



PAPER

Parameters of childhood obesity and their relationship to cardiovascular risk factors in healthy prepubescent children

HC Geiß¹, KG Parhofer^{1*} and P Schwandt¹

¹Ludwig-Maximilians-University Munich, Klinikum Grosshadern, Medical Department II, Munich, Germany

OBJECTIVE: To investigate which of the currently applied parameters to assess childhood overweight best predict cardiovascular risk factors.

DESIGN: Cross-sectional study comparing five different methods to define overweight with respect to their power to predict cardiovascular risk factors.

SUBJECTS: A total of 838 healthy children from the Prevention-Education-Program (Nuremberg, Germany; age 4–9y, 405 boys, 433 girls).

MEASUREMENTS: Obesity parameters—body mass index (BMI), ponderal index (PI), the sum of triceps and subscapular skinfold thickness (SFT), percentage body fat (%BF) using SFT and two different regression formulas (Slaughter, %BF-SL; Dezenberg, %BF-DZ). Overweight defined by the 90th age- and sex-specific percentile of each obesity parameter. Comparison of LDL- and HDL-cholesterol, apolipoprotein-B (apo-B), triglycerides (TG), fibrinogen and blood pressure values (SBP/DBP) between normal-weight and overweight children.

RESULTS: When overweight is defined by BMI or PI, all cardiovascular risk factors are significantly ($P < 0.01$) different between overweight and normal-weight children (BMI: TG + 20.5%, HDL-chol. – 8.6%, LDL-chol. + 9.6%, apo-B + 6.8%, SBP + 7.4%, DBP + 8.6%, fibrinogen + 13.2%; PI: TG + 24.3%, HDL-chol. – 6.1%, LDL-chol. + 9.0%, apo-B + 7.4%, SBP + 5.9%, DBP + 6.7%, fibrinogen + 13.9%), while SFT, %BF-SL and %BF-DZ did not predict all cardiovascular risk factors. A sex-specific analysis showed that in girls BMI and PI both predict cardiovascular risk factors, while in boys this is only valid for BMI.

CONCLUSION: In prepubescent children, height-to-weight indices such as BMI or PI better predict cardiovascular risk factors than obesity parameters using skinfold measurement. The BMI may be superior to the PI as the association between BMI and cardiovascular risk factors is less affected by gender.

International Journal of Obesity (2001) 25, 830–837

Keywords: childhood obesity; children; overweight; obesity parameters; cardiovascular risk factors; BMI

Introduction

Overweight and obesity are associated with increased morbidity and mortality.^{1,2} Different obesity parameters are currently used to differentiate between normal-weight, overweight and obese subjects. As cardiovascular diseases are major complications of overweight and obesity,^{1–3} an ideal obesity parameter should predict cardiovascular risk to facilitate further screening and treatment decisions.

In adults, the body mass index (BMI) represents a good parameter to describe overweight and obesity, as it estimates body fat by simple means¹ and predicts cardiovascular risk and mortality.³ In children it is not known which of the available obesity parameters can best predict the increased risk for obesity-related diseases and mortality.

An expert committee recommended the use of the age- and sex- adapted BMI to assess childhood overweight and obesity,^{4,5} but a direct comparison to other commonly used obesity parameters such as the ponderal index (PI,^{6–9}) percentage body fat (%BF^{10–12}) and skinfold thickness (SFT^{6,7}) with respect to their power to predict cardiovascular risk factors has never been systematically performed.

*Correspondence: KG Parhofer, Department of Internal Medicine II, Klinikum Grosshadern, Marchioninstr. 15, 81377 Munich, Germany.
E-mail: parhofer@med2.med.uni-muenchen.de
Received 23 June 2000; revised 24 November 2000;
accepted 8 December 2000

In the present study we evaluated which of the currently applied obesity parameters (BMI, PI, %BF-SL, %BF-DZ, SFT) best predict increased cardiovascular risk in healthy prepubescent children. The index allowing the best and most uniform prediction of the presence of cardiovascular risk factors in overweight children was judged to be the most useful obesity parameter.

Subjects and methods

Study population

The study population consists of children participating in the Prevention Education Program (PEP), which is a home-based and family-oriented intervention program, aimed to assess and improve cardiovascular risk factors in school children and their families living in the Nuremberg area.¹³ We included all children aged 4–9 y who were recruited between 1994 and 1997 and who had completed the entire evaluation program including determination of blood pressure, anthropometric parameters and blood lipids.

The study population consists of 405 boys (mean age 6.51 ± 1.14 y) and 433 girls (mean age 6.46 ± 1.13 y). All children were classified according to age using 2 y intervals (boys 4–5 y, $n=42$; 6–7 y, $n=306$; 8–9 y, $n=57$; and girls 4–5 y, $n=50$; 6–7 y, $n=324$; 8–9 y, $n=59$).

Methods

In each child we determined blood pressure (BP), height and weight, triceps- and subscapular skinfold thickness and a lipid profile including LDL-cholesterol, HDL-cholesterol, triglycerides, apolipoprotein B (apo-B) and the apolipoprotein E (apo-E) phenotype. Plasma fibrinogen was measured in a subgroup of 164 boys and 154 girls.

