Eur J Pediatr (2005) 164: 216–222
DOI 10.1007/s00431-004-1586-7

ORIGINAL PAPER

A. Miranda Fredriks · Stef van Buuren · Minne Fekkes
S. Pauline Verloove-Vanhorick · Jan Maarten Wit

Are age references for waist circumference, hip circumference and waist-hip ratio in Dutch children useful in clinical practice?

Received: 3 June 2004 / Accepted: 20 October 2004 / Published online: 21 January 2005

Abstract The aim of this study was to present age references for waist circumference (WC), hip circumference (HC), and waist/hip ratio (WHR) in Dutch children. Cross-sectional data were obtained from 14,500 children of Dutch origin in the age range 0–21 years. National references were constructed with the LMS method. This method summarises the distribution by three smooth curves representing skewness (L curve), the median (M curve), and coefficient of variation (S curve). The correlations between body mass index-standard deviation score (BMI-SDS), the circumferences and their ratio, and demographic variables were assessed by (multiple) regression analysis for three age groups: 0- < 5 years (1), 5- < 12.5 years (2), and 12.5- < 21 years (3). A cut-off for clinical use was suggested based on the International Obesity Task Force criteria for BMI. Mean WC and HC values increased with age. Mean WC was slightly higher in boys than in girls, and this difference was statistically significant from 11 years of age onwards. In contrast, HC was significantly higher in girls than in boys from 9 years onwards. The correlation between WC-SDS and BMI-SDS ($r=0.73$, $P<0.01$) and between HC and BMI-SDS ($r=0.67$, $P<0.01$) increased with age. With regard to WHR-SDS, a low correlation was found for 12.5–20 years of age ($r=0.2$, $P<0.01$). WC-SDS correlated positively with height SDS ($r=0.35$, $P<0.01$). *Conclusion:* Waist circumferences can be used to screen for increased abdominal fat mass in children, whereby a cut-off point of 1.3 standard deviation score seems most suitable.

A. M. Fredriks (✉) · S. van Buuren · M. Fekkes
S. P. Verloove-Vanhorick
TNO Prevention and Health,
2215, 2301 CE Leiden, The Netherlands
E-mail: miranda.fredriks@planet.nl
Tel.: +31-20-6718778
Fax: +31-71-5181920

A. M. Fredriks · S. P. Verloove-Vanhorick · J. M. Wit
Department of Paediatrics,
Leiden University Medical Centre,
Leiden, The Netherlands

Keywords Body mass index · Hip circumference · Standards · The Netherlands · Waist circumference

Abbreviations BMI: body mass index · HC: hip circumference · IOTF: International Obesity Task Force · QQ: quantile-quantile plot · WC: waist circumference · WFH: weight-for-height · WHR: waist-hip ratio

Introduction

In adults, there is abundant evidence that a predominantly central fat distribution is associated with increased risk of cardiovascular and metabolic diseases [18]. Originally, the waist/hip ratio (WHR) was used to estimate fat distribution but later studies suggested that waist circumference (WC) itself was a useful measure in its own right [21, 22, 32,35]. However, there is no consensus about the best cut-off points to be used for identifying individuals at risk. Some investigators suggested to use two cut-off points for each gender based on established cut-off points for body mass index (BMI): a WC >94 cm (level 1; overweight, BMI >25 kg/m^2) and >102 cm (level 2; obese, BMI >30 kg/m^2) in men and for women >80 and >88 cm, respectively [21]. Others proposed WC >100 cm when ≤40 years and WC >90 cm for adults >40 years, for both men and women [22]. There is considerable evidence that also in children, a greater central fat deposition increases the risk of metabolic complications such as atherogenic lipoprotein profile (high LDL cholesterol and triglycerides and low HDL cholesterol), insulin resistance and corresponding high basal insulin concentrations and glucose intolerance [6, 12, 13, 14, 23, 30,31], and high blood pressure. In addition, adiposity tracks from childhood into adulthood [16,36]. Therefore, early identification and treatment of children with central adiposity is important [35].

Reference charts of WC for children are available for several countries (United Kingdom, Spain, New Zealand, United States, Italy) [11, 23, 25, 28,35]. Some studies assessed the validity of WC, WHR, and various indices as indicators of trunk fat mass [34,35]; however, no long-term follow-up studies exist on the association between WC in childhood and adult diseases such as cardiovascular disease and metabolic syndrome. Consequently, there is no direct evidence available; longitudinal data are necessary to identify the best cut-off lines for children at risk.

