDS are significantly related to cardiovascular risk factors.

Another anthropometric method to determine intra-abdominal fat in adults is the direct measurement of the abdominal diameter [31]. Sagittal abdominal diameter is a solid anthropometric measurement and can be a useful alternative to predict visceral fat in epidemiological studies in adults [31, 32], but there are only few publications available concerning children [33]. In a cross-sectional study with 964 children (aged 5–17 years), sagittal abdominal diameter was a reliable indicator of visceral obesity in Arab children [33]. A study of 144 Swedish children revealed a positive correlation between BMI and sagittal abdominal diameter, which was as strong as the correlation between BMI and WC [34].

In the present study we observed in boys and girls that obesity defined by either a BMI ≥ 97 th or a WC ≥ 97 th percentile was associated with hypertension and dyslipidemia. Similar results have also been reported by others [35]. There were differences in the strength of the relationship for individual risk factors. A WC ≥ 97 th percentile was associated with higher cholesterol, triglyceride and lower HDL values, while a BMI ≥ 97 th percentile was associated with higher values of systolic and diastolic blood pressure. In boys, a BMI ≥ 97 th percentile was associated with high systolic blood pressure and high LDL values, while a WC ≥ 97 th percentile was associated more strongly with high cholesterol values. In girls, a BMI ≥ 97 th percentile was associated with increased systolic and diastolic blood pressure, cholesterol, triglyceride and lower HDL values compared to a WC ≥ 97 th percentile. This suggests that adolescent girls have more total fat mass than boys. Adolescent boys may have more visceral abdominal fat than total abdominal adipose tissue. Visceral fat is more closely correlated with metabolic risk than total fat [36]. These results confirm several studies which reported that sex differences in body fat distribution are amplified with maturation, especially from late puberty to early adulthood [36, 37]. They also report that girls have less waist fat and more hip fat than boys. This suggests that WC measurement may be more useful in boys than in girls [38].

Conclusion

Youths with high BMI-SDS or high WC-SDS were more likely to have abnormal lipid profiles and elevated systolic and diastolic blood pressure than normal-

weight youths. These findings demonstrate that BMI-SDS and WC-SDS are useful anthropometric measurements to identify children with higher cardiovascular risk factors. Both of the anthropometric measurements may be useful in large-scale surveys of youths as they are less time consuming, less invasive and less expensive than other screening tools (CT, DXA or BIA), and may be helpful to identify children who are at risk for CVD. However, there is no clear advantage of WC or the combination of BMI plus WC over BMI measurements alone.

Limitations

Limitations of the present study might be that elevated blood pressure could be white coat hypertension and that triglyceride measurements may not always be fasting in outpatients. This study has a focus on the at-risk group of overweight/obese youths. Different results may be found in primarily normal-weight subjects. In this analysis, the Tanner stage was not documented in all children and adolescents, so subgroup analysis could not be performed. If this had been done, perhaps we would have come to another picture. Due to privacy restrictions it could be that there is a very small percentage of different ethnicities included in the study. In the European center we included only Caucasian patients.

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