Physical examination. Body weight was measured by a digital scale (SECA, Hamburg, Germany) and body height was determined by a stadiometer. Skinfolts (triceps, subscapular) were determined according to WHO-standards on the left side to the nearest 0.1 mm using a Holtain skinfold caliper (GPM-caliper, Zurich, Switzerland). All skinfold measures were done by trained staff. Depending on the observer the coefficients of variation ranged between 2.0% and 5.1% for the triceps and between 3.3% and 5.4% for the subscapular skinfold. All skinfold measures were done in triplicate and mean values were used for analysis. After resting for 5 min blood pressure (BP) was measured in the sitting position using an appropriate sized cuff on both arms.¹⁴ The systolic (SBP) and diastolic (DBP) BP used for analysis is derived from the mean BP measured on both arms.

Laboratory determinations. Fasting plasma was obtained in every child. Total cholesterol and triglycerides (TG) were measured enzymatically by an autoanalyzer (Epos, Eppendorf, Hamburg, Germany). HDL-cholesterol was determined

after precipitation of apo-B containing lipoproteins by magnesium chloride and phosphotungstic acid. LDL-cholesterol was calculated by the formula of Friedewald¹⁵ because no child showed a plasma triglyceride concentration exceeding 400 mg/dl. Apo-B and fibrinogen levels were determined from an aliquot by immuno-nephelometry (Behring Laser Nephelometer, Marburg, Germany). All values were determined in duplicate. The apo-E phenotype was determined directly from delipidated plasma using isoelectric focussing and immunoblotting as described by Havekes.¹⁶

Parameters of obesity. BMI (kg/m^2) and PI (kg/m^3) were calculated from weight and height. The skinfold thickness (SFT, mm) was determined from the sum of the triceps and subscapular skinfold. Percentage body fat was determined by the formula described by Dezenberg¹² (%BF-DZ) using the triceps skinfold and the sex-specific equations evaluated for 4 to 11-y-old Caucasians and by the formula described by Slaughter¹⁷ for prepubescent children (%BF-SL). The 90th age- and sex-specific percentile (P) of each obesity parameter was used as the cut-off point between normal-weight (<90th P) and overweight (≥ 90 th P) children. The mean relative differences of plasma lipid (TG, HDL-cholesterol, LDL-cholesterol, apo-B) and fibrinogen concentrations as well as SBP and DBP values were compared between normal-weight and overweight children.

Odds ratios were calculated to indicate the relative risk of cardiovascular risk factors in overweight compared to normal-weight children. Hypertriglyceridemia was defined as $\text{TG} \geq 130 \text{ mg}/\text{dl}$,⁹ LDL-hypercholesterolemia as $\text{LDL-cholesterol} > 130 \text{ mg}/\text{dl}$,¹⁸ low-HDL-cholesterol as $\text{HDL-cholesterol} < 35 \text{ mg}/\text{dl}$ ¹⁸ and arterial hypertension as the SBP or DBP exceeding the 95th age-specific percentile.¹⁴

Statistics. All differences in biologic parameters between normal-weight and overweight children were evaluated by non-parametric tests. For all analyses, the distribution of the apo-E-phenotype distribution was compared between normal-weight and overweight children using the χ^2 -test. Phenotypes E2/2 ($n=4$) and E4/4 ($n=8$) were too rare for statistical evaluation, and thus evaluated together with E2/3 (E2/2) or E3/4 (E4/4). Children with the phenotype E2/4 ($n=12$) were excluded from this analysis. The odds ratios were evaluated by the χ^2 -test. The differences between normal-weight and overweight children were evaluated by the Mann–Whitney-test. Correlation coefficients (sex-specific, corrected for age, two-tailed test of significance) between different parameters of obesity and cardiovascular risk factors were determined.

Results

Table 1 shows the mean \pm sd of anthropometric parameters and cardiovascular risk factors in boys and girls. %BF is

Table 1 Mean (\pm s.d.) values of age, anthropometric parameters and cardiovascular risk factors and prevalence of overweight and obesity in 4 to 9-y-old boys and girls

	Boys, n = 405	Girls, n = 433
Age	6.5 \pm 1.1	6.5 \pm 1.1 ^{NS}
Anthropometric parameters		
weight (kg)	24.7 \pm 5.7	23.8 \pm 5.4*
BMI (kg/m ²)	15.8 \pm 2.1	15.7 \pm 2.1 ^{NS}
% BF-SL (%)	13.7 \pm 4.6	16.3 \pm 5.0**
% BF-DZ (%)	14.8 \pm 5.6	19.7 \pm 5.8**
Prevalence of overweight^a		
according to national standard ^{19b}	5.2% (7.0%) ^f	6.5% (7.0%) ^f
according to international standard ^{20c}	8.6% (8.5%) ^f	10.4% (9.4%) ^f
Prevalence of obesity		
according to national standard ^{19d}	3.5% (3.0%) ^f	3.7% (3.0%) ^f
according to international standard ^{20e}	2.7% (1.6%) ^f	3.5% (1.7%) ^f
Cardiovascular risk factors		
triglycerides (mg/dl)	61 \pm 25	68 \pm 28**
HDL-cholesterol (mg/dl)	61 \pm 13	59 \pm 15*
LDL-cholesterol (mg/dl)	104 \pm 26	111 \pm 30**
apo-B (mg/dl)	97 \pm 24	104 \pm 26**
SBP (mmHg)	104 \pm 10	104 \pm 10 ^{NS}
DBP (mmHg)	69 \pm 8	69 \pm 8 ^{NS}
fibrinogen (mg/dl)	303 \pm 71	311 \pm 67 ^{NS}
Apo-E-phenotype distribution		
apo-E 2/3 or 2/3 (%)	12.6	15.6 ^{NS}
apo-E 3/3 (%)	71.7	67.8 ^{NS}
apo-E 3/4 or 4/4 (%)	15.7	16.6 ^{NS}

**P < 0.01; *P < 0.05; NS, not significant, for differences between boys and girls.

^aObese subjects excluded.

