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Waist-to-height ratio, waist circumference and BMI as indicators of percentage fat mass and cardiometabolic risk factors in children aged 3–7 years

Anna Sijtsma [a], Gianni Bocca [b], Carianne L'Abée [b], Eryn T. Liem [b], Pieter J.J. Sauer [b], Eva Corpeleijn [a,*]

[a] Department of Epidemiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[b] Department of Pediatrics, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands

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SUMMARY

Objective: To assess whether waist-to-height-ratio (WHtR) is a better estimate of body fat percentage (BF %) and a better indicator of cardiometabolic risk factors than BMI or waist circumference (WC) in young children.

Methods: WHtR, WC and BMI were measured by trained staff according to standardized procedures. ^2H_2O and $^2H_2^{18}O$ isotope dilution were used to assess BF% in 61 children (3–7 years) from the general population, and bioelectrical impedance (Horlick equation) was used to assess BF% in 75 overweight/obese children (3–5 years). Cardiometabolic risk factors, including diastolic and systolic blood pressure, HOMA2-IR, leptin, adiponectin, triglycerides, total cholesterol, HDL- and LDL-cholesterol, TNFα and IL-6 were determined in the overweight/obese children.

Results: In the children from the general population, after adjustments for age and gender, BMI had the highest explained variance for BF% compared to WC and WHtR ($R^2 = 0.32$, 0.31 and 0.23, respectively). In the overweight/obese children, BMI and WC had a higher explained variance for BF% compared to WHtR ($R^2 = 0.68$, 0.70 and 0.50, respectively). In the overweight/obese children, WHtR, WC and BMI were all significantly positively correlated with systolic blood pressure ($r = 0.23$, 0.30, 0.36, respectively), HOMA2-IR ($r = 0.53$, 0.62, 0.63, respectively), leptin ($r = 0.70$, 0.77, 0.78, respectively) and triglycerides ($r = 0.33$, 0.36, 0.24, respectively), but not consistently with other parameters.

Conclusion: In young children, WHtR is not superior to WC or BMI in estimating BF%, nor is WHtR better correlated with cardiometabolic risk factors than WC or BMI in overweight/obese children. These data do not support the use of WHtR in young children.

1. Introduction

Various measures are used to detect obesity – defined in terms of excess body fat – and the risk of obesity-related co-morbidities. Body mass index (BMI) is the most commonly used measure, but waist circumference (WC) and waist-to-height ratio (WHtR) as measures of abdominal fat are also used. WHtR may have an advantage over BMI because BMI provides no information about body fat distribution, in particular abdominal fat. Central fat distribution is associated with greater health risks than total body fat.[1,2] Therefore, WHtR may be a better indicator of cardiometabolic risk factors than BMI. In adults, WHtR is found to be a better measure than BMI and WC for the prediction of obesity-related cardiometabolic risks factors.[3,4] An advantage of WHtR over BMI and WC in adults is that a general cut-off value of 0.5 can be used for both men and women across many ethnicities.[3,4] Moreover, the advantage of WHtR over WC is that WHtR adjusts for height. When compared to short people with the same WC, tall people have lower levels of cardiometabolic risk factors and a 30% lower prevalence of the metabolic syndrome.[5]

WHtR decreases from birth to the age of five from 0.69 to 0.48,[6] and this decrease continues until early adolescence to 0.40–0.41.[7] From then on it increases slightly to 0.42–0.43 towards the age of 18. Therefore, one cut-off value for all ages during childhood and adolescence is not feasible.[6,7] In contrast to adults, it is less clear in young children whether WHtR is better than BMI or WC in

* Corresponding author. Department of Epidemiology (FA40), University Medical Center Groningen, PO Box 30.001, 9700 RG Groningen, The Netherlands. Tel.: +31 050 3610738; fax: +31 050 3614493.
E-mail address: e.corpeleijn@umcg.nl (E. Corpeleijn).

