Percentile curves for fat patterning in German adolescents

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Background: **Because the body composition of adolescents varies more than that of adults and anthropometric parameters are regularly used for pediatric body fat measurements, we developed age-, gender-, and ethnicity-specific reference values for waist circumference (WC), hip circumference (HC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), and skinfold thickness (SFT) in German adolescents.**

Methods: **A representative sample of 1633 boys and 1391 girls aged 12–18 years participated in this cross-sectional study. Weight, height, body mass index (BMI), WC, HC, WHR, WHtR, and SFT were measured and smoothed; age-, gender-, and ethnicity-specific reference curves were developed using the LMS method.**

Results: **Females were significantly heavier than males at 12 years. Beyond age 14 males were significantly heavier and taller than females. The SFT sum increased continuously (+20%) in females and was significantly higher (7.4 mm) than in males. At the 90th percentile, $SFT_{triceps}$ decreased (−12%) in males but increased (+11%) in females; $SFT_{subscapular}$ increased in both genders. From 12 to 18 years, WHtR and WHR remained constant, whereas WC and HC increased in both genders. WHtR was the best predictor for abdominal obesity in males (area under the curve [AUC] 0.974 ± 0.004) and females (AUC 0.986 ± 0.003), followed by body fat percentage (AUC 0.937 ± 0.008) in males and WHR (AUC 0.935 ± 0.009) in females.**

Conclusion: **These age- and gender-specific percentile curves for SFT, WC, HC, WHR, and WHtR, derived from a large national sample of German adolescents, may be useful for developing international reference values for waist circumference and other predictors of adult obesity.**

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Key words: **German adolescents; skinfold thickness; waist circumference; waist-to-height ratio; waist-to-hip ratio**

Introduction

The average abdominal adiposity of youths in Europe, USA, Japan, Africa, India, Korea, Iran, Australia, and China has greatly increased over the past few decades.[1–10] However, although anthropometry is an inexpensive, noninvasive method of assessing the size, shape, and composition of the human body, in a recent study, only 38% of 8464 older adolescents had had a preventive care visit within the past 12 months.[11] Because of ethnic differences in body composition, the International Diabetes Federation (IDF) proposed pragmatic cut-offs for waist circumference of adult Europeans, South Asians, Chinese, and Japanese;[12] however, they have not yet proposed waist circumference cut-offs for children and adolescents.[13] Thus, comprehensive worldwide reference values are needed before the establishment of an internationally accepted age-, gender-, and ethnicity-specific definition of abdominal adiposity in youths, such as body mass index (BMI), established by the International Obesity Task Force (IOTF),[14] and blood pressure, established by the Working Group on High Blood Pressure in Children and Adolescents.[15] Because of the lack of reference values for German adolescents, we developed percentile curves for waist circumference (WC), hip circumference (HC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), and skinfold thickness (SFT) in a representative sample of German adolescents.

Methods

Study population

The Prevention Education Program (PEP) Family Heart Study is a prospective, community-based family study of cardiovascular disease risk factors and lifestyle behavior in children and parents, which has been conducted since 1995 in the city of Nuremberg,

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Germany.[16,17] Our analysis of 3024 (1633 males) adolescents (12-18 years old) was based on yearly cross-sectional surveys in the period of 2000-2007. PEP was approved by the ethical committee of the medical faculty of the Ludwig Maximilian University of Munich, the Bavarian Ministry of Science and Education, and local school authorities. Written informed consent, together with oral consent from children and adolescents, was obtained from all of the parents. The participants refused to undergo pubertal stage assessment. Exclusion criteria were non-European German ethnicity, incomplete datasets, apparent cardiovascular, metabolic, endocrine, or malignant diseases, and taking any medication.

Measurements

All of the measurements were performed by continuously trained research assistants in accordance with the PEP study manual. Weight and height were measured in duplicate and averaged to the nearest 0.1 cm and 0.1 kg, respectively, without shoes and in light clothing (SECA electronic scale, Germany; Stadiometer, Holtain, UK). BMI was calculated as weight divided by height squared (kg/m²).

WC was measured at the end of breath expiration to the nearest 0.1 cm, in accordance with the WHO recommendations,[18] with a flexible inextensible tape (Siber Hegner, Switzerland) placed directly on the skin horizontal to the floor at the midpoint between the lowest rib and the iliac crest and hip over the major trochanters. Participants were standing erect with abdomen relaxed, and were balanced on both feet with the feet touching each other and both arms hanging freely; special attention was paid to ensuring that the tape lay perpendicular to the long axis of the body and parallel to the floor. Two measurements were obtained, and the mean value was used in the calculation of WHtR and WHR.

