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Original Article

BMI or BIA: Is Body Mass Index or Body Fat Mass a Better Predictor of Cardiovascular Risk in Overweight or Obese Children and Adolescents?

A German/Austrian/Swiss Multicenter APV Analysis of 3,327 Children and Adolescents

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Key Words

Bioelectrical impedance analysis · Body fat · Body mass index · Cardiovascular risk · Hypertension · Dyslipidemia · Children · Adolescent

Abstract

Background: Body fat (BF) percentiles for German children and adolescents have recently been published. This study aims to evaluate the association between bioelectrical impedance analysis (BIA)-derived BF and cardiovascular risk factors and to investigate whether BF is better suited than BMI in children and adolescents. **Methods:** Data of 3,327 children and adolescents (BMI > 90th percentile) were included. Spearman's correlation and receiver operating characteristics (ROCs) were applied determining the associations between BMI or BF and cardiovascular risk factors (hypertension, dyslipidemia, elevated liver enzymes, abnormal carbohydrate metabolism). Area under the curve (AUC) was calculated to predict cardiovascular risk factors. **Results:** A significant association between both obesity indices and hypertension was present (all $p < 0.0001$), but the correlation with BMI was stronger ($r = 0.22$) compared to BF

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($r = 0.13$). There were no differences between BMI and BF regarding their correlation with other cardiovascular risk factors. BF significantly predicted hypertension (AUC = 0.61), decreased HDL-cholesterol (AUC = 0.58), elevated LDL-cholesterol (AUC = 0.59), elevated liver enzymes (AUC = 0.61) (all $p < 0.0001$), and elevated triglycerides (AUC = 0.57, $p < 0.05$), but not abnormal carbohydrate metabolism (AUC = 0.54, $p = 0.15$). For the prediction of cardiovascular risk factors, no significant differences between BMI and BF were observed. **Conclusion:** BIA-derived BF was not superior to BMI to predict cardiovascular risk factors in overweight or obese children and adolescents.

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Introduction

Obesity, defined as excessive fat accumulation, has a significant impact on the occurrence of cardiovascular disease (CVD). There is evidence that obesity is associated with other CVD risk factors like hypertension, dyslipidemia, insulin resistance, or increased liver enzymes [1–3]. Total body fat mass (BF) as well as the body fat distribution (especially visceral adipose tissue) contribute to this association [4, 5]. There are several obesity indices to estimate the CVD risk. The most common method is calculating the BMI (weight/height²) [6]. However, the BMI is only a measure of weight relative to height and does not provide information about BF or body fat distribution [7]. Due to this limitations, it is discussed whether other anthropometric measurements should be considered. An alternative is using the waist circumference (WC), a good surrogate of visceral obesity [7]. However, findings from recently published studies indicate no major benefits compared to BMI standard deviation score (SDS) [8, 9]. Moreover, a systematic review by Browning et al. [10] suggested that waist-to-height-ratio (WHtR) with a cut-off of 0.5 might be a good predictor of CVD risk factors. Another possibility is to determine BF for example by bioelectrical impedance analysis (BIA) [11]. In children and adolescents, sex- and age-specific percentiles are commonly used for anthropometric measurements. The first BF percentiles for German children have recently been published [12]. Therefore, the aim of this study is to evaluate the association between BIA-derived BF and CVD risk factors as well as the comparison with BMI in overweight or obese children and adolescents.

Material and Methods

Patients and Data Documentation

Patients were selected from the Adiposity Patients Registry (APV), a database for standardized, prospective documentation of anthropometric and metabolic parameters in overweight or obese children and adolescents. APV is currently used by centers specialized in obesity care for children and adolescents from Germany, Austria, and Switzerland. Twice a year, data are anonymously transmitted from participating health care facilities to Ulm, Germany, and aggregated into a cumulative database for clinical research and quality assurance [9]. Implausible and inconsistent data are reported back to the centers for verification or correction. The APV initiative is authorized by the Ethics Committee of the University of Ulm, Germany, and data collection by the local review boards.