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predicting obesity-related cardiometabolic risk factors. Most of the studies available evaluated the relationship between WHtR and body fat percentage (BF%) or cardiometabolic risk factors over a large age range, including both children and adolescents, with most studies using children aged 6 years or older. To prevent overweight and obesity in adolescents and adults, early detection of overweight and obesity in young children is needed. During early childhood especially (2–6 years of age), excessive BMI gain is predictive of obesity and cardiometabolic risk in adolescence[8] and adulthood.[9–11] Furthermore, adipose tissue produces cytokines, like IL-6 and TNFa, which may cause metabolic syndrome, this is already seen in children.[12] These cytokines may be a possible link between insulin resistance and adiposity. Increased levels of the separate components of metabolic syndrome have already been demonstrated in children 6–9 years old.[13] In children aged younger than 6 it is unknown whether these processes are present yet.

Few studies have examined the association between WHtR and BF%[14,15] or cardiometabolic risk factors[15–17] in children aged younger than 6 years. Of the three studies investigating the associations between WHtR and cardiometabolic risk factors in children aged younger than 6 years, only one study analysed the associations between WHtR and more than one cardiometabolic risk factor. Moreover, these studies lack information about overweight/obese children, despite these children being the target group for treatment programmes.

The aim of this study is to assess whether WHtR is a better estimate of BF% than BMI and WC in very young non-obese and obese children (3–7 years of age), and whether it is a better indicator of obesity-related cardiometabolic risk factors.

2. Materials and methods

2.1. Subjects

Three groups of children were included in this study. The first group consisted of children ($n = 30$) from the general healthy Dutch population, 3–4 years of age, who were randomly selected from the GECKO Drenthe cohort.[18] Data were collected between March 2010 and March 2011. The second group consisted of children ($n = 31$) from the general healthy Dutch population, 6–7 years of age. These children were recruited through advertisements in a local newspaper and on the hospital information site, and by word of mouth. Data were collected in October 2006 and have been partly described in previous studies.[19,20] In these two groups, children having medical problems which could affect physical activity, and children diagnosed with a disease or using medication known to affect body composition were excluded from the study. These two groups were combined as one group of children from the general population. The third group consisted of overweight/obese children ($n = 75$), 3–5 years of age, who were part of a randomized controlled clinical trial (GECKO Outpatients Clinic) aimed at reducing overweight.[21] The baseline data of the participants were used for this analysis and were measured during the children's first visit to the hospital. Data were collected between October 2006 and March 2008. Only children with overweight or obesity, according to the International Obesity Task Force (IOTF) definitions[22] were included. Children with overweight or obesity due to known medical conditions or eating disorders according to the Dutch Eating Behaviour Questionnaire, mental retardation, severe behavioural problems or other criteria interfering with participation were excluded. Almost all of the children were Caucasian, one child from the first group had an Asian father and two children had African parents (one in the second and one in the third group). Written informed consent was obtained for all children, and the studies were approved by the Medical Ethics Committee of the University Medical Center Groningen (UMCG).

2.2. Body composition

In all children, height to the nearest 0.1 cm and weight to the nearest 0.1 kg were measured without shoes in light clothing using a stadiometer and a calibrated digital scale, respectively. BMI was calculated as weight/height^2. WC was performed with a standard tape measure and recorded to the nearest 0.1 cm in standing position. WC was measured at the mid-point between the lower costal margin and the level of the anterior superior iliac. BF% was measured using different methods for the three groups. In the first group (3–4 years of age from the general population), BF% was determined by the $^2H_2^{18}O$ isotope dilution method. Children drank a weighted amount (around 50 grams) of doubly labelled water (Buchem, Apeldoorn, the Netherlands [^2H_2O: 6.02%, $H_2^{18}O$: 12.05%]; Campro Scientific, Berlin, Germany [^2H_2O: 6.63%, $H_2^{18}O$: 11.50%]). Saliva samples were collected by the parents before administration and approximately 4, 16, 72 and 120 h after administration. Total body water (TBW) was determined from the dilution spaces of both isotopes. The component TBW in fat free mass (FFM) was set at 0.775 for the 3-year-old boys, 0.770 for the 4-year-old boys, 0.779 for the 3-year-old girls, and 0.777 for the 4-year-old girls.[23] BF% was calculated as ([weight-FFM]/weight) * 100. More detailed information is described elsewhere.[24] In the second group (6–7 years of age from the general population), BF% was calculated from TBW, determined by an orally administered dose of 99.8% ^2H_2O of 0.15 g per kilogram body weight. Detailed information about the method has been described before.[20] In the third group (3–5 years of age overweight/obese children), BF% was estimated using a 50 kHz fixed frequency hand-to-foot bio-impedance analyzer (BIA-101, Akern S.r.l./RJL Systems, Florence, Italy). The measurements were performed three times and the average calculated. The resistance (R_z) value from BIA together with height, weight, age and sex were used to calculate the FFM using the Horlick equation.[25] BF% was calculated as ([weight − FFM]/weight) × 100.