SFT was measured on the left side of the body in accordance with the WHO standards, with a Holtain skinfold caliper (GPM, Switzerland) to the nearest 0.1 mm. Measurements of SFTs were obtained for biceps (directly above the center of the cubital fossa, at the same level as the triceps skinfold), triceps (on the posterior aspect of the left arm over the triceps muscle, midway between the lateral projection of the acromion process of the scapular and the inferior margin of the olecranon process of the ulna), and subscapular (1 cm below the lowest angle of the scapula and long axis of the skinfold at a 45° angle directed down and to the left side).[19] For SFT measurements, the interobserver coefficient of variation (CV) was 5.4%, and the intra-observer CV was 2.0%. All of the SFT measurements were performed in triplicate, and mean values were used for analysis. Percentage body fat (%BF) was calculated by the formula described by Slaughter.[20]

Statistical analysis

All of the statistical analyses were performed with PASW 17.0 version for Windows (SPSS, Illinois, USA) according to a predefined analysis plan and program. Continuous variables were presented as mean ± standard deviation (SD). All of the tests were 2-sided, and *P* values of <0.05 were considered to be statistically significant. Nonparametric receiver operating characteristic (ROC) analysis was used. Smoothed age- and gender-specific curves were constructed using the software package LMS Chart Maker Pro, version 2.3.

Table 1. Age-dependent mean values (SD) of weight, height, waist circumference (WC), body mass index (BMI), hip circumference (HC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) in male and female German adolescents aged 12-18 years (mean age 14.3±1.9 years)

Age (y)	*n*	Weight (kg)	Height (cm)	WC (cm)	BMI (kg/m²)	HC (cm)	WHR	WHtR
Boys								
12	361	46.4 ± 9.8	155.3 ± 7.6	69.3 ± 8.4	19.1 ± 3.0	82.0 ± 7.8	0.84 ± 0.05*	0.44 ± 0.05*
13	317	51.8 ± 10.6	162.0 ± 8.1	71.3 ± 8.2	19.6 ± 3.1	85.2 ± 7.6	0.84 ± 0.05*	0.44 ± 0.05
14	277	58.2 ± 11.0*	169.1 ± 8.2*	73.8 ± 8.7*	20.3 ± 3.0	89.2 ± 7.7	0.83 ± 0.05*	0.44 ± 0.05
15	222	64.4 ± 11.4*	174.7 ± 7.7*	70.1 ± 8.9	21.0 ± 2.9	92.1 ± 7.4	0.83 ± 0.05*	0.44 ± 0.05
16	186	68.6 ± 10.7*	177.9 ± 6.6*	77.6 ± 8.6*	21.6 ± 2.9	94.6 ± 6.9	0.82 ± 0.05*	0.44 ± 0.05
17	162	70.8 ± 11.8*	178.8 ± 7.0*	79.1 ± 8.4*	22.1 ± 3.3	96.2 ± 7.5	0.82 ± 0.05*	0.44 ± 0.05
18	108	72.3 ± 12.0*	179.5 ± 8.2*	80.4 ± 8.6*	22.3 ± 2.9	97.0 ± 7.2	0.83 ± 0.05*	0.45 ± 0.04
Total	1633	58.5 ± 14.2*	168.1 ± 11.8*	74.0 ± 9.3*	20.5 ± 3.2	89.0 ± 9.2	0.83 ± 0.05*	0.44 ± 0.05
Girls								
12	315	47.4 ± 10.4*	156.5 ± 7.4*	68.0 ± 8.9	19.2 ± 3.4	84.9 ± 8.5*	0.80 ± 0.06	0.43 ± 0.05
13	269	52.6 ± 10.6	161.0 ± 6.8	70.2 ± 8.9	20.2 ± 3.6	89.4 ± 8.0*	0.78 ± 0.06	0.44 ± 0.05
14	231	54.8 ± 8.8	163.9 ± 6.7	70.9 ± 8.5	20.4 ± 2.9	91.6 ± 6.6*	0.77 ± 0.06	0.43 ± 0.05
15	197	58.5 ± 11.2	165.7 ± 6.5	73.5 ± 9.8*	21.3 ± 3.7	94.3 ± 7.6*	0.78 ± 0.07	0.44 ± 0.05
16	144	58.7 ± 11.9	165.6 ± 6.5	73.9 ± 8.3	21.1 ± 2.8	95.0 ± 7.9	0.78 ± 0.06	0.45 ± 0.05*
17	131	59.2 ± 8.7	166.3 ± 6.4	74.4 ± 8.0	21.4 ± 2.9	95.3 ± 6.4	0.78 ± 0.06	0.45 ± 0.05
18	104	58.9 ± 7.0	166.1 ± 6.2	73.7 ± 8.1	21.4 ± 2.4	95.3 ± 5.6	0.77 ± 0.07	0.44 ± 0.05
Total	1391	54.3 ± 11.0	162.5 ± 7.7	71.4 ± 9.2	20.5 ± 3.4	91.0 ± 8.5*	0.78 ± 0.06	0.44 ± 0.05