In January 2014, 86,341 patients from 199 centers were registered in APV. Patients with an age between 3 and <16 years were included. Patients without BIA measurement were excluded, leaving 3,327 subjects from 22 centers (fig. 1).

Anthropometric Measurements and Biochemical Parameters

BMI was calculated as the ratio of body weight in kilograms and squared body height in meters (kg/m²). BMI was expressed as SDS, using data from a nationally representative sample of German adolescents

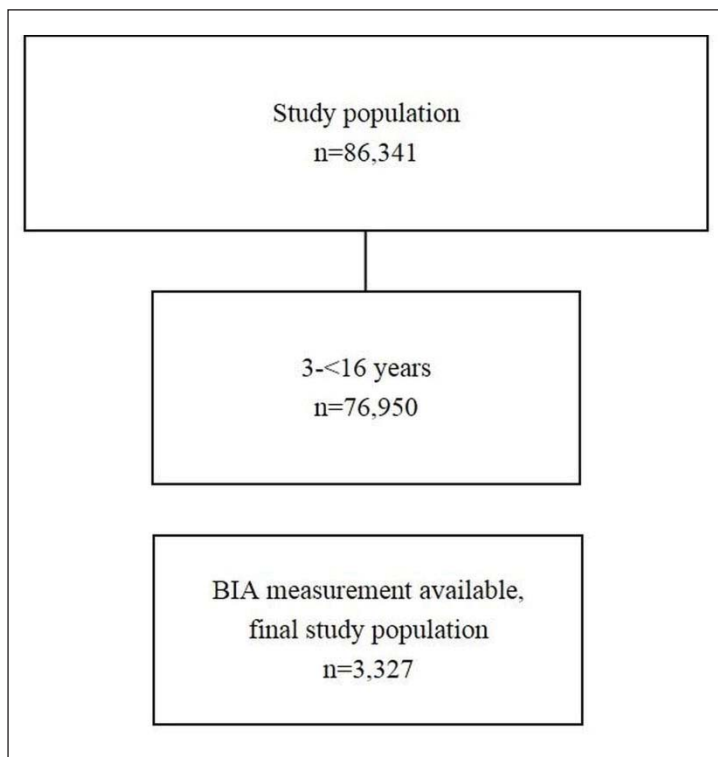


Fig. 1. Selection of study population.

(German Health Interview and Examination Survey for Children and Adolescents (KiGGS)) as reference parameters [13]. The LMS method was used for modelling sex- and age-specific percentile curves. BF was determined via BIA. In each APV center, BIA measurements were performed by trained staff according to standardized procedures (in the morning, in supine position). Measurements were conducted on the dominant side of the body (in most cases the right side). Two electrodes were placed on the dorsal surface of the hand and the foot. An overview of the different BIA devices applied by the collaborating centers is given in table 1. Studies reveal that estimating BF by BIA is a suitable method in lean subjects. In obese subjects, BF seems to be underestimated [14]. One reason might be that BIA algorithms were developed in normal-weight subjects and transferred to obese subjects without further validation of the equation [14]. Since our study sample is characterized by overweight or obese patients, we applied the equation of Wabitsch et al. [15], because the reference population which refers to this algorithm was overweight or obese, too. The following BIA algorithm was used (height in cm, weight in kg, age in years):

$$\text{Fat free mass (FFM)} = \frac{0.35 \times \text{height}^2}{r} + \frac{0.27 \times \text{age}}{365.24} + \frac{(0.14 \times \text{weight}) - 0.12}{0.732} \quad (1).$$

BF was also expressed as SDS value. Reference parameters are premised on three different German surveys (Kiel Obesity Prevention Study (KOPS), KINDERLEICHT-REGIONS, and Examination of Jena Schoolchildren) [12].