The most common methods for diagnosing overweight and obesity are based on weight-for-height and BMI (kg/m^2). However, both measures are suboptimal markers for total body fat percentage and even less suitable to assess body fat distribution. In the light of the trend of increasing percentages of overweight and obese children, and in view of the special risk of excessive abdominal fat deposition, WC may serve as an easy and direct diagnostic measure for detecting overweight and obese children at risk. Then, early detection should in turn lead to early interventions to prevent later metabolic complications in adulthood.

Hip circumference (HC) also reflects to a certain extent the body composition (i.e. muscle mass, fat mass and skeletal frame), but in childhood its prognostic value in childhood for later health risks in adulthood is limited [11]. WHR is a measure of relative overall body fat distribution and has been widely used in adults. Similar to the situation with regard to WC, there is no consensus about the best cut-off limits for WHR. In one study, it was suggested to use high ratio ('apple' shape): 0.94 to >1.0 for men and >0.80 to >0.90 for women, since these were associated with increased risk for cardiovascular diseases and related mortality, while a lower ratio ('pear' shape) was not [26]. In children, however, the prognostic value of WHR appears to be low compared to WC and does not accurately reflect intra-abdominal fat mass [13,35]. Weight-for-height (WFH) ratio is a better predictor for visceral fat and of mortality than WHR [26].

Here we present reference SD curves for WC, HC, and WHR for Dutch children, aged 0–21 years, as well as the correlations with BMI-SDS, height SDS and demographic variables. We also present a proposal concerning cut-off lines for screening overweight and obese children and adolescents.

Subjects and methods

Subjects

Cross-sectional data on height, weight, WC, and HC were collected from 14,500 children, 7,482 boys and 7,018 girls, of Dutch origin aged 0–21 years in the Fourth Dutch Growth Study. They were measured in 1996–1997. Children with known growth disorders and those on medication known to interfere with growth were excluded from the sample ($n=108$). Until 4 years of age, measurements were mainly performed during the regular periodical health examinations by instructed health professionals in 24 Well Baby Clinics. From the age of 4 years onward, children were measured at 25 offices of the Municipal Health Services during regular preventive health assessments (at mean ages 5.5 and 7.5 years) or after receiving a personal invitation based on a stratified sample from the Municipal Register Office (≥9 years of age). To obtain a sufficiently large sample, additional measurements took place in high schools, universities, and a youth festival and during medical examinations for joining the army. In the age range 12–17 years, 25% of the measurements of the study population were derived from this additional sample, and between 40% between 17 and 21 years. The final sample is nationally representative [8,9]. Anthropometric measurements were performed by trained staff and a questionnaire on demographic variables was completed [8].

Measurements

Until 2 years of age, length of infants was measured in the supine position; thereafter standing height was measured. Infants until 15 months of age were weighed naked on calibrated baby-scales, older children on calibrated mechanical or electronic step-scales, wearing underwear only.

WC was measured midway between the lowest rib and the top of the iliac crest at the end of gentle expiration. HC was measured over the great trochanters. This was not necessarily the widest circumference. Circumferences were measured over the naked skin and noted to the nearest 0.1 cm. Infants were measured in the supine position.

Statistical analysis

BMI was calculated as weight (kg)/height (m^2). References for WC, HC, and WHR for age were constructed with the LMS method and presented as SD lines. This method summarises the distribution of the data by three spline curves, the L, M, and S, that vary in time: the Box-Cox transformation power that converts data to normality and minimises the skewness of the dataset (L), the median (M), and the coefficient of variation (S) [4]. The choice of the smoothing factors for the L, M, and S curves was made by creating local detrended quantile-quantile (QQ) plots [2]. Besides WC (cm) / height (cm) the conicity index was calculated (WC/ 0.109×square root of weight/height), in which WC and height were expressed in meters and weight in kg. The associations between WC-SDS, HC-SDS, WHR-SDS, and BMI-SDS and height SDS, and the association with demographic variables were calculated by (multiple) regression analyses and studied for three age groups: 0- < 5 years (1), 5- < 12.5 years (2) and 12.5- < 21 years (3).

In order to determine which cut-off of WC would be best for screening purposes, we used the following strategy. First, we calculated for all children over 2 years of age if they were detected to be overweight or obese according the cut-off limits proposed by the International Obesity Task Force (IOTF) for BMI [5]. Second, we calculated contingency tables for WFH -SDS, WC-SDS and WHR-SDS according to possible screening criteria; which means SDS > 2.5 (0.5% detected for follow-up), SDS > 2.3 (1%), SDS > 2 (2%), SDS > 1.7 (5%), and SDS > 1.3 (10%). In this way, we estimated the amount of misclassification for each separate screening criterion.