*: *P*<0.05, between genders.

Results

Age-dependent anthropometric data of the 3024 adolescents (mean age 14.3 ± 1.9 years) who participated in the study are shown in Table 1. Females were significantly taller and heavier than males aged 12 years, whereas from 14 to 18 years of age, boys were significantly taller and heavier than girls. Female adolescents reached their maximal weight and height at age 17 years, 1 year earlier than males. For girls, the SFT sum continuously increased (+20%) until 17 years of age, while for boys, it decreased (-9%) until 15 years of age (Table 2). The SFT sum was significantly higher (7.4 mm) in females than in males. Between 12 and 18 years of age, the %BF increased by 3.7% in females without substantial changes in the ratio of $\text{SFT}_{\text{subscapular}}$ to $\text{SFT}_{\text{triceps}}$. In contrast, in males, the %BF increased by only 0.5%, but the ratio of $\text{SFT}_{\text{subscapular}}$ to $\text{SFT}_{\text{triceps}}$ as a measure of trunk fat was significantly higher.

Age- and gender-specific percentile values at the third, tenth, 25th, 50th, 75th, 90th, and 97th percentiles are presented in Tables 3, 4 and in Fig. 1. At the 90th percentile, $\text{SFT}_{\text{triceps}}$ decreased by −12% (2.1 mm) and $\text{SFT}_{\text{subscapular}}$ increased by +5% (0.6 mm) in males. In females, both SFTs increased: $\text{SFT}_{\text{triceps}}$ by 11% (2.1 mm) and $\text{SFT}_{\text{subscapular}}$ by 16% (2.4 mm). In both genders, WHtR and WHR remained constant from 12 to 18 years of age. The increase in the WC of males was nearly twice that of females (11.4 cm and 6.0 cm, respectively). HC increased by 16% in males and by 11% in females, resulting in percentile curves with comparable slopes.

The receiver operating curves [ROC] (Fig. 2)