To determine whether CVD risk factors of the study population differ according to high body fat or high lean body mass, subjects were stratified in three groups. Therefore, the difference between BMI SDS and BF SDS was calculated. Groups were classified according to tertiles (<-0.415, -0.415 to 0.500 and >0.500).

Furthermore, it was investigated whether there is an additional value of a combined use of BMI SDS and BIA-derived BF SDS in the prediction of CVD risk factors in children and adolescents.

The 95th age- and sex-specific percentile of the KiGGS study was used to define hypertension, elevated LDL-cholesterol as well as elevated triglycerides [16, 17]. The 5th percentile was used to define decreased levels of HDL-cholesterol [17]. Elevated liver enzymes were characterized as at least one increased value for GOT, GPT or γ GT (>50 U/l) [18] and abnormal carbohydrate metabolism as fasting glucose level > 110 mg/dl or 2-hour glucose level > 140 mg/dl [19].

Table 1. Overview of BIA-devices applied by the collaborating centers

Manufacturer	Name of the device	Type of measurement
Data input	B.I.A. 2000-M	multifrequent, tetrapolar
Data input	Nutriguard MS	multifrequent, tetrapolar
Data-input	Nutriguard M	multifrequent, tetrapolar
Data input	Nutribox	monofrequent, tetrapolar
Ego fit Gesundheitsberatung	BIA Serie 4	monofrequent, tetrapolar

Statistical Analysis

Descriptive statistics were implemented for the whole study population and separately for boys and girls. Baseline characteristics are presented as median with lower (Q1) and upper quartile (Q3) or as percentage. Gender differences in the prevalence of CVD risk factors were examined using chi-square test. P value for trend was calculated to determine whether prevalence of CVD risk factors increases with fat mass. Spearman's correlation coefficients were calculated for the associations between BMI SDS and BF SDS as well as between BMI SDS or BF SDS and hypertension, decreased HDL-cholesterol, elevated values of LDL-cholesterol, triglycerides and liver enzymes and abnormal carbohydrate metabolism. Furthermore, receiver operating characteristics (ROCs), based on logistic regression, were calculated. Logistic regression models were adjusted for age class (3 to <5, 5 to <7, 7 to <9, 9 to <11, 11 to <13, 13 to <15, 15 to <16 years), sex as well as for the interaction between age and sex. Area under the curves (AUCs) were compared to investigate whether BF SDS is more suitable for the prediction of CVD risk factors than BMI SDS. Therefore, chi-square test was applied.

A two-sided p value < 0.05 was considered significant. All statistical analyses were implemented with SAS 9.3 (Statistical Analysis Software, SAS Institute, Cary, NC, USA).

Results

Study Population

Data on BMI SDS and BIA-derived BF SDS are available for 3,327 children and adolescents (1,603 boys; 1,724 girls) between 7 and 16 years of age. The prevalence of hypertension in the whole population was 45.85%. 22.67% of the population had decreased HDL-cholesterol, 11.72% elevated LDL-cholesterol, 4.03% elevated triglycerides, 4.70% abnormal carbohydrate metabolism, and 10.35% elevated liver enzymes. Differences between boys and girls were present with regard to elevated liver enzymes (boys 13.52%, girls 7.12%; $p < 0.0001$) and elevated LDL-cholesterol (boys 14.66%, girls 8.75%; $p < 0.0001$). Baseline characteristics (table 2) did not differ between sexes.