Table 1 0 and ± 2 SD reference values for WC (cm), HC (cm), and WHR for boys and girls of Dutch origin aged 0–21 years

Boys

Age		WC			HC			WHR	
Years	**−2 SD**	**0 SD**	**+2 SD**	**−2 SD**	**0 SD**	**+2 SD**	**−2 SD**	**0 SD**	**+2 SD**
0.25	33.0	39.4	45.4	31.6	37.3	43.9	0.899	1.041	1.196
0.50	35.9	42.0	48.0	35.5	41.4	48.3	0.885	1.013	1.152
0.75	37.4	43.4	49.5	37.6	43.4	50.4	0.879	0.998	1.128
1.0	38.3	44.3	50.6	39.1	44.7	51.6	0.875	0.988	1.111
2.0	41.1	46.9	53.7	42.9	48.5	55.6	0.869	0.968	1.077
3.0	44.0	49.7	56.9	45.5	51.4	59.0	0.866	0.962	1.070
4.0	45.5	51.2	59.0	47.8	54.2	62.5	0.849	0.945	1.053
5.0	46.3	52.1	60.7	49.8	56.7	66.0	0.827	0.923	1.032
6.0	47.2	53.3	62.9	51.5	59.0	69.6	0.810	0.905	1.015
7.0	48.4	54.8	65.5	53.2	61.3	73.2	0.796	0.891	1.002
8.0	49.7	56.5	68.5	55.3	64.2	77.5	0.784	0.878	0.990
9.0	51.0	58.2	71.4	57.8	67.4	81.7	0.773	0.866	0.978
10.0	52.3	59.9	74.3	60.2	70.4	85.2	0.763	0.855	0.966
11.0	53.8	61.8	77.2	62.4	73.3	88.4	0.755	0.846	0.957
12.0	55.4	63.9	80.0	64.7	76.3	91.7	0.748	0.838	0.949
13.0	57.2	66.1	82.8	67.4	79.8	95.5	0.741	0.831	0.942
14.0	59.1	68.2	85.2	70.7	83.7	99.1	0.735	0.825	0.937
15.0	60.9	70.3	87.4	74.2	87.1	102.0	0.730	0.821	0.933
16.0	62.6	72.3	89.4	76.9	89.6	104.0	0.729	0.820	0.934
17.0	64.1	74.0	91.1	78.6	91.3	105.4	0.729	0.821	0.936
18.0	65.4	75.6	92.6	79.8	92.3	106.3	0.731	0.824	0.941
19.0	66.6	77.0	94.0	80.6	93.1	107.0	0.733	0.827	0.946
20.0	67.7	78.3	95.4	81.2	93.6	107.5	0.735	0.831	0.951
21.0	68.8	79.6	96.6	81.6	94.1	107.9	0.738	0.834	0.956

Girls

Age		WC			HC			WHR	
Years	**−2 SD**	**0 SD**	**+2 SD**	**−2 SD**	**0 SD**	**+2 SD**	**−2 SD**	**0 SD**	**+2 SD**
0.25	32.1	38.4	44.2	31.4	36.8	43.7	0.885	1.031	1.174
0.50	35.0	41.0	47.0	35.3	41.1	48.4	0.868	0.997	1.128
0.75	36.4	42.3	48.5	37.2	43.1	50.4	0.863	0.982	1.105
1.0	37.4	43.2	49.6	38.5	44.4	51.6	0.863	0.973	1.091
2.0	40.9	46.4	53.0	42.3	48.4	55.8	0.864	0.959	1.063
3.0	43.5	49.2	56.6	45.4	52.0	60.1	0.856	0.946	1.047
4.0	44.6	50.6	58.7	47.6	54.8	63.9	0.835	0.923	1.028
5.0	45.1	51.3	60.4	49.2	57.0	67.0	0.809	0.899	1.008
6.0	45.9	52.5	62.7	51.0	59.6	70.9	0.788	0.879	0.993
7.0	47.1	54.0	65.5	53.0	62.4	75.3	0.772	0.863	0.981
8.0	48.3	55.7	68.5	55.1	65.5	80.0	0.757	0.849	0.970
9.0	49.6	57.3	71.4	57.6	69.0	85.0	0.743	0.834	0.958
10.0	50.9	59.0	74.2	59.9	72.1	89.4	0.730	0.820	0.946
11.0	52.3	60.6	76.9	62.2	75.2	93.2	0.716	0.806	0.934
12.0	53.8	62.4	79.3	65.1	79.0	97.2	0.703	0.792	0.922
13.0	55.3	64.1	81.4	68.5	83.2	101.2	0.691	0.779	0.911
14.0	56.6	65.6	83.2	71.4	86.6	104.3	0.681	0.768	0.903
15.0	57.8	66.8	84.6	73.5	89.0	106.4	0.673	0.760	0.898
16.0	58.8	67.9	85.7	74.9	90.6	107.9	0.667	0.755	0.897
17.0	59.6	68.8	86.7	76.1	91.9	109.1	0.664	0.752	0.898
18.0	60.3	69.5	87.5	77.1	93.0	110.3	0.662	0.750	0.900
19.0	60.9	70.2	88.3	77.8	93.8	111.0	0.661	0.750	0.904
20.0	61.4	70.8	88.9	77.9	93.9	111.2	0.661	0.750	0.908
21.0	61.9	71.3	89.5	78.5	94.5	111.7	0.660	0.750	0.912