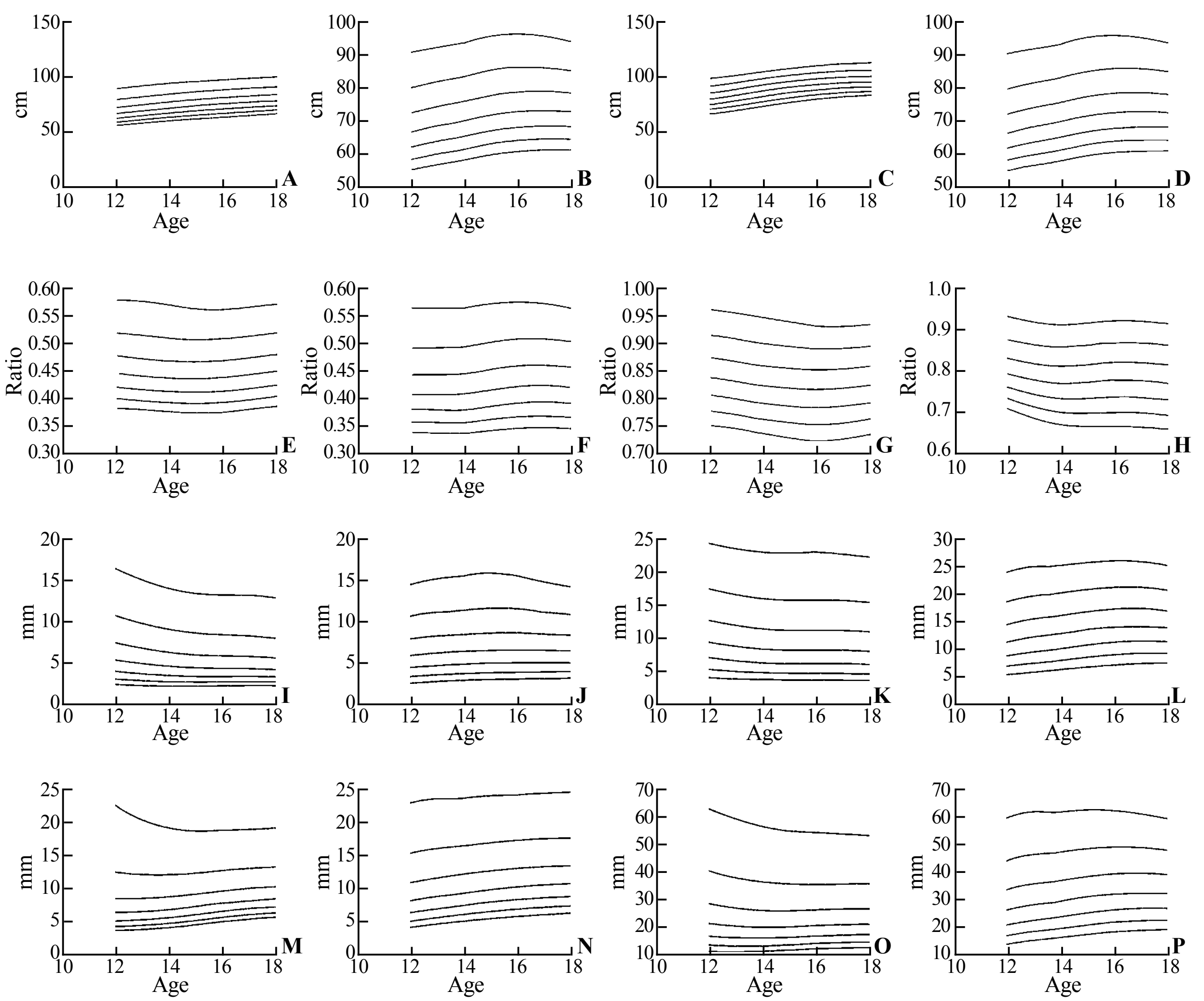

Fig. 1. LMS curves of the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles of **waist circumference** (cm) (**A**: male; **B**: female), **hip circumference** (cm) (**C**: male; **D**: female), **waist-to-height ratio** (**E**: male; **F**: female), **waist-to-hip ratio** (**G**: male; **H**: female), **biceps** (**I**: male; **J**: female), **triceps** (**K**: male; **L**: female), **subscapular skinfold thickness** (**M**: male; **N**: female), and **sum of skinfold thickness** (mm) (**O**: male; **P**: female) in 1634 male and 1392 female adolescents aged 12-18 years.

Table 2. Age-dependent skinfold thickness (SFT) (mm) in male and female adolescents

Age (y)	*n*	Biceps	Triceps	Subscapular	Subscapular/triceps	SFT sum	Body fat, %
Boys							
12	361	6.4 ± 3.3	10.7 ± 4.8	7.9 ± 4.8	0.75 ± 0.23	25.0 ± 12.0	13.9 ± 7.2
13	317	5.8 ± 3.2	10.2 ± 5.1	7.8 ± 4.5	0.80 ± 0.24	23.9 ± 12.0	13.4 ± 7.2
14	277	5.5 ± 3.0	9.7 ± 4.7	8.0 ± 4.1	0.88 ± 0.27	23.2 ± 11.0	13.2 ± 6.8
15	222	5.2 ± 2.8	9.4 ± 4.5	8.2 ± 3.6	0.95 ± 0.31*	22.8 ± 10.2	13.1 ± 6.1
16	186	5.1 ± 2.9	9.5 ± 4.9	8.7 ± 3.3	1.00 ± 0.29*	23.2 ± 10.5	13.7 ± 6.1
17	162	5.2 ± 3.2	9.5 ± 4.9	9.2 ± 4.3	1.06 ± 0.35*	23.9 ± 11.4	14.1 ± 6.5
18	109	4.9 ± 2.6	9.4 ± 4.8	9.6 ± 3.9	1.14 ± 0.37*	23.9 ± 10.5	14.4 ± 6.3
Total	1634	5.6 ± 3.1	9.9 ± 4.8	8.3 ± 4.2	0.90 ± 0.30*	23.8 ± 11.3	13.4 ± 6.8
Girls							
12	316	6.8 ± 3.0	12.0 ± 4.7*	9.2 ± 4.7*	0.77 ± 0.21	27.9 ± 11.5*	18.8 ± 5.5*
13	269	7.2 ± 3.1*	13.2 ± 5.2*	10.4 ± 5.5*	0.79 ± 0.25	30.8 ± 12.8*	20.3 ± 5.5*
14	231	7.1 ± 2.7*	13.3 ± 4.6*	10.0 ± 4.3*	0.77 ± 0.22	30.5 ± 10.5*	20.6 ± 5.0*
15	197	7.8 ± 4.1*	14.4 ± 5.2*	11.1 ± 4.8*	0.79 ± 0.22	33.2 ± 12.9*	21.8 ± 4.9*
16	145	7.4 ± 3.1*	14.7 ± 4.4*	11.2 ± 4.8*	0.78 ± 0.25	33.4 ± 10.6*	22.4 ± 4.4*
17	131	7.4 ± 2.9*	15.0 ± 4.8*	11.7 ± 4.6*	0.80 ± 0.23	34.0 ± 10.7*	22.8 ± 4.8*
18	103	7.3 ± 2.7*	14.5 ± 4.5*	11.7 ± 4.5*	0.83 ± 0.23	33.4 ± 10.1*	22.5 ± 4.5*
Total	1392	7.2 ± 3.1*	13.5 ± 4.9*	10.5 ± 4.9*	0.79 ± 0.23	31.2 ± 11.7*	20.8 ± 5.2*