Spearman's Correlation Analysis

Spearman's correlation showed a significant association between BMI SDS and BF SDS ($r = 0.58$; $p < 0.0001$). There were no gender-specific differences in the correlation (girls $r = 0.59$; boys $r = 0.58$; both $p < 0.0001$). Associations between both anthropometric measurements and hypertension were significant ($p < 0.0001$), but the correlation with BMI SDS was stronger ($r = 0.22$) compared to BF SDS ($r = 0.13$). There were no further differences between measurements in regard to their correlation with other CVD risk factors. The associations with decreased HDL-cholesterol and with elevated liver enzymes were also significant (all $p < 0.0001$). However, no significant relationships between BMI SDS or BF SDS and elevated LDL-cholesterol, elevated triglycerides and abnormal carbohydrate metabolism were observed (all $p > 0.05$). For boys, the correlation between hypertension and BMI SDS ($r = 0.25$, $p < 0.0001$) was stronger compared to BF SDS ($r = 0.07$, $p < 0.01$). The association between the remaining CVD risk factors and anthropometric measurements did not differ.

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Table 2. Baseline characteristics for the whole study population^a and for boys and girls separately

	Whole study population		Boys		Girls	
	n	median (Q1; Q3)	n	median (Q1; Q3)	n	median (Q1; Q3)
Age, years	3,327	12.47 (10.65; 14.05)	1,603	12.43 (10.72; 13.92)	1,724	12.54 (10.60; 14.15)
Weight, kg	3,327	73.90 (58.80; 90.20)	1,603	73.55 (59.10; 90.90)	1,724	74.00 (58.30; 89.55)
Height, cm	3,327	159.00 (148.00; 167.00)	1,603	159.00 (149.00; 169.00)	1,724	158.40 (148.00; 165.00)
BMI, kg/m ²	3,327	29.05 (26.01; 32.98)	1,603	28.99 (26.01; 32.62)	1,724	29.11 (26.02; 33.27)
BMI SDS	3,327	2.03 (1.72; 2.35)	1,603	2.04 (1.75; 2.34)	1,724	2.01 (1.69; 2.35)
BIA-derived body fat, kg	3,327	38.15 (29.95; 48.35)	1,603	37.57 (30.03; 47.88)	1,724	38.79 (29.86; 48.86)
Body fat SDS	3,327	1.87 (1.05; 2.77)	1,603	1.88 (1.18; 2.65)	1,724	1.85 (0.93; 2.98)
Blood pressure, mm Hg						
Systolic	2,436	119.00 (110.00; 125.00)	1,237	120.00 (110.00; 125.59)	1,199	118.00 (110.00; 125.00)
Diastolic	2,435	71.00 (66.00; 80.00)	1,237	72.00 (67.00; 80.00)	1,198	71.00 (65.00; 80.00)
Total cholesterol, mg/dl	2,278	162.41 (142.00; 185.00)	1,149	163.00 (142.00; 186.00)	1,129	161.00 (142.69; 183.00)
LDL-cholesterol, mg/dl	2,209	98.00 (80.05; 118.00)	1,112	98.00 (81.00; 119.44)	1,097	98.00 (79.66; 116.01)
HDL-cholesterol, mg/dl	2,232	45.00 (39.00; 54.00)	1,127	45.00 (38.67; 54.00)	1,105	46.00 (39.00; 53.00)
Triglycerides, mg/dl	2,258	87.00 (63.00; 121.35)	1,133	87.00 (62.00; 124.00)	1,125	87.00 (66.00; 118.00)
Fasting glucose, mg/dl	1,995	84.00 (76.00; 91.80)	1,027	84.60 (77.00; 92.70)	968	82.80 (75.00; 90.00)
2-hour plasma glucose, mg/dl	1,103	98.28 (85.00; 113.00)	595	98.00 (86.00; 113.00)	508	99.00 (83.50; 113.40)
GOT, U/l	1,471	25.20 (20.50; 31.00)	747	27.00 (22.00; 32.00)	724	24.00 (19.00; 30.00)
GPT, U/l	1,507	22.20 (17.40; 32.00)	762	25.00 (19.00; 36.00)	747	20.40 (16.00; 27.00)
γGT, U/l	1,360	17.40 (14.00; 22.00)	682	19.00 (16.00; 24.00)	678	16.00 (13.00; 20.00)

^an = 3,327; 48.18% male.