2.3. Overweight/obesity-related cardiometabolic risk factors

Cardiometabolic risk factors were only measured in the overweight/obese group. Systolic and diastolic blood pressures were measured in supine position at the right upper arm with a Dinamap Critikon 1846SX digital sphygmomanometer (Critikon Inc., Tampa, Florida, USA) and an appropriate cuff size. The child was instructed not to speak or move during the measurements. The mean of two measurements was calculated. Blood was drawn after an overnight fast. An enzymatic colorimetric method (Roche Modular, Basel, Switzerland) was used to determine total cholesterol, high-density lipoprotein (HDL)-cholesterol, low-density lipoprotein (LDL)-cholesterol and triglycerides. The updated homeostasis model assessment of insulin resistance (HOMA2-IR) was used to calculate insulin resistance.[26] HOMA2-IR was calculated from fasting plasma glucose and fasting plasma insulin, determined by enzymatic method (hexokinase-mediated reaction, Roche Modular, Basel, Switzerland) and radioimmunoassay (Diagnostic Systems Laboratories, Inc., Webster, TX, USA), respectively. Serum levels of leptin, interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNFα) were measured by a combination enzyme-linked immunosorbent assay (ELISA; Milliplex Map Human Adipokine Panel B, Millipore, St. Charles, MN, USA). Serum levels of adiponectin were quantified by ELISA (Millipore, St. Charles, MN, USA).

2.4. Statistics

Mean and standard deviations were calculated for all of the characteristics measured. Univariate linear regression analyses were performed with BF% as the dependent variable and WHtR, WC

Table 1
Anthropometric characteristics in the three groups of children.

	3–4 years of age General population ($n = 30$, 40% boys)		6–7 years of age General population ($n = 31$, 56% boys)		3–5 years of age Overweight/obese population ($n = 75$, 28% boys)	
	Mean	SD	Mean	SD	Mean	SD
Age	3.5	0.3	6.7	0.5	4.7	0.8
Weight (kg)	16.3	1.9	25.1	3.9	28.2	6.5
Height (cm)	101.0	5.4	124.8	6.4	114.9	7.8
Waist (cm)	51.7	2.7	57.0	3.9	64.9	7.5
BMI	15.9	1.2	16.0	1.6	21.1	2.8
WHtR	0.51	0.03	0.46	0.03	0.56	0.05
BF%[a]	22.0[b]	6.4	17.5[b]	5.3	28.3[c]	6.8

BF%, body fat percentage; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio.
[a] Data on BF% were missing in four children aged 3–4 years, in three children aged 6–7 years, and in nine overweight/obese children aged 3–5 years.
[b] BF% as determined by BIA with Horlick equation.
[c] BF% as determined by isotope dilution method.

or BMI as the independent factors. In the multivariate linear regression analyses gender and age were added as independent factors. Effect modification of age or gender with WHtR, WC and BMI were checked. Pearson correlations were used to analyse the relationship between the BF% or cardiometabolic risk factors and WHtR, WC or BMI. Statistical analyses were performed using PASW 18.0.3 for Windows (SPSS, Chicago Illinois, USA). The significance level was set to $p < 0.05$ (2-tailed).