*: $P<0.05$ between genders.

Table 3. Age- and gender-specific percentile values of skinfold thickness (SFT, mm) in German adolescents aged 12-18 years

	Age (y)	−2.0001 (3rd percentile)	−1.3334 (10th percentile)	−0.6667 (25th percentile)	0 (50th percentile)	0.6667 (75th percentile)	1.3334 (90th percentile)	2.0001 (97th percentile)
Boys (*n* = 1634)								
Triceps	12	4.2	5.5	7.2	9.6	13.0	17.8	24.8
	13	4.0	5.1	6.7	8.9	12.1	16.8	23.9
	14	3.9	4.9	6.4	8.5	11.5	16.1	23.1
	15	3.8	4.9	6.3	8.3	11.3	15.7	22.6
	16	3.8	4.9	6.3	8.3	11.3	15.8	22.8
	17	3.8	4.8	6.2	8.3	11.2	15.7	22.8
	18	3.6	4.7	6.1	8.2	11.1	15.7	22.8
Subscapular	12	3.7	4.3	5.2	6.5	8.6	12.6	23.4
	13	3.8	4.5	5.3	6.6	8.5	12.1	20.6
	14	4.1	4.7	5.6	6.8	8.7	12.0	18.8
	15	4.6	5.2	6.1	7.3	9.2	12.3	18.4
	16	5.1	5.8	6.6	7.9	9.7	12.9	19.4
	17	5.5	6.1	7.0	8.2	10.0	13.2	20.3
	18	5.7	6.4	7.3	8.6	10.3	13.1	18.3
Subscapular/triceps	12	0.4	0.5	0.6	0.7	0.9	1.1	1.3
	13	0.4	0.5	0.6	0.8	0.9	1.1	1.4
	14	0.5	0.6	0.7	0.8	1.0	1.3	1.5
	15	0.5	0.6	0.7	0.9	1.1	1.4	1.7
	16	0.5	0.6	0.8	1.0	1.2	1.4	1.8
	17	0.5	0.7	0.8	1.0	1.3	1.5	1.9
	18	0.5	0.7	0.9	1.1	1.3	1.7	2.0
Girls (*n* = 1392)								
Triceps	12	5.3	6.8	8.7	11.2	14.4	18.6	24.0
	13	5.8	7.5	9.6	12.2	15.6	19.8	25.2
	14	6.2	7.9	10.1	12.8	16.2	20.3	25.3
	15	6.7	8.6	10.8	13.6	16.9	21.0	25.9
	16	7.2	9.1	11.4	14.1	17.5	21.4	26.2
	17	7.5	9.3	11.5	14.2	17.5	21.4	26.0
	18	7.6	9.3	11.4	13.9	17.0	20.7	25.2
Subscapular	12	4.0	5.0	6.2	8.0	10.8	15.1	22.7
	13	4.5	5.5	6.8	8.7	11.5	15.9	23.5
	14	5.0	6.0	7.3	9.2	12.0	16.3	23.5
	15	5.4	6.5	7.9	9.8	12.6	16.9	23.9
	16	5.8	6.8	8.2	10.2	12.9	17.2	24.0
	17	6.1	7.1	8.5	10.5	13.3	17.4	24.3
	18	6.3	7.3	8.7	10.7	13.4	17.5	24.4
Subscapular/triceps	12	0.4	0.5	0.6	0.7	0.9	1.1	1.3
	13	0.4	0.5	0.6	0.8	0.9	1.1	1.3
	14	0.4	0.5	0.6	0.7	0.9	1.1	1.3
	15	0.4	0.5	0.6	0.7	0.9	1.1	1.3
	16	0.4	0.5	0.6	0.7	0.9	1.1	1.3
	17	0.4	0.5	0.6	0.8	0.9	1.1	1.4
	18	0.5	0.6	0.7	0.8	1.0	1.2	1.4

