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Original article

Usefulness of the waist-to-height ratio for predicting cardiometabolic risk in children and its suggested boundary values

Judit Muñoz-Hernando [a], Joaquin Escribano [a, **], Natalia Ferré [a], Ricardo Closa-Monasterolo [a], Veit Grote [b], Berthold Koletzko [b, c], Dariusz Gruszfeld [d], Alice ReDionigi [e], Elvira Verduci [e], Annick Xhonneux [f], Veronica Luque [a, g, *]

[a] Paediatrics, Nutrition and Development Research Unit, Universitat Rovira i Virgili, IISPV, 43201, Reus, Spain
[b] Dept. Paediatrics, Dr von Hauner Children's Hospital, University Hospital, LMU – Ludwig-Maximilians-Universität, 80337, Munich, Germany
[c] Else-Kröner-Seniorprofessor of Paediatrics, LMU Ludwig-Maximilians-Universität, 80337, Munich, Germany
[d] Neonatal Department, Children's Memorial Health Institute, 04-730, Warsaw, Poland
[e] Department of Health Sciences, University of Milan, 20146, Milan, Italy
[f] CHC Sant Vincent, 4000, Liège-Rocourt, Belgium
[g] Serra Hunter Fellow, Universitat Rovira i Virgili, 43201, Reus, Spain

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SUMMARY

Background & aims: Only limited information is available on the usefulness of the waist-to-height ratio (WHtR) as an abdominal obesity marker in children. Our aim was to compare the ability of a WHtR >90th percentile, a WHtR ≥0.50, a WHtR ≥0.55 and a BMI z-score ≥2 SD to predict cardiometabolic risk in children followed-up at different ages.

Methods: We evaluated data from 660 children at 5, 8 and 11 years of age who participated in the Childhood Obesity Project trial in 5 European countries. We classified children with or without cardiometabolic (CMet) risk (yes *vs.* no) according to the presence of ≥2 parameters (blood pressure, HOMA-IR, triglyceride levels and high-density lipoprotein (HDL) cholesterol levels) ≥90th percentile.

Results: The odds ratio for CMet risk in children at all followed-up ages was statistically significant for all measures. The OR for the WHtR≥0.55 cut-off was 29.1 (5.6, 151.7) at 5 years of age, 11.8 (4.1, 33.8) at 8 year of age and 3.6 (1.7, 7.7) at 11 years of age, compared to the WHtR<0.55 cut-off. The WHtR≥0.55 cut-off showed a higher OR at younger ages than the BMI z-score ≥2SD, WHtR ≥90th percentile and WHtR≥0.50 cut-offs and a higher positive predictive value (82% at 5 years of age compared to 55%, 36% and 41%, respectively).

Conclusion: A WHtR≥0.55 is a suitable cut-off for screening children at high cardiometabolic risk in the general young European population.

1. Introduction

The World Health Organization (WHO) defines overweight and obesity as abnormal or excessive fat accumulation that may impair health [1]. Body mass index (BMI) is the most commonly used diagnostic criterion for excess weight because it is a simple indicator that relates weight and height to identify overweight and obesity in adults and in the paediatric population using sex- and age-specific charts [1]. However, BMI does not differentiate between fat and lean mass or consider the distribution of fat mass [2]. In contrast, waist circumference (WC) is a low-cost, simple and valid measurement that has the strength of being a better indicator of abdominal fat mass, which has been related to cardiovascular risk parameters in both adults and children [3–6].

Abbreviations: BMI, Body mass index; WC, Waist circumference; WHtR, Waist-to-height ratio; CMet risk, Cardiometabolic risk; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; HDL cholesterol, High-density lipoprotein cholesterol; LDL cholesterol, Low-density lipoprotein cholesterol; HOMA-IR, Homeostasis model assessment of insulin resistance.

* Corresponding author. C/Sant Llorenç 21, 43201, Reus, Spain.
** Corresponding author.
E-mail addresses: judit.munoz@urv.cat (J. Muñoz-Hernando), joaquin.escribano@urv.cat (J. Escribano), berthold.koletzko@med.uni-muenchen.de (B. Koletzko), d.gruszfeld@czd.pl (D. Gruszfeld), alice.redionigi@yahoo.it (A. ReDionigi), elvira.verduci@unimi.it (E. Verduci), annick.xhonneux@chc.be (A. Xhonneux), veronica.luque@urv.cat (V. Luque).