3. Results

Table 1 shows the characteristics of the three groups of children. The children aged 3–4 years ($n = 30$) and 6–7 years ($n = 31$) were representatives of the general population, which was reflected in the number of overweight children, three and six children were overweight, based on the IOTF definitions,[22] respectively. The third group consisted of overweight/obese children aged 3–5 years ($n = 75$). Overweight was present in 38.7% ($n = 29$) of the children and 61.3% ($n = 46$) were obese. In addition to the anthropometric measures, the following cardiometabolic measures were also determined in the overweight/obese children: systolic and diastolic blood pressure (113 ± 13 and 64 ± 7 mmHg, respectively), HOMA2-IR (1.0 ± 0.5), leptin (9.4 ± 9.4 ng/mL), adiponectin (18.3 ± 4.7 ng/mL), triglycerides (69.0 ± 33.1 mg/dL), total cholesterol (149.0 ± 23.4 mg/dL), HDL-cholesterol (49.5 ± 10.4 mg/dL), LDL-cholesterol (95.8 ± 20.9 mg/dL), TNFα (3.6 ± 3.2 pg/mL) and IL-6 (1.5 ± 1.2 pg/mL).

Table 2 shows the associations of BF% with WHtR, WC and BMI. In the crude models, WHtR ($r = 0.48$, $p < 0.001$) and BMI ($r = 0.44$, $p < 0.001$) were associated with BF% in the children from the general population when age groups were combined. In the overweight/obese children, WHtR was correlated with BF% ($r = 0.65$, $p < 0.001$), but WC and BMI were even better correlated with BF% ($r = 0.81$, $p < 0.001$ and $r = 0.81$, $p < 0.001$, respectively). When adjusted for gender and age, WHtR, WC and BMI were significantly associated with BF% in all groups. In the adjusted model for the children from the general population with age groups combined, BMI had the highest explained variance ($R^2 = 0.32$) for BF%. This was also true for the children of 6–7 years of age, but WHtR performed best in the children of 3–4 years of age. In the adjusted models for the overweight/obese children, WHtR had the lowest explained variance ($R^2 = 0.50$), compared to WC ($R^2 = 0.70$) and BMI ($R^2 = 0.68$). We checked if effect modifications of age or gender with WHtR, WC or BMI were present in the models on top of the adjustments for age and gender. The only significant interaction term was for gender with WHtR in the children from the general population with age groups combined. Adding this term to the model for predicting BF%, the explained variance increased from $R^2 = 0.23$ to $R^2 = 0.33$. This resulted in a beta coefficient of 74.9 for boys and 74.0 for girls. The additional adjustment for interaction with gender makes the explained variance of WHtR, WC or BMI for BF% comparable.

Table 3 shows the associations of WHtR, WC and BMI with cardiometabolic risk factors for the overweight/obese children. WHtR, WC and BMI were positively correlated with systolic blood pressure, HOMA2-IR, leptin and triglycerides. For these significant

Table 2
Associations of WHtR, WC and BMI with body fat percentage.