Results

Reference SD charts for WC, HC, BMI (including the IOTF overweight and obesity lines), and WHR for age were constructed for boys and girls aged 0–21 years [15]. Mean WC and HC increase in boys and girls with age and vary with gender, so separate age reference charts are necessary to evaluate an individual's position. In infancy, gender differences were small; however, at all ages, WC was higher in boys than in girls and this difference was significant from 11 years of age onwards. Boys' curves continued to increase more sharply after this age whereas girls' curves began to level off. In contrast, at all ages HC was higher in girls than in boys, and from 9 years onwards differences were statistically significant. From 16 years of age, differences decreased again. Because the increase with age was relatively greater for HC than for WC, mean WHR decreased from 1.01 (0.5 years) to 0.83 (21 years) in boys and from 1.0 to 0.75 in girls. The reference values are shown in Table 1.

The correlations between the different variables for all ages are shown in Table 2. For WHR-SDS, the correlation with BMI-SDS was low, the highest was seen in boys ($r=0.13$) and girls ($r=0.25$) over 12.5 years ($P<0.01$). The correlation between WC-SDS and BMI-SDS was relatively low in 0- < 5-year-olds ($r=0.55$ in boys, 0.59 in girls), and considerably higher in 5- < 12.5-year-olds ($r=$ 0.79 and 0.81) and ≥12.5 years ($r=0.82$ and 0.77) ($P<0.01$). Similar but somewhat lower correlations were observed between HC-SDS and BMI-SD: for age group 1 $r=0.63$ and 0.66; for group 2 $r=0.75$ and 0.76, and for group 3 $r=0.72$ and 0.69 ($P<0.01$). For WHR-SDS, only a low correlation was found for age group 3 ($r=0.20$; $P<0.01$). The correlations between WC-SDS and height SDS were much lower than those between WC-SDS and BMI-SDS: in group 1 $r=0.33$ in boys, 0.36 in girls, in group 2 $r=0.43$ and 0.42, and in group 3 $r=0.34$ and 0.27 ($P<0.01$).

In the multivariate regression model, the variance ($r^2=0.63$) of BMI-SDS was predicted by WC-SDS ($\beta+0.64$, SE 0.024), HC-SDS ($\beta+0.32$, SE 0.024), WHR-SDS ($\beta-0.14$, SE 0.019), and height SDS ($\beta-0.26$, SE 0.006) in which WC was the strongest predictor ($P<0.001$). Predictive variables for WC-SDS were BMI-SDS ($\beta+0.07$, SE 0.003), HC-SDS ($\beta+0.86$, SE 0.003), height SDS ($\beta+0.06$, SE 0.002), WHR-SDS ($\beta+0.71$, SE 0.002), and gender ($\beta-0.014$, SE 0.002, higher for males) ($r^2=0.96$).

The strategy to determine which cut-off WC value would be the best for screening purposes resulted in a cut-off > 1.3 SDS for overweight and > 2.3 SDS to detect obesity. The first cut-off point would classify approximately 10% as overweight children, a similar percentage as detected by the IOTF cut-off lines in BMI. Of these children, 6%–7% were classified as overweight by both BMI and WC cut-off lines, but 3%–4% by only one of the two. We found significantly higher height SDS, higher WC-SDS, higher WHR-SDS, lower BMI-SDS, higher WFH-SDS, higher weight for age SDS, higher head circumference SDS, and a higher conicity index in the 'WC only group' compared to the 'BMI only group'. A WC cut-off value of > 2.3 SDS was needed to classify a similar percentage of obese children as found by the BMI cut-off criterion. Of these children, 0.5% was detected by both screening criteria. When we compared the group of children who would only be detected by the WC cut-off line for obesity and the group only detected by the BMI cut-off line for obesity, we found that the 'WC only group' was older and consisted of more boys. The group had also a higher height SDS, higher WC-SDS, higher WHR-SDS, higher head circumference SDS, and a higher conicity index. The 'BMI only group' had higher WFH-SDS, and higher BMI-SDS (all significant at $P<0.05$). Table 3 reports the suggested cut-off points for each 1-year age group in boys and girls.