^bOverweight as defined in Kromeyer-Hauschild et al¹⁹: 90th P \geq BMI < 97th P (boys and girls).

^cOverweight as defined in Cole et al²⁰: 89.9 P \geq BMI < 98.4 P (boys), 88.9 P \geq BMI < 98.3 P (girls).

^dObesity as defined in Kromeyer-Hauschild et al¹⁹: BMI \geq 97th P (boys and girls).

^eObesity as defined in Cole et al²⁰: BMI \geq 98.4 P (boys), BMI \geq 98.3 P (girls).

^fThe number in brackets is the prevalence in the standard populations.^{19,20}

higher in girls compared to boys, whereas age and BMI are not different. Furthermore, girls show higher LDL-cholesterol, apo-B and TG concentrations, but lower HDL-cholesterol, while there was no difference in blood pressure, fibrinogen and in the apo-E-phenotype distribution. Compared to a current national¹⁹ and international²⁰ standard using BMI-percentiles to define childhood obesity, the prevalence of obesity was slightly elevated in boys (3.5 vs 3.0%,¹⁹ 2.7 vs 1.6%²⁰) and in girls (3.7 vs 3.0,¹⁹ 3.5 vs 1.7%²⁰). However, boys and girls were less overweight compared to the national reference (boys 5.2 vs 7.0%, girls 6.5 vs 7.0%,¹⁹) but comparable or slightly more overweight compared to the international standard (boys 8.6 vs 8.5%, girls 10.4 vs 9.4%²⁰).

To evaluate different obesity parameters with respect to their prediction of cardiovascular risk factors, all children equal or exceeding the 90th age- and sex-adjusted percentile of BMI, PI, SFT, %BF-SL and %BF-DZ were defined as overweight (Figure 1). Using the BMI or the PI as obesity parameter, normal-weight and overweight children differ significantly in all cardiovascular risk factors (BMI: TG + 20.5%, HDL-cholesterol - 8.6%, LDL-cholesterol + 9.6%, apo-B + 6.8%, SBP + 7.4%, DBP + 8.6%, fibrinogen + 13.2% in overweight vs normal-weight children; PI: TG + 24.3%, HDL-cholesterol - 6.1%, LDL-cholesterol + 9.0%, apo-B + 7.4%, SBP + 5.9%, + 5.9%, DBP + 6.7%, fibrinogen + 13.9% in overweight vs normal-weight children), whereas %BF-DZ, %BF-SL and SFT fail to show differences in LDL-cholesterol and apo-B concentrations as well as in the HDL-cholesterol (%BF-SL, SFT) or fibrinogen (%BF-DZ).

Stratification by gender revealed that no obesity parameter predicts the presence of all cardiovascular risk factors