demonstrate that WHtR was the best predictor for abdominal obesity in both boys (area under the curve [AUC] 0.974 ± 0.004) and girls (AUC 0.986 ± 0.003). In boys, this was followed by %BF (AUC 0.937 ± 0.008), $SFT_{subscapular}$ (AUC 0.936 ± 0.008), and the sum of the SFTs (AUC 0.934 ± 0.008). In girls, after WHtR, the best predictors for abdominal obesity were WHR (AUC 0.935 ± 0.009), the sum of the SFTs (AUC 0.903

Table 4. LMS percentile values of waist circumference (WC, cm), hip circumference (HC, cm), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) in 3024 German adolescents aged 12-18 years

	Age (y)	−2.0001 (3rd percentile)	−1.3334 (10th percentile)	−0.6667 (25th percentile)	0 (50th percentile)	0.6667 (75th percentile)	1.3334 (90th percentile)	2.0001 (97th percentile)
Boys (*n* = 1634)								
WC	12	56.6	59.7	63.4	67.8	73.3	80.4	90.2
	13	58.9	62.0	65.7	70.1	75.7	82.9	92.7
	14	61.0	64.2	67.9	72.5	78.1	85.3	95.0
	15	62.8	66.1	70.0	74.6	80.3	87.4	96.7
	16	64.3	67.7	71.7	76.4	82.1	89.1	98.0
	17	65.9	69.3	73.3	78.0	83.7	90.6	99.5
	18	67.2	70.6	74.6	79.2	84.9	91.8	100.8
HC	12	68.5	72.3	76.5	81.3	86.6	92.7	99.5
	13	71.5	75.6	80.0	84.8	90.1	95.8	102.0
	14	75.1	79.3	83.8	88.6	93.8	99.3	105.2
	15	78.6	82.7	87.0	91.8	96.8	102.3	108.2
	16	81.5	85.4	89.6	94.1	99.1	104.6	110.6
	17	83.4	87.1	91.1	95.6	100.5	106.0	112.2
	18	84.7	88.2	92.1	96.4	101.3	106.8	113.1
WHR	12	0.75	0.78	0.81	0.84	0.88	0.92	0.96
	13	0.75	0.77	0.80	0.83	0.87	0.91	0.96
	14	0.74	0.76	0.79	0.82	0.86	0.90	0.95
	15	0.73	0.76	0.79	0.82	0.86	0.90	0.94
	16	0.72	0.75	0.78	0.82	0.85	0.89	0.93
	17	0.73	0.76	0.79	0.82	0.85	0.89	0.93
	18	0.74	0.76	0.79	0.83	0.86	0.90	0.94
WHtR	12	0.38	0.39	0.41	0.44	0.47	0.51	0.57
	13	0.37	0.39	0.41	0.43	0.46	0.50	0.56
	14	0.37	0.39	0.41	0.43	0.46	0.50	0.56
	15	0.37	0.38	0.40	0.43	0.46	0.50	0.55
	16	0.37	0.39	0.41	0.43	0.46	0.50	0.55
	17	0.37	0.39	0.41	0.44	0.46	0.50	0.55
	18	0.38	0.40	0.42	0.44	0.47	0.51	0.56
Girls (*n* = 1392)								
WC	12	51.4	57.0	62.6	68.2	73.8	79.4	85.0
	13	52.8	58.5	64.3	70.0	75.8	81.5	87.2
	14	53.7	59.5	65.4	71.2	77.0	82.9	88.7
	15	54.9	60.9	66.8	72.8	78.8	84.7	90.7
	16	55.6	61.7	67.7	73.8	79.8	85.9	91.9
	17	55.8	61.8	67.9	74.0	80.0	86.1	92.2
	18	55.3	61.3	67.3	73.3	79.3	85.4	91.4
HC	12	70.7	75.6	80.4	85.3	90.1	95.0	99.8
	13	74.0	79.1	84.1	89.2	94.3	99.4	104.4
	14	76.0	81.3	86.5	91.7	96.9	102.1	107.3
	15	77.7	83.0	88.3	93.6	99.0	104.3	109.6
	16	78.4	83.8	89.2	94.6	100.0	105.3	110.7
	17	78.7	84.1	89.5	94.9	100.3	105.7	111.1
	18	78.6	84.0	89.4	94.8	100.2	105.6	111.0
WHR	12	0.71	0.73	0.76	0.79	0.83	0.88	0.94
	13	0.68	0.71	0.74	0.78	0.82	0.87	0.92
	14	0.67	0.70	0.73	0.77	0.81	0.86	0.91
	15	0.66	0.70	0.73	0.77	0.82	0.86	0.91
	16	0.66	0.70	0.74	0.78	0.82	0.87	0.92
	17	0.66	0.70	0.74	0.78	0.82	0.87	0.92
	18	0.66	0.69	0.73	0.77	0.81	0.86	0.91
WHtR	12	0.36	0.38	0.40	0.43	0.46	0.51	0.58
	13	0.36	0.38	0.40	0.43	0.46	0.51	0.57
	14	0.36	0.38	0.40	0.43	0.46	0.51	0.57
	15	0.36	0.38	0.40	0.43	0.47	0.51	0.57
	16	0.37	0.39	0.41	0.44	0.47	0.52	0.57
	17	0.37	0.39	0.41	0.44	0.47	0.52	0.57
	18	0.36	0.39	0.41	0.44	0.47	0.51	0.57