The strategy converting the cut-off points as used in adults towards SDS for young adults in our study population are shown in Table 4. The lowest reported circumferences in literature (90 cm for boys and 80 cm for girls) would fit best in our population. Higher cut-off limits would mean that too many young adults at risk would remain undetected.

Discussion

This study provides reference SD charts for WC, HC and WHR for age for a large and representative sample of Dutch boys and girls between 0–21 years old. Our results indicate that compared to the other two indicators, WC has a strong correlation with BMI. Furthermore, using a WC above 1.3 SDS gives a reasonable approximation of overweight as defined according the international BMI cut-off values.

The American Bogulesa study [28] found similar WC values between 5–7 years of age, and somewhat higher

Table 2 Pearson correlation coefficient between the SD of the variables BMI, WFH, WC, HC, conicity index and height. All significance levels (two tailed) $P<0.01$ except for height and WFH ($P=0.79$) ($n=13{,}418$–$14{,}427$)

	BMI SD	WFH SD	WC SD	HC SD	Conicity	Height SD
BMI SD	1.000	0.969	0.703	0.694	0.069	0.111
WFH SD	0.969	1.000	0.652	0.638	0.063	−0.002
WC SD	0.703	0.652	1.000	0.693	0.634	0.351
HC SD	0.694	0.638	0.693	1.000	0.207	0.425
Conicity	0.069	0.063	0.634	0.207	1.000	0.025
Height SD	0.111	−0.002	0.351	0.425	0.025	1.000

Table 3 Suggested cut-off points for waist circumference for age (years) for boys and girls aged 2.0–21.0 years based on the IOTF cut-off criteria for overweight and obesity in the Dutch reference population

	Boys			Girls		
Age (years)	Mean	SDS > 1.3	SDS > 2.3	Mean	SDS > 1.3	SDS > 2.3
2.0	46.93	51.23	54.86	46.38	50.56	54.16
2.5	48.40	52.81	56.64	47.93	52.27	56.10
3.0	49.68	54.18	58.20	49.20	53.75	57.84
3.5	50.59	55.21	59.44	50.04	54.81	59.20
4.0	51.18	55.94	60.43	50.56	55.55	60.25
4.5	51.64	56.59	61.38	50.94	56.16	61.19
5.0	52.10	57.25	62.38	51.34	56.80	62.19
5.5	52.64	58.02	63.52	51.85	57.58	63.38
6.0	53.28	58.91	64.84	52.50	58.53	64.79
6.5	54.01	59.91	66.31	53.25	59.60	66.36
7.0	54.79	60.98	67.87	54.04	60.72	68.01
7.5	55.61	62.12	69.53	54.86	61.86	69.70
8.0	56.46	63.27	71.23	55.68	63.00	71.40
8.5	57.31	64.43	72.91	56.49	64.14	73.11
9.0	58.16	65.58	74.56	57.31	65.26	74.79
9.5	59.02	66.74	76.22	58.14	66.36	76.40
10.0	59.91	67.90	77.83	58.96	67.45	77.98
10.5	60.83	69.08	79.43	59.79	68.51	79.47
11.0	61.80	70.30	81.00	60.64	69.57	80.91
11.5	62.82	71.56	82.57	61.51	70.62	82.28
12.0	63.88	72.82	84.06	62.38	71.65	83.58
12.5	64.96	74.08	85.48	63.25	72.66	84.81
13.0	66.06	75.34	86.86	64.08	73.58	85.86
13.5	67.16	76.56	88.12	64.85	74.44	86.83
14.0	68.24	77.75	89.30	65.57	75.23	87.71
14.5	69.31	78.89	90.41	66.23	75.93	88.46
15.0	70.33	79.97	91.40	66.82	76.57	89.12
15.5	71.32	81.00	92.34	67.37	77.14	89.71
16.0	72.27	82.00	93.25	67.87	77.67	90.28
16.5	73.16	82.92	94.07	68.33	78.16	90.80
17.0	74.01	83.79	94.86	68.75	78.61	91.26
17.5	74.80	84.62	95.59	69.15	79.02	91.68
18.0	75.56	85.41	96.30	69.51	79.42	92.11
18.5	76.28	86.17	97.01	69.86	79.78	92.50
19.0	76.98	86.89	97.65	70.17	80.12	92.85
19.5	77.65	87.60	98.31	70.47	80.44	93.18
20.0	78.31	88.29	98.91	70.76	80.73	93.48
20.5	78.96	88.97	99.54	71.03	81.03	93.82
21.0	79.60	89.62	100.13	71.30	81.31	94.10