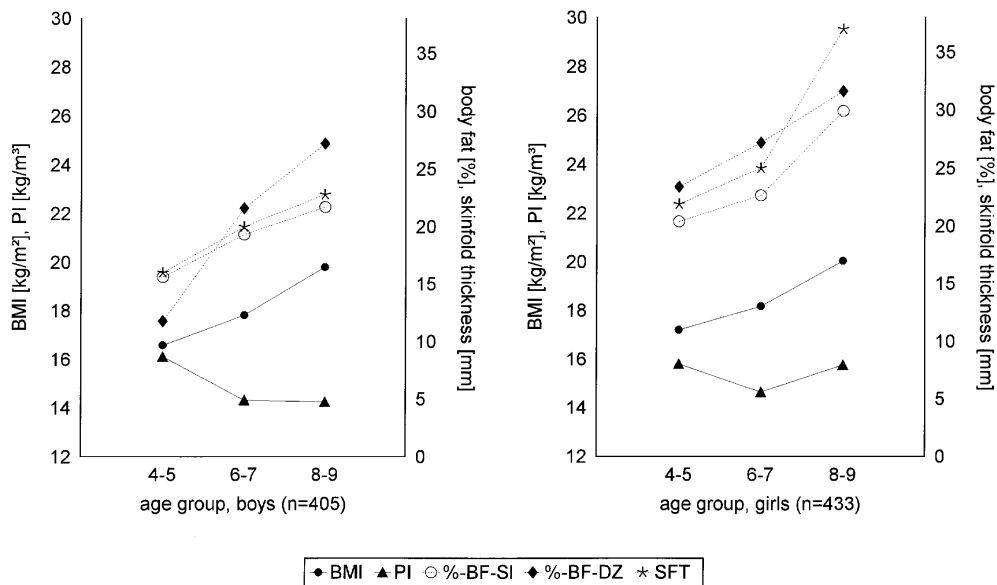
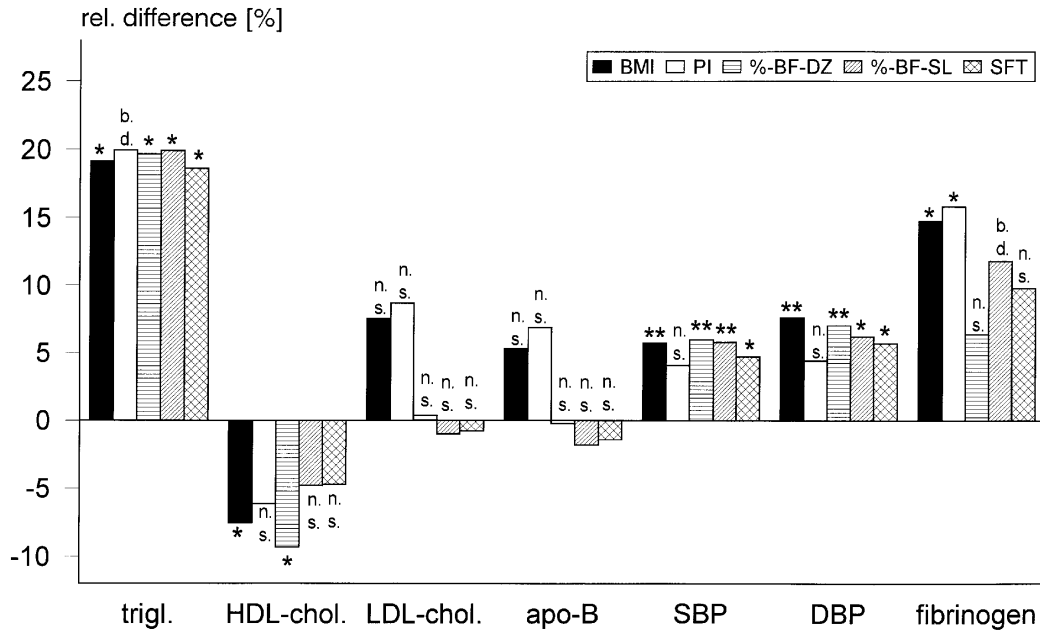


Figure 1 The 90th percentile of BMI, PI, %BF-SL, %BF-DZ and SFT in boys and girls aged 4–5, 6–7 and 8–9 y.

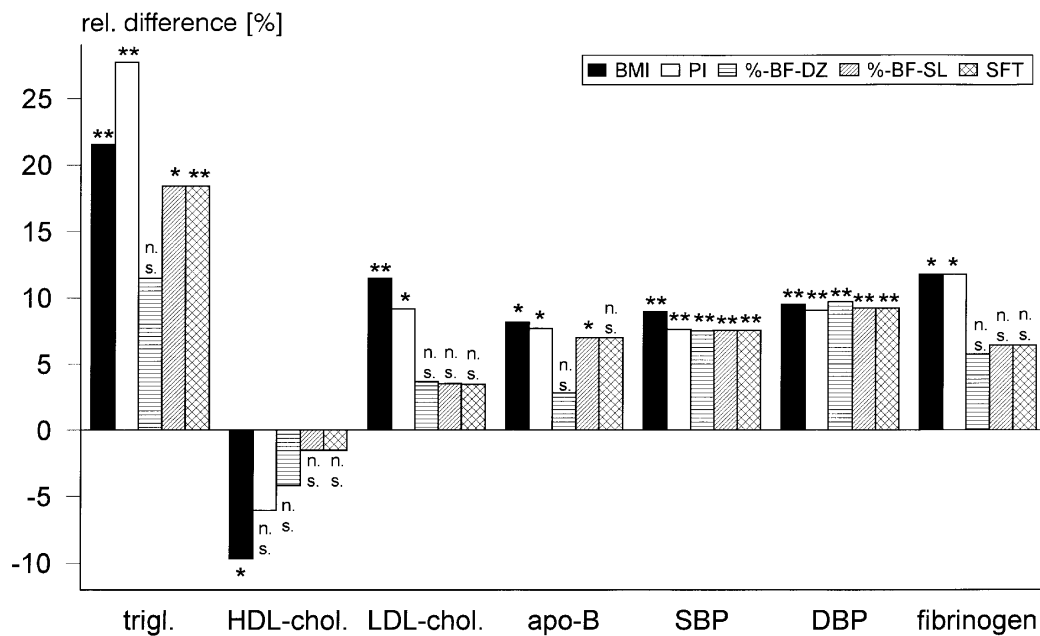
in overweight boys (Figure 2a), although the BMI performed better than any other parameter as it predicted all cardiovascular risk factors except LDL-cholesterol and apo-B. In girls, obesity defined by BMI predicts the presence of all

cardiovascular risk factors, while PI did not predict lower HDL-cholesterol (Figure 2b).

As the Slaughter-equations are not sufficiently validated for children younger than 6 y, the analysis was repeated for



** p < 0.01, * p < 0.05, b., d.: borderline significant (p = 0.055), n.s.: not significant, Mann-Whitney-test



** p < 0.01, * p < 0.05, n.s.: not significant, Mann-Whitney-test

Figure 2 (a) Relative differences between normal-weight (< 90th P) and overweight (≥ 90th P) boys (n = 405) (a) and girls (n = 433) (b) with respect to cardiovascular risk factors.

children aged 6–9 y. However, also in this subgroup, % BF-SL did not better predict cardiovascular risk factors than BMI or PI (data not shown).