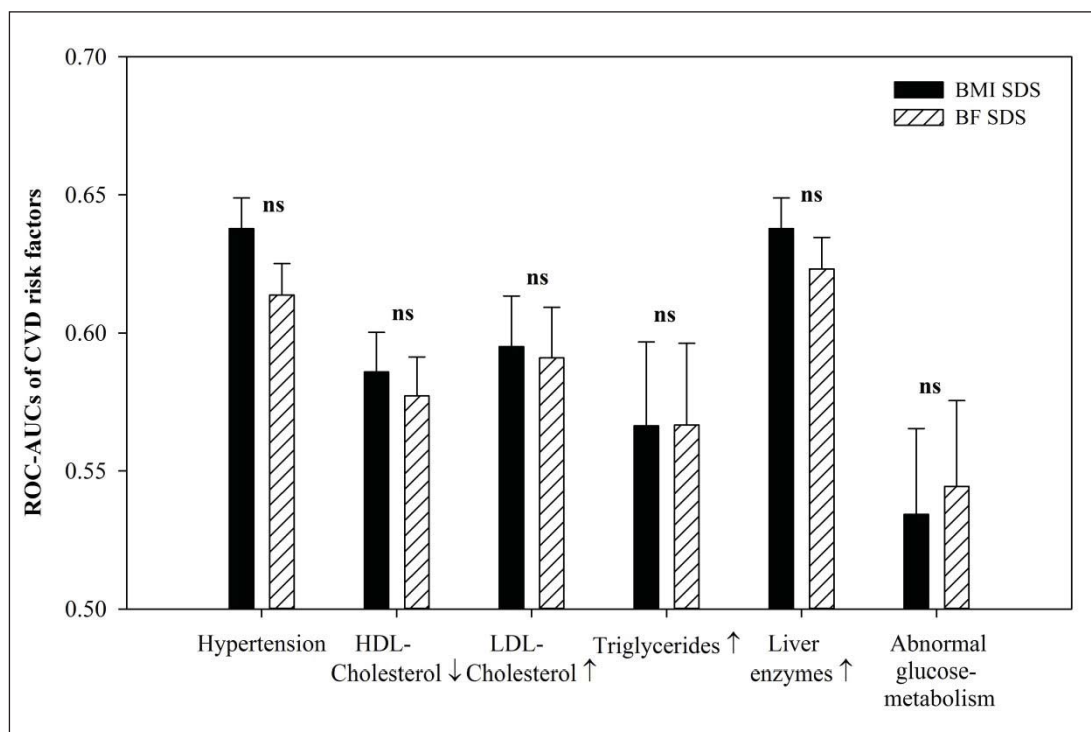


Fig. 2. Comparison of ROC-AUCs for BMI SDS and BF SDS to predict CVD risk factors.

Logistic Regression Analysis

Based on logistic regression models adjusted for age, sex and the interaction between age and sex, for BF SDS the AUCs of ROC (ROC-AUCs) demonstrated a significant prediction of hypertension (AUC = 0.61), decreased HDL-cholesterol (AUC = 0.58), elevated LDL-cholesterol (AUC = 0.59), elevated liver enzymes (AUC = 0.61) (all $p < 0.0001$), and elevated triglycerides (AUC = 0.57; $p < 0.05$) for the whole study population. No significant prediction of abnormal carbohydrate metabolism was found (AUC = 0.54; $p = 0.15$). Gender-specific analyses revealed no significant prediction of elevated LDL-cholesterol for boys and no significant prediction of elevated triglycerides for both sexes (all $p > 0.05$).

Comparison of Anthropometric Measurements

The comparison of ROC-AUCs indicated no differences between BMI SDS and BF SDS to predict CVD risk factors (all comparisons $p > 0.05$) (fig. 2). Even the comparison of ROC-AUCs between BMI SDS and the combined use of both anthropometric measurements provided no significant differences (all comparison $p > 0.05$). This applied to the whole study population as well as to boys and girls, separately.