Table 4 According to the suggested cut-off points commonly used in adults, WC were calculated towards SDS for young Dutch adults aged 18, 19, and 21 years in our study population

Dutch boys WC (cm)	SDS (18 years)	SDS (19 years)	SDS (21 years)
90	1.77	1.62	1.34
94	2.12	2.00	1.75
100	2.57	2.48	2.29
Dutch girls WC (cm)			
80	1.36	1.29	1.16
88	2.03	1.98	1.89
90	2.17	2.12	2.04

values from 8 years onwards to 17 years in both American boys and girls. However, these differences for girls quickly decreased after 16 years of age. Compared to a Spanish study, WC in Dutch children was lower in boys aged 4–14.9 years, and the differences increased with age to a maximum of 4 cm. For girls a similar phenomenon was seen [28]. Spanish children had higher BMI references values and lower mean heights for age [27]. Dutch mean WC values were comparable with British data from 1977 (boys, 11 to 17 years) and for girls with data from 1986, and were lower than British WC values measured in 1997 [23]. Similar results were found for BMI.

The prevalence of overweight in the Netherlands has doubled over the last 20 years. For WC, no Dutch data were available until now. In Spain and the United Kingdom [23,29], the secular increase in WC greatly exceeded that of BMI, especially in girls. Consequently the British study concluded that the prevalence of obesity has been systematically underestimated in 11–16-year-old British children [23]. This suggests that the central accumulation of body fat has risen more steeply than total body mass as derived from height and weight. In other words, the increase in the prevalence of overweight and obesity may have been underestimated, as BMI fails to distinguish between muscle and fat, and BMI seems therefore a poor proxy for central fatness [23]. We assume that a similar process have occurred in the Netherlands. WC, rather than BMI, could therefore be a better candidate for acting as a screening instrument; especially when one considers the special role that abdominal fat appears to play as a risk factor for later metabolic and heart disease, and the ease with which WC can be measured in preventive health programmes. It is also a good instrument to monitor the prevalence of (central) obesity over time. Therefore, WC should certainly be included in future growth studies.

There are several advantages of WC measurement compared to BMI and WHR: (1) WC is relatively easy to perform, (2) it is easy to instruct, so subjects can measure themselves [19], and (3) WC predicts mortality better than other anthropometric measures because of the association with BMI, fat distribution, and metabolic abnormalities [12]. BMI can provide a general description of adiposity characteristics in a healthy paediatric population, but it is less accurate in predicting fatness in an individual child [7]. A longitudinal study in 8-year-olds showed that WC was the best predictor for overweight at the age of 12 years, but more longitudinal studies from young childhood to young adulthood are necessary [24].

As mentioned above, one of the advantages of WC is that children can measure it themselves. The studied validity of self-reported circumferences in adults is reasonable [21]. There was only a slight overestimation of waist girths and underestimation of hip girths when self-measurement was compared with technician measurement. The within-person correlation between two measurements was 0.96 for WC and 0.93 when self-measurement in adult women was compared with technician measurement. The within-person variation in WC measurement increased as WC increased [20].

Before WC can be used as a screening instrument in youth health care programmes, a rational cut-off line for an increased risk is needed. We found that the correlation between BMI-SDS and WC-SDS increases with age from 0.57 to 0.8. Ideally, we need prospective studies in order to determine appropriate cut-off values for identifying children at risk and data on metabolic abnormalities and high fat mass. As long as these are lacking, a strategy comparing a reference group and a disease group might be used [3]. Such design enables to calculate both sensitivity and specificity as well as the median detection times. For screening purposes, we will usually strive for cut-off values with a high specificity, e.g. >99%. A cross-sectional study by an Italian group [25] found that prepubertal children with a WC >90th percentile were more likely to have multiple risk factors than children with a WC <90th percentile. Their conclusions were based on the relationship between WC and lipid concentrations and blood pressure. In a Spanish study, the screening performance for BMI and WC were studied based on total body adiposity [34]. Both measurements were highly correlated with total fat percentage. A WC >70th percentile was recommended as cut-off for abnormal metabolic variables based on ROC analyses (sensitivity 76%, specificity 81%) [29,34]. Using a similar method with ROC curves, a study in New Zealand (children aged 3–19 years) found that a WC above the 80th percentile best correlated with high trunk fat mass measured by dual energy X-ray absorptiometry [35]. WC (sensitivity 88%, specificity 93%) was a significantly better predictor than WHR [35]. A study in the United Kindom recently used the cut-off points of 91st percentile and the 98th percentile (SD 1.33 and 2) to define overweight and obesity, based on BMI and WC separately [23]. Based on the approaches described in this paper, we suggest a cut-off value for WC of 1.3 SDS for screening overweight and of 2.3 SDS for obesity in cases where direct measures of abdominal fat are not available.