	Body fat percentage											
	3–4 years of age General population[a]			6–7 years of age General population[a]			3–4 and 6–7 years of age General population[a]			3–5 years of age Overweight/obese population[b]		
	B [95% CI]	R^2 model	Pearson r	*B* [95% CI]	R^2 model	Pearson r	*B* [95% CI]	R^2 model	Pearson r	*B* [95% CI]	R^2 model	Pearson r
WHtR												
Crude	67.5 [−9.1;144.0]	0.12	0.35	56.2 [−9.5;121.9]	0.11	0.33	72.6 [35.7; 109.6]	0.23***	0.48***	92.9 [66.1;119.8]	0.43***	0.65***
+Gender	72.5 [−0.4;145.4]	0.24*		84.1 [20.2;147.9]	0.29*		73.1 [34.7; 111.4]	0.23***		94.5 [66.7;122.4]	0.43***	
+Gender, age	94.8 [25.7;164.0]	0.40**		85.8 [20.3;151.3]	0.30*		71.3 [20.5; 122.0]	0.23***		97.4 [71.2;123.7]	0.50***	
WC												
Crude	1.09 [0.24;1.93]	0.23*	0.48*	0.75 [0.30;1.21]	0.31**	0.56**	0.17 [−0.22; 0.56]	0.02	0.12	0.77 [0.63;0.90]	0.66***	0.81***
+Gender	1.09 [0.29;1.89]	0.34**		0.89 [0.48;1.30]	0.49***		0.17 [−0.22; 0.57]	0.03		0.80 [0.66;0.94]	0.67***	
+Gender, age	0.99 [0.14;1.84]	0.35*		0.93 [0.51;1.36]	0.51***		0.87 [0.42; 1.33]	0.31***		0.87 [0.71;1.02]	0.70***	
BMI												
Crude	1.64 [−0.42;3.70]	0.10	0.32	2.18 [1.24;3.12]	0.46***	0.68***	1.87 [0.79; 2.94]	0.19***	0.44***	2.14 [1.75;2.53]	0.65***	0.81***
+Gender	1.72 [−0.25;3.69]	0.22		2.34 [1.50;3.17]	0.61***		1.85 [0.77; 2.93]	0.20***		2.27 [1.87;2.67]	0.67***	
+Gender, age	2.14 [0.24;4.03]	0.35*		2.34 [1.49;3.20]	0.61***		1.96 [0.95; 2.97]	0.32***		2.23 [1.82;2.63]	0.68***	

BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
[a] Body fat percentage measured by isotope dilution method
[b] Body fat percentage measured by BIA with Horlick equation.

Table 3
Pearson correlation coefficients regarding the associations between cardiometabolic risk factors and WHtR, WC and BMI in overweight/obese children aged 3–5 years.

	WHtR (r)	WC (r)	BMI (r)
SBP	0.233*	0.303**	0.361**
DBP	0.076	0.127	0.168
HOMA2-IR	0.534***	0.618***	0.627***
Leptin[a]	0.701***	0.769***	0.779***
Adiponectin	−0.211	−0.311**	−0.152
TG	0.330**	0.364**	0.244*
TC	0.035	0.085	0.056
HDL-C	−0.231*	−0.040	−0.012
LDL-C	0.064	0.033	0.038
TNFα	0.094	0.107	0.158
IL-6	0.030	−0.057	−0.018

BMI, body mass index; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA2-IR, updated homeostasis model assessment of insulin resistance; IL-6, interleukin-6; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides; TNFα, tumour necrosis factor-alpha; WC, waist circumference; WHtR, waist-to-height ratio. Less than 4% of data was missing, with the exception of HOMA2-IR, which was missing in 10 children (13%).
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
[a] Log transformed.

associations, WHtR was not superior to WC and BMI. For adiponectin we found only a significantly inverse correlation with WC and for HDL-cholesterol only an inverse correlation with WHtR.

4. Discussion

This study revealed that WHtR is associated with BF% in children. However, even after adjustments for gender and age, WHtR is not better associated with BMI and WC. Neither is WHtR a better indicator of most cardiometabolic risk factors than WC and BMI.

4.1. WHtR, WC and BMI as indicators of body fat percentage

Previous studies that investigated the association between WHtR and BF% in both normal and overweight children found that WHtR was associated with total or abdominal BF%.[15,27–31] Studies in older children (8–16 years of age) showed a better correlation of WHtR with BF% than BMI.[27,28] Studies that only included children younger than 10 years have found that WHtR was not better correlated with BF% than BMI or WC.[15,29,30] Therefore, this association may be dependent on age. The correlation between WHtR and BF% has been evaluated in only two studies of children of less than 6 years of age.[14,15] In these studies the prevalence of overweight/obesity was around 30% [14,15] and the associations were adjusted for age and shown separately for boys and girls. In both studies a significant correlation was found. In our study we also found this significant correlation, both in the overweight obese group as well as in the group from the general population, although the associations seemed to be stronger in the older children (6–7 years compared to 3 years of age). The finding that the association between WC and BF% was initially lost after combining the two age groups in one general population group stresses the importance to look at age-range specific subgroups. But, because WHtR is not better related to BF% than BMI and WC in both the unadjusted and adjusted models, we conclude that WHtR has no advantage over BMI in predicting BF%. It is common to define overweight in children based on the BMI adjusted for gender and age.[22] WHtR, either with or without these adjustments, is not a better screening method than adjusted BMI and WC for predicting BF%.