Association between BF and CVD Risk Factors

The prevalence of CVD risk factors according to high body fat or high lean body mass is demonstrated in table 3. A significant trend for increasing prevalence of hypertension, decreased HDL-cholesterol, and elevated liver enzymes in subjects with high body fat was present ($p < 0.01$).

Table 3. CVD risk factors stratified by high body fat or high lean body mass, prevalence was adjusted for age, sex and the interaction between age and sex

	BMI SDS to BF SDS						p-value (trend)
	<-0.415		-0.415 to 0.500		>0.500		
	n	%	n	%	n	%	
Hypertension	843	51.62	821	44.59	772	41.22	0.0090
Reduced HDL-cholesterol	799	28.71	741	22.76	692	16.83	0.0023
Elevated LDL-cholesterol	789	11.98	735	9.87	685	11.07	0.6129
Elevated triglycerides	803	3.24	753	3.80	702	4.49	0.4325
Abnormal carbohydrate metabolism	678	5.29	691	4.39	630	3.78	0.4208
Elevated liver enzymes	406	15.76	535	10.66	586	5.01	0.0013

Discussion

Due to several limitations of BMI [7, 20], we hypothesized that BIA-derived BF SDS is a more suitable obesity index to predict CVD risk in overweight or obese children and adolescents compared to BMI SDS. However, the comparison of both measurements indicated no superiority. Overall, the associations between obesity indices and CVD risk factors were rather weak. There was no significant correlation between BMI SDS or BF SDS with elevated LDL-cholesterol or elevated triglycerides. The absence of a significant correlation for elevated LDL-cholesterol is in line with other studies, whereas for elevated triglycerides it is not [3, 21]. In contrast to previous studies, no association between BMI SDS or BF SDS and abnormal carbohydrate metabolism was observed. A recently published study from Germany depicted that an increasing BMI SDS results in an increasing risk of impaired fasting glucose. They also pointed out that there was a correlation with age. The highest risk was shown for German children between 9 and <13 years of age [22].

Possibly, our findings can be explained by a metabolically healthy obese phenotype. Studies revealed that up to 30% of obese children and adolescents do not have any or just minor CVD risk factors and can therefore be defined as metabolically healthy [23]. The comparison of metabolically healthy to metabolically unhealthy obese subjects implied that the amount of total BF might be less detrimental than the accumulation of ectopic fat (fat infiltration in liver, pancreas, or skeletal muscle) with regard to CVD risk. Moreover, a better cardiorespiratory fitness was considered to be associated with metabolically healthy obese subjects [24]. However, our data do not provide information on fat distribution or cardiorespiratory fitness to confirm this assumption.

Studies focused on the prediction of CVD risk factors in children and adolescents by BIA-derived BF appear to be very scarce. Hence, a comparison of our results with current literature is rather difficult. Although data indicated that determining BF by BIA correlates with CVD risk factors [24], there seems to be no evidence whether BIA-derived BF is better suited to predict CVD risk factors in children and adolescents compared to BMI. In KOPS, the associations of BMI, triceps skinfold, WC, or calculated %BF by BIA with CVD risk factors (systolic and diastolic blood pressure, HDL-cholesterol, LDL-cholesterol, total cholesterol, triglycerides) were compared in predominantly normal-weight children and adolescents. Analysis was stratified by age and sex. Overall, %BF was correlated slightly weaker with CVD risk factors than BMI and is thus in line with our findings. These results were present for both sexes and for all age groups. For example, in 9- to 11-year-old boys, BMI was stronger correlated with elevated blood pressure (%BF:BP_{sys} r = 0.25, %BF:BP_{dias} r = 0.07; BMI:BP_{sys} r =

0.33, BMI:BP_{dias} $r = 0.12$), triglycerides ($r_{\%BF} = 0.06$; $r_{BMI} = 0.09$) and HDL-cholesterol ($r_{\%BF} = 0.11$; $r_{BMI} = 0.15$) compared to %BF [21]. In adults, there are studies suggesting that BIA-derived BF is not superior to calculated BMI regarding the prediction of CVD risk factors [25–27] as well as those indicating superiority [28, 29].