The differences between normal-weight and overweight children with respect to lipid concentrations were not related to the apo-E-phenotype, as the apo-E-phenotype distribution was similar between normal-weight and overweight children ($P > 0.27$, χ^2 -test).

All parameters of obesity only correlated weakly with cardiovascular risk factors (Table 2). Overall, weight-to-height indices correlated slightly better with cardiovascular risk factors than indices based on skinfold measurement. Furthermore, with the exception of HDL-cholesterol all correlations were somewhat stronger in girls compared to boys.

The relative risk for the presence of cardiovascular risk factors in overweight children (defined by the 90th percentile) is shown in Table 3. When overweight is defined by BMI or PI there is a significant increase in the relative risk for the presence of hypertriglyceridemia, LDL-hypercholesterolemia and hypertension. Overweight defined by %BF-DZ, %BF-SL, or SFT fails to indicate an increased relative risk for LDL-hypercholesterolemia. In addition, the obesity index %BF-DZ does not predict hypertriglyceridemia.

Discussion

Obesity parameters using weight-to-height indices such as the BMI and the PI are better predictors of cardiovascular risk factors than parameters estimating %BF by skinfold measurement (SFT, %BF-DZ, %BF-SL) in healthy 4 to 9-y-old children. While PI and BMI were equivalent in girls, BMI predicted risk factors in boys much better than PI. Thus, overall BMI is the most useful parameter in assessing childhood obesity, when the presence of cardiovascular risk factors is a major concern.

Previous studies have indicated that in adults² and children^{4,5} the BMI reflects body fat mass and that BMI and

Table 2 Correlation coefficients between different parameters of obesity and cardiovascular risk factors in 4–9-y-old boys ($n = 405$) and girls ($n = 433$). Correlation coefficients are corrected for age

	TG	HDL-C	LDL-C	apo-B	SBP	DBP	Fibrinogen
Boys							
BMI	0.19**	-0.16**	NS	NS	0.24**	0.20**	0.16*
PI	0.21**	-0.17**	NS	NS	0.14**	0.14**	0.18*
%BF-DZ	0.11*	-0.11**	NS	NS	0.27**	0.18**	NS
%BF-SL	0.18**	NS	NS	NS	0.19**	0.16**	NS
SFT	0.19**	NS	NS	NS	0.20**	0.18**	0.15*
Girls							
BMI	0.23**	NS	NS	NS	0.36**	0.32**	0.21**
PI	0.25**	NS	NS	NS	0.29**	0.25**	0.23**
%BF-DZ	0.16**	NS	NS	NS	0.34**	0.27**	0.19*
%BF-SL	0.22**	NS	NS	NS	0.28**	0.24**	0.19*
SFT	0.23**	NS	NS	NS	0.27**	0.25**	0.19*

** $P < 0.01$; * $P < 0.05$, NS, not significant.

cardiovascular morbidity and cardiovascular mortality are correlated with each other.^{3,21–23} Therefore, BMI has been recommended as an appropriate parameter to define obesity in adults^{1,2} and, more recently, in children.^{4,24} However, it was also shown that childhood obesity defined by other obesity parameters (PI,^{7,25} weight-for-height,²⁶ and skinfold thickness⁷ is associated with increased cardiovascular risk^{7,25} and mortality.²⁶ Thus, we compared these commonly used obesity parameters with respect to their power to predict the presence of cardiovascular risk factors.

Our analysis refers to healthy children, which are comparable to a national reference standard which was recently calculated from over 34 000 1 to 18-y-old children recruited between 1985 and 1995 in Germany.¹⁹ Compared to a new international reference standard (six nations, over 60 000 children²⁰), the prevalence of overweight and obesity is slightly higher in our study group. Furthermore, our analysis was done on the basis that being equal or exceeding the 90th sex- and age-specific percentile defines overweight. Although such a cut-off point is arbitrary, a recent publication indicates that overweight (boys BMI > 89.9th P, girls BMI > 88.9th P) 2 to 18-y-old children track to the cut-off point commonly used to define adult overweight (25 kg/m²) when they become 18 y old.²⁰

The analysis was repeated with other commonly used cut-points such as the 85th P and 95th P (Table 4). However, the

Table 3 Relative risk for the presence of hypertriglyceridemia, low HDL-cholesterol, LDL-hypercholesterolemia and arterial hypertension in overweight children. Overweight is defined by the 90th percentile with regard to BMI, PI, %BF-DZ, %BF-SL, SFT