WHR is generally considered a good tool to distinguish between the different types of fat distribution because it is highly correlated with visceral fat and plasma lipid concentrations. WHR showed negative associations with HDL and positive associations in the ratio total cholesterol/HDL in pre- and postpubertal girls [13]. The decrease of WHR with age, especially in girls, is due to increase in pelvic diameter and predominant fat deposition in the gluteal area [33]. WHR correlates with intra-abdominal fat, but higher correlations were found for WC [33]. One of the disadvantages of WHR is that a reduction in weight usually results in a reduction in both WC and HC, so that WHR may not decrease despite the leaner body composition. In addition, a decrease in WHR may not be related to a reduction in cardiovascular risk factors [26]. All in all it appears that WHR is less useful for identifying children at risk.

In a Japanese study, waist-height ratio was proposed as the best predictor of cardiovascular risk and metabolic risk factors in schoolchildren [17]. This result was found earlier in adults, when waist-to-height was suggested to be the best simple anthropometric predictor of visceral fat and a better predictor of morbidity and mortality than WHR and WC [1,26]. A disadvantage is that waist-to-height is a ratio whereby height is inversely associated with morbidity/mortality independently of fat distribution. In addition, WC is only weakly correlated with height, so there is a minimal need to adjust waist-for-height [26].

It is likely that in the Netherlands, as in other industrialised countries, a further increase in the prevalence of overweight and obesity will occur. Because of the risk of future morbidity, particularly due to accumulation of excess central fat, an active preventive campaign in the Netherlands would be of great importance. It would also be advisable to monitor WC in groups with known high prevalences of overweight and obesity, such as certain ethnic groups and children living in urban areas [10].

Acknowledgements This study was carried out in co-operation with the Well Baby Clinics and Municipal Health Services and was financially supported by The Ministry of Health, Welfare and Sports, Netherlands Organisation for Health Research and Development, Nutricia Nederland BV, and Pfizer BV.

References

1. Ashwell M, Cole TJ, Dixon AK (1996) Ratio of waist circumference to height is strong predictor of intra-abdominal fat. BMJ 313: 559–560
2. van Buuren S, Fredriks AM (2001) Worm plot: a simple diagnostic device for modelling growth reference curves. Stat Med 20: 1259–1277
3. van Buuren S, van Dommelen P, Zandwijken GRJ, Grote FK, Wit JM, Verkerk PH (2004) Towards evidence based referral criteria for growth monitoring. Arch Dis Child 89: 336–341
4. Cole TJ, Green PJ (1992) Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med 11: 1305–1319
5. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 320: 1240–1243
6. Daniels SR, Khoury PR, Morrison JA (2000) Utility of different measures of body fat distribution in children and adolescents. Am J Epidemiol 152: 1179–1184
7. Ellis KJ (1996) Measuring body fatness in children and young adults: comparison of bioelectric impedance analysis, total body electrical conductivity, and dual-energy X-ray absorptiometry. Int J Obes Relat Metab Disord 20: 866–873
8. Fredriks AM, Van Buuren S, Burgmeijer RJ, Meulmeester JF, Beuker RJ, Brugman E Roede MJ, Verloove-Vanhorick SP, Wit JM (2000) Continuing positive secular growth change in The Netherlands 1955–1997. Pediatr Res 47: 316–323
9. Fredriks AM, Buuren S Van, Wit JM, Verloove-Vanhorick SP (2000) Body mass index measurements in 1996–7 compared with 1980. Arch Dis Child 82: 107–112
10. Fredriks, AM, van Buuren S, Hira Sing RA, Wit JM, Verloove-Vanhorick SP (2004) Alarming prevalences of overweight and obesity for children of Turkish, Moroccan and Dutch origin in the Netherlands according to the international standard. Acta Paediatr (in press)