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WC has been suggested as the dominant component of metabolic syndrome leading to the development of diabetes and cardiovascular (CV)-related mortality [7,8]. Several studies have reported that individuals with a large WC have hypertrophic subcutaneous adipose cells and dysfunctional adipose tissue, and present increased ectopic fat accumulation, which leads to a major risk of diabetes and metabolic syndrome [9–11]. Independent of BMI, higher values of WC have been related to higher cardiometabolic risk compared to lower values of WC [12]. However, it is still controversial whether WC is able to distinguish subjects with a relatively low BMI but increased intra-abdominal fat accumulation [7,13].

In children and adolescents, abdominal adiposity may better predict cardiometabolic risk factors than BMI alone and is considered an independent risk factor for type 2 diabetes mellitus, dyslipidaemia, systemic arterial hypertension, and coronary artery disease [14]. Abdominal adiposity and visceral fat were positively associated with elevated blood pressure and dyslipidaemia in children, independent of BMI [15,16]. This could be sex specific; indeed, in a large sample of children and adolescents, boys showed a higher WC, WHtR, fasting glucose level, and systolic blood pressure, independent of BMI [17]. In addition, in the last few decades, a higher increase in waist circumference compared to BMI was observed, suggesting that abdominal adiposity has proportionally increased more than overall body fatness [18].

In adults, waist circumference cut-offs >102 cm in men and >88 cm in women are used as abdominal adiposity criteria. In children, the measures change with age, sex and ethnicity, and hence, no single waist circumference value can be used. Rather, age-, sex- and ethnic-specific percentiles or Z scores are used [5,19,20].

The waist-to-height ratio (WHtR) predicts abdominal fat mass and takes body size into account [21–23]. The WHtR has certain advantages compared to WC alone, since having a universal cut-off would help standardize practice, which may be independent of age, sex, height and race [24,25]. A general WHtR cut-off value of ≥0.50 in adults and adolescents has been proposed to indicate abdominal adiposity [22]. In the paediatric population, a WHtR >0.50 was related to CV alterations [26], and children with normal weight showed a less favourable metabolic profile if their WHtR was over 0.50 [27]. Mehta et al. proposed the use of two paediatric cut-offs derived from the BMI growth charts for age and sex, WHtR ≥0.5 and WHtR ≥0.55 cut-offs as equivalents to BMI ≥85th and BMI ≥95th percentiles, respectively, to diagnose abdominal overfatness and abdominal adiposity in children. However, these proposed cut-off points were not based on their relationship with clinical alterations such as hypertension or insulin resistance but only on BMI extrapolation [28].

Therefore, our objective was to compare the sensitivity, specificity and predictive capacity of the 4 obesity-related criteria, a BMI z-score ≥2, abdominal adiposity according to the WHtR ≥90th percentile by age and sex, a WHtR ≥0.50 and a WHtR ≥0.55, as cut-offs for predicting cardiometabolic risk factors in a European sample followed-up at 5, 5.5, 8 and 11 years of age.

2. Material and methods

2.1. Design

This is an observational longitudinal study secondary to the EU Childhood Obesity Project (CHOP) (formerly a randomized controlled clinical trial).

Briefly, the CHOP study was a prospective, multicentre, randomized, double-blind nutritional intervention trial conducted in Belgium, Germany, Italy, Poland and Spain. Formula-fed infants were randomly assigned during their first eight weeks of life to a higher or lower protein formula until the age of 12 months. A group of breastfed infants was included as the reference group. All children were followed until the age of eleven years. Their objective was to compare the amount of protein in infant formulas to determine whether there was any association with rapid growth and overweight or obesity in childhood. Further details of the clinical trial were previously published [29].

2.2. Study population

Newborn, apparently healthy, singleton full-term children born between October 1, 2002, and July 31, 2004, were recruited at the 11 study centre sites in Germany (Munich and Nuremberg), Belgium (Liege and Brussels), Italy (4 sites in Milano), Poland (Warsaw) and Spain (Reus and Tarragona). At recruitment, breastfeeding was promoted and supported. A total of 1678 infants were enrolled in the study (the median age at enrolment was 16 days). The clinical characteristics of all the participants at study entry were previously published [29]. In the present study, all 654 children who had participated in at least one follow-up visit from 5 to 11 years of age and had available anthropometric and cardiometric risk outcomes (blood pressure and blood samples) were analysed.