BIA-derived BF has been criticized due to elusive calculation methods and inconsistent results if applying different algorithms. Körner et al. [30] indicated that there are substantial discrepancies (up to 10%) in the estimation of %BF depending on the algorithm used. Similar findings were reported by Mast et al. [31]. For example, in 5-year-old boys, %BF varied between 13.8% and 31.4% according to the algorithm applied. BIA-derived BF can be biased by various factors like differences between study and reference population, skin temperature, skin blood flow, or nutritional status [14, 30–32].

Another possibility estimating BF is using dual-energy x-ray absorptiometry (DXA). In a study of Shen et al. [33], DXA-estimated BF, BMI, and WC were compared regarding the prediction of CVD risk in predominantly overweight white and African-American adults. In white men and women, BMI was stronger correlated with HDL-cholesterol ($p < 0.05$), triglycerides, serum glucose, systolic and diastolic blood pressure (all $p > 0.05$) than %BF. Except for HDL-cholesterol, the differences between BMI and %BF did not reach statistical significance [33]. Although there are also studies in adult subjects which revealed a superiority of determining BF by DXA [34], due to the radiation exposure the use of DXA in children and adolescents is prohibited in Germany. Beside further methods appearing rather complex (e.g. hydrodensitometry weighing, potassium-40 content, computed tomography, or magnetic resonance imaging), there are also less extensive and more feasible screening tools like skinfold measurements (e.g. using prediction equation by Slaughter et al. [35]), WC, WHtR and waist-to-hip ratio to determine BF. In solely pediatric populations, meta-analyses or reviews are lacking. The systematic review of Browning et al. [10] included studies of adults ($n = 65$) as well as of children and adolescents ($n = 13$). The authors supposed that WHtR is a better predictor of CVD risk compared to WC or BMI in children and adolescents [10]. Though, there are also current studies in overweight or obese pediatric subjects which indicated no or just minor benefits of WHtR or WC [8, 9].

Although determining BF by BIA seems to have no or just minor benefits to predict CVD risk factors at baseline in children and adolescents compared to BMI, advantages in other fields of prevention or therapy cannot be ruled out. For example, a more precise statement with regard to the actual loss of body fat might be better suited to motivate and to increase the patient's compliance to continue weight loss programs compared to a less meaningful BMI value. This in turn might decrease the CVD risk. Prospective studies are needed to examine this assumption.

Strengths of our study are the large number of patients and the multicentric design. The APV database also provides detailed information on patient characteristics that allow careful adjustment for potential confounders. However, due to the multicenter nature of data collection, variability in the measurements of body height and weight (and therefore BMI) as well as of biochemical parameters may appear despite standardized procedures. There is also no guarantee that triglycerides were recorded under fasting conditions. It was advised that BF percentiles should not be used with other BIA devices or other algorithms to calculate BF [12]. However, in our study, at least 5 different BIA devices (4 from the same manufacturer) were applied (table 1). The BIA algorithm which refers to the BF percentiles was developed in predominantly normal-weight children and adolescents (prevalence of overweight/obesity: $<10\%$) [12]. As our study was conducted in high-risk overweight or obese subjects, we decided to use a BF formula specifically developed for obese children [15].

Conclusion

BMI SDS and BF SDS are comparable with regard to their correlation and prediction of CVD risk factors in overweight or obese children and adolescents. The combined use of these obesity indices did not provide an additive value. Whether BIA-derived BF might have benefits in other fields of preventing or treating overweight or obesity cannot be excluded.

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Disclosure Statement

The authors report no conflicts of interest.

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