	TG ≥ 130 mg/dl	HDL-choL. < 35 mg/dl	LDL-choL. > 130 mg/dl	SBP or DBP > 95th P ¹⁴
All children				
BMI	2.64*	1.14 ^{NS}	1.63*	3.31**
PI	2.61*	1.76 ^{NS}	1.69**	2.89**
%BF-DZ	1.63 ^{NS}	1.76 ^{NS}	1.30 ^{NS}	2.88**
%BF-SL	2.54*	1.04 ^{NS}	1.04 ^{NS}	2.78**
%BF-SL ^a	2.79*	1.18 ^{NS}	0.88 ^{NS}	2.87**
SFT	2.43*	1.00 ^{NS}	1.07 ^{NS}	2.78**
Boys				
BMI	2.68 ^{NS}	1.00 ^{NS}	1.11 ^{NS}	3.21**
PI	2.68 ^{NS}	2.36 ^{NS}	1.53 ^{NS}	2.35**
%BF-DZ	2.68 ^{NS}	2.37 ^{NS}	0.71 ^{NS}	2.90**
%BF-SL	2.58 ^{NS}	2.18 ^{NS}	0.67 ^{NS}	2.76**
%BF-SL ^a	2.41 ^{NS}	2.17 ^{NS}	0.76 ^{NS}	2.92**
SFT	2.37 ^{NS}	2.09 ^{NS}	0.79 ^{NS}	2.79**
Girls				
BMI	2.64 ^{bd}	1.55 ^{NS}	1.92**	3.40**
PI	2.59 ^{NS}	1.52 ^{NS}	1.75*	3.32**
%BF-DZ	1.15 ^{NS}	1.52 ^{NS}	1.63*	2.86**
%BF-SL	2.50 ^{NS}	0.70 ^{NS}	1.24 ^{NS}	2.06**
%BF-SL ^a	2.94*	0.81 ^{NS}	0.96 ^{NS}	2.81**
SFT	2.53 ^{NS}	0.70 ^{NS}	1.24 ^{NS}	2.78**

** $P < 0.01$; * $P < 0.05$; bd, $P < 0.07$; NS, not significant.

^aChildren aged 6–9 y. Normal-weight and overweight children were not significantly different with respect to age ($P > 0.19$ for all groups, χ^2 -test).

Table 4 Summary of the relative differences (%) between normal-weight and overweight boys (a) and girls (b) aged 4–9 y with respect to cardiovascular risk factors. Using age- and sex-related percentiles calculated for each obesity parameter children were defined as overweight (≥ 85 th P) or obese (≥ 95 th P). An international BMI reference²⁰ was also used to define obesity; the cut-off points used in Cole et al²⁰ (BMI ≥ 98.4 P in boys, BMI ≥ 98.3 P) correspond to the 97.3 P for boys and to the 96.5 P for girls in the study population. The relative differences between normal-weight and overweight/obese children are given for all parameters with at least borderline ($P < 0.07$) significance

	BMI			PI			%BF-DZ			%BF-SL			SFT		
(a) Boys (n = 405)	85.P	95.P	97.3 P	85 P	95 P	97.3 P	85 P	95 P	97.3 P	85 P	95 P	97.3 P	85 P	95 P	97.3 P
TG	NS	25.7*	56.7*	NS	36.6**	50*	NS	NS	NS	NS	24.4*	16.4*	NS	24.4*	16.4*
HDL-chol.	-6.3*	NS	NS	-6.3*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LDL-chol.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
apo-B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SBP	5.1**	6.9*	5.8 ^{bd}	NS	NS	NS	4.1**	10.9**	8.7**	4.0*	7.3**	5.7 ^{bd}	3.9*	7.3*	5.7 ^{bd}
DBP	5.4**	12.5**	10.1**	NS	NS	NS	3.8**	14.9**	17.4**	NS	10.2**	11.6*	NS	10.2*	11.6*
fibrinogen	10.4*	20.3*	26.9*	NS	22.9**	30 ^{bd}	NS	13.1	NS	NS	NS	22.6*	NS	NS	22.6*
(b) Girls (n = 433)	85 P	95 P	96.5 P	85 P	95 P	96.5 P	85 P	95 P	96.5 P	85 P	95 P	96.5 P	85 P	95 P	96.5 P
TG	19.2**	25.3*	43.3**	19.9**	24.3*	38.8**	11.0 ^{bd}	35.5**	33.8*	13.7**	NS	38.8*	13.7**	NS	38.8*
HDL-chol.	NS	-10.7*	-10.0 ^{bd}	NS	-13.9*	NS	NS	NS	-13.3*	NS	NS	NS	NS	NS	NS
LDL-chol.	8.4**	11.1*	NS	5.8 ^{bd}	12.0*	NS	6.0*	NS	NS	5.2 ^{bd}	NS	NS	5.2 ^{bd}	NS	NS
apo-B	7.8**	10.3*	12.6 ^{bd}	6.9**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SBP	7.9**	11.2**	13.5**	5.9**	8.2**	9.6**	6.5**	10.0**	10.6**	6.1**	9.4**	11.5**	6.1**	9.4**	11.5**
DBP	7.9**	16.1**	15.9**	6.4**	11.9**	14.5**	8.6**	12.5**	10.1**	8.2**	11.1**	17.4**	8.2**	11.1**	17.4**
fibrinogen	10.1**	16.9**	19.2*	9.4*	NS	16.8 ^{bd}	NS	17.1**	12.9*	NS	16.3*	20.1*	NS	16.3*	20.1*

** $P < 0.01$; * $P < 0.05$; bd, $P < 0.07$; NS, not significant, Mann–Whitney test.

use of these cut-off points did not affect the conclusions of our study. We repeated the analysis in children defined as obese by an international standard²⁰ to examine whether the above mentioned results also held true in this context. In boys (Table 4a) and girls (Table 4b) BMI best predicts cardiovascular risk factors. However, the results were not as unequivocal as when lower percentiles (85th–95th P) are used. This is most likely related to the low number of subjects in these groups.