11. Freedman DS, Serdula MK, Scrinivasan R, Berenson S (1999) Relation of circumferences and skinfold thickness to lipid and insulin concentrations in children and adolescents: the Bogulesa heart Study. Am J Clin Nutr 69: 308–317
12. Flodmark CE, Sveger T, Nilsson-Ehle P (1994) Waist measurement correlates to a potantially atherogenic lipoprotein profile in obese 12–14-year-old children. Acta Paediatr 83: 941–945
13. Gillum RF (1999) Distribution of waist-to-hip ratio, other indices of body fat distribution and obesity and associations with HDL cholesterol in children and young adults aged 4–19 years: the Third National Health and Nutrition Examination Survey. Int J Obes Relat Metab Disord 23: 556–563
14. Gower BA, Nagy TR, Goran MI (2001) Visceral fat, insulin sensitivity, and lipids in prepubertal children. Diabetes 50: 477–478
15. Growth charts 1997. Dutch Growth Study TNO/LUMC (2002) Bohn Stafleu van Loghum, Houten, The Netherlands
16. Guo SS, Roche AF, Chumlea WC, Gardner JD, Siervogel RM (1994) The predictive value of childhood body mass index values for overweight at age 35 years. Am J Clin Nutr 59: 810–819
17. Hara M, Saitou E, Iwata F, Okada T, Harada K (2002) Waist-to-height ratio is the best predictor of cardiovascular disease risk factors in Japanese schoolchildren. J Atheroscler Thromb 9: 127–132
18. Kissebah AH (1996) Intra-abdominal fat: is it a major factor in developing diabetes and coronary artery disease? Diabetes Res Clin Pract 30[Suppl]: 25–30
19. van der Kooy K, Leenen R, Seidell JC, Deurenberg P, Droop A, Bakker CJ (1993) Waist-hip ratio is a poor predictor of changes in visceral fat. Am J Clin Nutr 57: 327–333
20. Kushi LH, Kaye SA, Folsom AR, Soler JT, Prineas RJ (1988) Accuracy and reliability of self-measurement of body girths. Am J Epidemiol 28: 740–748
21. Lean MEJ, Han TS, Seidell JC (1995) Impairment of health and quality of life in people with large waist circumference. Lancet 351: 853–856
22. Lemieux S, Prud'homme D, Bouchard C, Tremblay A, Despres JP (1996) A single threshold value of waist girth identifies normal weight and overweight subjects with excess visceral adipose tissue. Am J Clin Nutr 64: 685–693
23. McCarthy HD, Ellis SM, Cole TJ (2003) Central overweight and obesity in British youth aged 11–16 years: cross sectional surveys of waist circumference. BMJ 326: 624
24. Maffeis C, Pietrobelli A, Grezzania, Provera S, Tato L (2001) Waist circumference and cardio vascular risk factors in prepubertal children. Obes Res 9: 179–187
25. Maffeis C, Grezzani A, Pietrobelli A, Provera S, Tato L (2001) Does waist circumference predict fat gain in children? Int J Obesity 25: 978–983
26. Molarius A, Seidell JC (1998) Selection of anthropometric indicators for classification of abdominal fatness- a critical review. Int J Obes 22: 719–727
27. Moreno LA, Fleta J, Mur L, Rodriguez G, Sarria A, Bueono M (1997) Indices of body fat distribution in Spanish children aged 14.0–14.9 years. J Pediatr Gastroenterol Nutr 25: 175–181
28. Moreno LA, Fleta J, Mur L, Rodriguez G, Sarria A, Bueono M (1999) Waist circumference values in Spanish children-Gender related differences. Eur J Clin Nutr 53: 429–433
29. Moreno LA, Pineda I, Rodriguez G, Fleta J, Sarria A, Bueono M (2002) Waist circumference for the screening of the metabolic syndrome in children. Acta Paediatr 91: 1307–1312
30. Owens S, Litaker M, Allison J, Riggs S, Ferguson M, Gutin B (1999) Prediction of visceral adipose tissue from simple anthropometric measurements in youths with obesity. Obes Res 7: 16–22
31. Poskitt EME (2002) At risk "waistlines". Acta Paediatr 91: 1283–1284
32. Rankinen T, Kim SY, Perusse L, Despres JP, Bouchard C (1999) The prediction of abdominal visceral fat level from body composition and anthropometry: ROC analysis. Int J Obes Relat Metab Disord 23: 801–809
33. de Ridder CM, De Boer RW, Seidell JC, Nieuwenhoff CM, Jeneson JA, Bakker CJ, Zonderland ML, Erich WB (1992) Body fat distribution in pubertal girls quantified by magnetic resonance imaging. Int J Obes Relat Metab Disord 16: 443–449
34. Sarria A, Moreno LA, Garcia-Llop LA, Fleta J, Morellon MP, Bueno M (2001) Body mass index, triceps skinfold and waist circumference in screening for adiposity in male children and adolescents. Acta Paediatr 90: 387–392
35. Taylor RW, Jones IE, Williams SM, Goulding A (2000) Evaluation of waist circumference, waist to hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3–19 years. Am J Clin Nutr 72: 490–495
36. Wattigney WA, Webber LS, Srinivasan SR, Berenson GS (1995) The emergence of clinically abnormal levels of cardiovascular disease risk factor variables among young adults: the Bogalusa Heart Study. Prev Med 24: 617–626