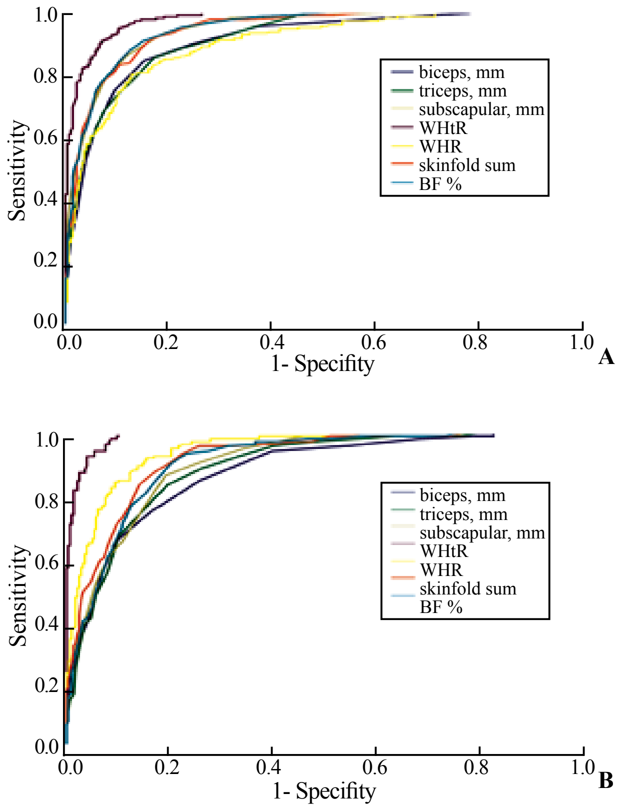

Fig. 2. ROC curves for prediction of abdominal obesity calculated from WHtR, WHR, sum of SFT, SFT_{biceps}, $SFT_{triceps}$, and %BF in males (**A**) and females (**B**). WHtR: waist-to-height ratio; WHR: waist-to-hip ratio; SFT: skinfold thickness; BF: body fat.

± 0.013), and %BF (AUC 0.891 ± 0.013).

Discussion

Our study presents age- and gender-specific percentile curves for WC, WHR, HC, WHtR, biceps, triceps, subscapular, and the sum of SFTs of a representative sample of 3024 German adolescents aged 12-18 years. As described previously for children 3-11 years of age,[21] WC increased with age at all percentiles. The increase of WC and HC was continuous in boys, and leveled off in girls at the age of 17.