We observed stronger associations between BF% and WHtR, WC and BMI in the overweight/obese group compared to the general population group. An explanation might be that BMI is a better measure of excess body fat in obese children compared to normal weight or overweight children, because BMI is not only dependent on fat mass but also on muscle mass,[32] and the higher the fat mass, the smaller the influence of variation in muscle mass. Almost 70% of the children in the overweight/obese group were obese, which may explain why BMI has a higher association with BF% in the overweight/obese group compared to the general population groups. BF% was measured using the isotope dilution method in the general population group, while in the group with overweight/obese children it was assessed by BIA and estimated using the Horlick equation. As expected, BF% was higher in the overweight/obese group compared to the children from the general population group. Even if the BF% may have been underestimated by the BIA method.[20] this will not have influenced the correlations with WHtR, WC and BMI, so the difference in methods is not a likely explanation for the higher correlation between the anthropometric measurements and BF%. Moreover, the overweight/obese group consisted of more children than the group from the general population. A group with more children has more power to find a significant effect, but the correlation coefficients will not automatically be higher. Finally, the standard deviations and ranges of WHtR, WC, BMI and BF% were wider in the overweight/obese group, which means a higher chance of finding an association.

4.2. WHtR, WC and BMI as indicators of cardiometabolic risk factors

We found only three studies that investigated the relationship between WHtR and one or more cardiometabolic risk factors in children younger than 6 years.[15–17] Corvalan et al. assessed the relationship between the anthropometric measures (e.g. WHtR, WC and BMI) and different cardiometabolic markers in 3 to 4-year-old children.[15] Whitrow et al. assessed whether WHtR is a better indicator than BMI of SBP in children, 3.5 years of age.[17] Campagnolo et al. assessed the accuracy of WHtR, WC and BMI in identifying children (3–4 years of age) with multiple risk factors for cardiovascular disease. No correlations between the anthropometric measures and the separate cardiovascular risk factors were found.[16]

We found that apart from HDL-cholesterol none of the cardiovascular risk factors were better correlated with WHtR than with BMI or WC (i.e. SBP, HOMA2-IR, leptin and triglycerides). This is in accordance with most previous studies in children aged 4–17 years, based on a review by Browning et al.[3] For HDL-cholesterol we found a significant inverse association with WHtR, while no association was found with BMI or WC. This inverse association was also found in a previous review,[3] while no association was found in young children.[15] The lack of association between total cholesterol and IL-6 with WHtR has also been found in previous studies.[3,15] The positive association with triglycerides is consistent with studies in older children, but was not found in young children.[15] The absence of an association of WHtR with DBP, adiponectin, LDL-cholesterol and TNFα in young children has not been published before.

A major strength of our study is that the sample was composed of young children of 3–7 years of age. In addition, relationships were studied in overweight/obese children. Studies analysing these relationships in young children are limited and we found no studies that analysed these in overweight/obese children at this young age, despite these children being the target population for intervention programmes. The low number of children in the general population groups is a limitation of our study. Although for diagnosis purposes, the cross-sectional design of the study is adequate, the drawback is that it gives no information about the ability of the proxy measures to predict cardiometabolic risk factors later in life. For diagnosis of excess adiposity, cross-sectional data are sufficient, but it would be

interesting and very relevant to relate the adiposity measures to future health outcomes.

In conclusion, in young children, either from the general population or overweight/obese, WHtR was not superior to WC or BMI in estimating BF%, nor was WHtR better correlated with cardiometabolic risk factors than WC or BMI in overweight/obese children. These data do not support the use of WHtR in young children.

Conflict of interest

The authors declare there are no competing financial interests in relation to the work described.

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