Another approach to examining the relationship between different obesity parameters and cardiovascular risk factors is the use of correlation coefficients. However, similar to other studies,^{11,25} all parameters of obesity only correlated weakly with cardiovascular risk factors in our study (Table 2). This may be related to the fact that the associations may not be linear.⁹

Although a previous study suggested that PI is a better parameter of obesity than BMI in children aged 10–15 y,⁸ we found that both parameters similarly predict cardiovascular risk in prepubescent children. Our results are comparable to findings from another study which describes a similar increase in the relative risk for the presence of cardiovascular risk factors in obese children defined by the 95th BMI or PI-percentile.⁹

The separate analysis of boys and girls revealed considerable sex-specific differences between BMI and PI. While BMI predicted cardiovascular risk factors in both sexes, PI failed to do so in boys.

Although BMI most uniformly predicted cardiovascular risk factors in both genders, the prediction of adverse lipid levels was stronger in girls than in boys. The reason for this finding is unknown, but differences in age or in the apo-E phenotype distribution can be excluded and differences in

the hormonal status are unlikely as both genders are prepubescent. However, sex-related differences in physical activity or dietary behavior may account for this observation. In a previous study, prepubescent boys showed an increased level of physical activity compared to girls²⁷ which may explain a more favorable lipid profile.

Our results show that parameters of obesity based on the estimation of body fat by skinfold measurement (SFT, %BF-SL, %BF-DZ) have no advantage compared to height-to-weight indices. The measurement of skinfolds was made by trained staff with a good reproducibility of measurement (coefficient of variation $< 5.5\%$). In addition, we used the triceps and subscapular skinfolds, which are relatively precise to measure as they are determined at well-defined sites. Nevertheless determination of skinfold thickness is never as precise and reproducible as the measurement of height and weight. This may, at least in part, explain why height-to-weight indices are better predictors of cardiovascular risk factors than indices based on skinfold thickness.

The application of the Slaughter formula,¹⁷ which was derived from hydrodensitometry, was not superior to measurement of skinfolds alone. As the application of this equation is of unknown validity for children below 6 y,²⁸ we repeated the analysis in 6 to 9-y-old children. However, the results in this subgroup were not different from those seen in the entire group.

We also evaluated the equation from Dezenberg,¹² which is based on another reference method (dual-energy X-ray absorptiometry, DEXA) and was validated for children aged 4–11 y. This equation uses body weight and triceps skinfold thickness to estimate %BF. Although the Dezenberg formula is sex-specific, cardiovascular risk factors were not predicted uniformly in our population. %BF-DZ was an appropriate

obesity-parameter in boys, but failed to predict adverse lipid levels in girls.

Our study may be limited by the fact that there was not an identical number of subjects in all age groups, as 6 to 7-y-old boys and girls were more frequent than children from the other age-groups. Thus, our results are predominantly valid for 6 to 7-y-old children. Furthermore, we did not include parameters describing body fat distribution such as waist-to-hip ratio which additionally modulate cardiovascular risk. However, these parameters are regarded as ancillary rather than global obesity parameters.²⁴

Since the apo-E-polymorphism influences plasma lipid concentrations and also modulates the association between various indices of obesity with serum lipids,²⁹ differences between normal-weight and overweight children with respect to plasma lipids could reflect differences in the apo-E-phenotype distribution. However, normal-weight and overweight children showed a similar apo-E-phenotype distribution.

In prepubescent children height-to-weight indices such as the BMI and the PI better predict cardiovascular risk factors than obesity parameters using skinfold measurement. BMI may be superior to PI as the association between BMI and cardiovascular risk is less affected by gender.

Acknowledgements

This research was supported by the Public Foundation for the Prevention of Atherosclerosis, the Bavarian Ministry of Health, the AOK Bavaria, the Friedrich Baur Foundation and the Dr Democh Mauermeier Foundation. We gratefully appreciate the technical assistance of K Henze, I Biller-Friedmann, E Fleischer-Brielmeyer and S Szasz and are indebted to G-M Haas, Dr E Laubach, Ch Luxbacher, E Liepold, Dr E Öhrig, Dr C Otto, C Rohrer, M Roßkopf, R Stark MD FRCP(C), and Ch Üblacker.