Because there are considerable differences in the four commonly used anatomical sites for WC measurements,[4,22] it is difficult to make international comparisons of WC, and to assess the prevalence of metabolic syndrome. For example, the prevalence of metabolic syndrome as predicted by WC measurements differed by 3% among the measurement sites in men between the umbilicus and minimal waist, whereas in women, the prevalence ranged from 15.1% (umbilicus) to 14.4% (iliac crest), 14.1% (midpoint between iliac crest and the lowest rib), and 13.1% (minimal waist).[23] Considering the predictive role of WC in the IDF criteria for metabolic syndrome, and the differences in mean WC among different ethnicities,[12] international standardization of the protocol for measurement of WC is warranted. From 12 to 18 years of age, at the 90th percentile, WC increased in German adolescents from 80.4 to 91.8 cm in boys and from 79.4 to 85.4 cm in girls, and in Hong Kong Chinese from 74.0 to 81.6 cm in boys and from 68.4 to 72.6 cm in girls. The WHtR of Hong Kong Chinese adolescents was slightly higher in both boys (0.50 *vs.* 0.47) and girls (0.51 *vs.* 0.45) compared to German adolescents.[24] Because measurements were performed at the same site, during comparable periods (2000-2007 and 2005-2006, respectively, for German and Hong Kong Chinese adolescents) and in an urban area, these differences could be due to ethnic differences. In the period of 2003-2004, children and adolescents, 85% of whom lived in urban areas, had their WC measured at the same site.[25] As described previously for children, the percentile curves were steeper and higher in Iranians than in Germans.[26] Interestingly, the four-times-higher prevalence of metabolic syndrome according to the IDF criteria in Iranian adolescents was due mainly to the higher prevalence of dyslipoproteinemia in this population; however, it was also based on a two-times-higher prevalence of high WC.[27] White US adolescents aged 12-18 years had slightly lower WC values than German adolescents (males: 71.3 to 80.4 cm *vs.* 80.4 to 91.8 cm; females: 68.0 to 71.2 cm *vs.* 79.4 to 85.4 cm in US and German adolescents, respectively).[28] These differences could be due to the period of data collection (1992-1994), because ethnicity and measurement sites were similar.

In adolescents, BMI and SFT are significantly correlated with dual emission X-ray absorptiometry (DXA) measurements of body fat.[29] Compared to BMI, measurement of $SFT_{triceps}$ yielded better results for obesity screening in Portuguese boys and girls aged 10-15 years; there was a decrease of 2.9 mm in males and an increase of 3.0 mm in females.[30] Our 12-18-year-old male adolescents had a 2.1 mm decrease in $SFT_{triceps}$ overall, and a 2.1 mm increase at the 90th percentile. Furthermore, both in our study and the Portuguese study, SF triceps was a sensitive tool for detection of obesity using ROC curves with an AUC of 0.903 ± 0.010 (95%CI 0.883–0.924) in German male adolescents and an AUC of 0.868 ± 0.015 (95%CI 0.839–0.898) in German female adolescents aged 12–18 years. In 12-15 year old Portuguese males, the AUC ranged from 0.94 ± 0.045 (95%CI 0.84–0.98) to 0.86 ± 0.087 (95%CI 0.74–0.93), and in females from 0.94 ± 0.034 (95%CI 0.85–0.98) to 0.95 ± 0.036 (95%CI 0.84–0.99).[30] However, in German adolescents, abdominal obesity was better detected by WHtR in males (0.974 ±

0.004) and females (0.986 ± 0.003), as well as by four other parameters (Fig. 3). In 6-12 year old children, a previous study found that %BF calculations based on four SFT measurements was 40%–50% more sensitive than the IOTF definition of obesity.[31] We conclude that SFT measurements of adolescents should be used as the preferred screening tool because SFT predicts adult body fatness better than adolescent BMI does.[32]

The strengths of our study include the fact that similar studies have not been previously performed in German adolescents, and that we had a large sample population that was followed up over a long period of time in accordance with a consistently reproducible study procedure. A limitation of our study was its cross-sectional design and the missing informed consent for assessment at the pubertal stage. Furthermore, we do not describe the nutritional habits, physical activity, and other lifestyle choices of the study population. In addition, in general, comparisons of anthropometric data are complicated by different anatomic sites of measurement, different methods of establishing percentile curves, different periods of data collection, and overlapping age groups and populations (e.g., urban *vs.* rural).

In conclusion, this study adds to previous reports of percentile curves in children for fat patterning[21] by providing information about age- and gender-specific percentile curves of WC and HC, WHR and WHtR, and SFTs in adolescents. Our data may prove to be useful for establishing a multiethnic international definition of abdominal obesity in adolescents to be used for early detection and continuous global intervention. These fat patterning measurements are inexpensive and reproducible clinical screening methods without any adverse effects and are highly sensitive tools for detecting abdominal adiposity, especially WC and WHtR.

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Contributors: Haas GM contributed to study design, supervision, and data analysis, Liepold E contributed to data collection and Schwandt P contributed to study design, manuscript writing and was the guarantor.

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