References

- 1 Bray GA. Overweight is risking fate. Definition, classification, prevalence, and risks. *Ann NY Acad Sci* 1987; **499**: 14–28.
- 2 Willet WC, Dietz WH, Colditz GA. Primary care: guidelines for healthy weight. *New Engl J Med* 1999; **341**: 427–434.
- 3 Calle EE, Thun MJ, Petrelli JM, Rodriguez C, Heath CW. Body mass index and mortality in a prospective cohort of US adults. *New Engl J Med* 1999; **341**: 1097–1105.
- 4 Barlow SE, Dietz WH. Obesity evaluation and treatment: expert committee recommendations. *Pediatrics* 1998; **102**: e29.
- 5 Dietz WH, Belizzi MC. Introduction: the use of the body mass index to assess obesity in children. *Am J Clin Nutr* 1999; **70**: 123S–125S.
- 6 Guillaume M. Defining obesity in childhood: current practice. *Am J Clin Nutr* 1999; **70**: 126S–130S.
- 7 Berenson GS, Srinivasan SR, Wattigney WA, Harsha DW. Obesity and cardiovascular risk in children. *Ann NY Acad Sci* 1993; **699**: 93–101.
- 8 Valdez R, Greenlund KJ, Wattigney WA, Bao W, Berenson GS. Use of weight-for-height indices in children to predict adult overweight: the Bogalusa Heart Study. *Int J Obes Relat Metab Disord* 1996; **20**: 715–721.
- 9 Freedman DS, Dietz WH, Srinivasan SR, Berenson GS. The relation of overweight to cardiovascular risk among children and adolescents: the Bogalusa Heart Study. *Pediatrics* 1999; **103**: 1175–1182.
- 10 Schaefer F, Georgi M, Wühl E, Schärer K. Body mass index and percentage fat mass in healthy German schoolchildren and adolescents. *Int J Obes Relat Metab Disord* 1998; **22**: 461–469.
- 11 Dwyer T, Blizzard L. Defining obesity in children by biological endpoint rather than population distribution. *Int J Obes Relat Metab Disord* 1996; **20**: 472–480.
- 12 Dezenberg CV, Nagy TR, Gower BA, Johnson R, Goran MI. Predicting body composition from anthropometry in pre-adolescent children. *Int J Obes Relat Metab Disord* 1999; **23**: 253–259.
- 13 Schwandt P, Geiß HC, Ritter MM, Üblacker Ch, Parhofer KG, Otto C, Laubach E, Donner MG, Haas G-M, Richter WO. The Prevention Education Program (PEP). A prospective study of the efficacy of family oriented life style modification in the reduction of cardiovascular risk and disease. Design and baseline data. *J Clin Epidemiol* 1999; **52**: 791–800.
- 14 The fifth report of the Joint National Committee on detection, evaluation, and treatment of high blood pressure (JNC V). *Arch Intern Med* 1993; **153**: 154–183.
- 15 Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin Chem* 1972; **18**: 499–502.
- 16 Havekes LM, de Knijff P, Beisiegel U, Havinga J, Smit M, Klasen E. A rapid micromethod for apolipoprotein E phenotyping directly in serum. *J Lipid Res* 1987; **28**: 455–463.
- 17 Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, van Loan MD, Bembien DA. Skinfold equations for estimation of body fatness in children and youth. *Hum Biol* 1988; **60**: 709–723.
- 18 National Cholesterol Education Program (NCEP): Highlights of the report of the expert panel on blood cholesterol levels in children and adolescence. *Pediatrics* 1992; **89**: 495–501.
- 19 Kromeyer-Hauschild K, Wabitsch M, Geller F, Ziegler A, Geiß HC, Hesse V, Hippel V, Jaeger U, Johnsen D, Kiess W, Korte W, Kunze D, Menner K, Müller M, Niemann-Pilatus A, Remer Th, Schaefer F, Wittchen H-U, Zabransky S, Zellner K, Hebebrand J. Perzentile für den Body-Mass-Index für das Kindes und Jugendalter unter Heranziehung Verschiedener Deutscher Stichproben. *Monatsschrift Kinderheilkunde* (in press).
- 20 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *Br Med J* 2000; **320**: 1240–1243.
- 21 Dietz WH. Childhood weight affects adult morbidity and mortality. *J Nutr* 1998; **128**: 411S–414S.
- 22 Gunnell DJ, Frankel SJ, Nanchahal K, Peters TJ, Smith GD. Childhood obesity and adult cardiovascular mortality: a 57-y follow-up study based on the Boyd Orr cohort. *Am J Clin Nutr* 1998; **67**: 1111–1118.
- 23 Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents. A follow-up study of the Harvard Growth Study of 1922 to 1935. *New Engl J Med* 1992; **327**: 1350–1355.
- 24 Belizzi MC, Dietz WH. Workshop on childhood obesity: summary of the discussion. *Am J Clin Nutr* 1999; **70**: 173S–175S.
- 25 Wattigney WA, Harsha DW, Srinivasan SR, Webber LS, Berenson GS. Increasing impact of obesity on serum lipids and lipoproteins in young adults. The Bogalusa Heart Study. *Arch Intern Med* 1991; **151**: 2017–2022.

- 26 Mossberg H-O. 40-year follow-up of overweight children. *Lancet* 1989; **2**: 491–493.
- 27 McKenzie TL, Sallis JF, Nader PR, Broyles SL, Nelson JA. Anglo- and Mexican-American preschoolers at home and at recess: activity patterns and environmental influences. *J Dev Behav Pediatr* 1992; **13**: 173–180.
- 28 Reilly JJ, Wilson J, Durnin VGA. Determination of body composition from skinfold thickness: a validation study. *Arch Dis Child* 1995; **73**: 305–310.

- 29 Srinivasan SR, Ehnholm CH, Wattigney WA, Berenson GS. Relationship between obesity and serum lipoproteins in children with different apolipoprotein E phenotypes: the Bogalusa Heart Study. *Metabolism* 1994; **43**: 470–475.