2.3. Data collection

Visits took place at ages 5, 5.5, 8 and 11 years. Anthropometry was measured at all visits, blood pressure was assessed at 5, 8 and 11 years of age, and a blood sample was drawn and analysed at 5.5, 8 and 11 years of age.

2.3.1. Anthropometry

All anthropometric measurements were performed by dedicated dieticians and nurses who were instructed on specific procedures and received 4 h of training conducted four times throughout the duration of the study. Measurements were taken following the World Health Organization (WHO) recommendations [30] based on the Lohman reference manual [31]. All the study centres used the same equipment to obtain the measurements: for the weight and height, a Seca 702 scale and a SECA 242 stadiometer were used at the 5-, 5.5-, 8- and 11-year visits. All measurements were made twice and recorded with an accuracy of 50 g for weight and 0.1 cm for height. The average of both results was used for subsequent analyses. Waist circumference [cm] (WC) was measured at the midpoint between the iliac crest and the lower rib according to the WHO procedures [32]; the waist-to-height ratio was calculated as WHtR = WC [cm]/height [cm], and body mass index (BMI) [kg/m^2] was calculated as BMI = weight [kg]/height^2 [m]. BMI z-scores for age and sex were calculated according to the World Health Organization (WHO) references [33].

To identify the most accurate cut-off of the WHtR to predict cardiometabolic risk, all participants were categorized into two groups (above or below) for each of the following four different obesity-related criteria: a BMI z-score ≥2, a WHtR ≥90th percentile based on the IDEFICS reference by age and sex [34], a WHtR ≥0.50 and a WHtR ≥0.55.

2.3.2. Blood pressure

At the 5-, 8- and 11-year visits, blood pressure was measured using an oscillometric technique with the Dinamap Procare blood pressure monitor (GE Medical Systems, Freiburg, Germany) on the left arm, while the child remained seated with the arm resting comfortably, using the most adequate cuff size for each participant. Systolic (SBP) and diastolic (DBP) blood pressure were each measured twice, with a time interval of at least 5 min between the measurements. The average of both measurements was used.

SBP and DBP variables were standardized according to the American Academy of Pediatrics (AAP 2017) references [35]

considering a SBP and DBP ≥90th percentile for age, sex and height as elevated for subsequent analyses.

2.3.3. Blood samples

At the 5.5-, 8- and 11-year visits, a sample of venous blood was taken. Serum samples were stored at −80 °C and transported on dry ice to the central laboratory. Serum insulin levels were quantified using an immunoradiometric assay (DiaSource, Nivelles, Belgium) following the manufacturer's instructions. Glucose, total cholesterol, high-density lipoprotein cholesterol (HDL cholesterol), low-density lipoprotein cholesterol (LDL cholesterol), and triglyceride levels were analysed in the respective laboratories of local study centres using routine methods. Total and HDL cholesterol, triglyceride, and glucose levels were analysed by indirect or enzymatic potentiometric methods. LDL cholesterol values were calculated by the Friedewald equation [36]. Insulin [AIU/ml] was quantified at the Department of Biochemistry, Radioimmunology and Experimental Medicine of the Institute for Children's Memorial Health using an immunoradiometric assay (DiaSource, Nivelles, Bélgica) [37]. Fasting insulin and glucose levels were used to estimate insulin resistance using the homeostasis model assessment of insulin resistance (HOMA-IR) [38].

For all of the biochemical measurements, only the participants who fasted for at least 6 h before the blood test were considered.

2.3.4. Assessment of cardiometabolic risk

The metabolic syndrome definition for a subject includes accounting for at least three of the following altered cardiovascular risk parameters, as suggested by Ahrens [39]: SBP, DBP, waist circumference, HOMA, triglyceride level and HDL cholesterol level. However, as our aim was relating a waist circumference cut-off to cardiometabolic (CMet) risk, we excluded waist circumference from the definition. Thus, we established cardiometabolic risk (CMet risk), as a binary variable (yes *vs*. no) in our sample as having at least two of the following altered conditions: a systolic or diastolic blood pressure ≥90th percentile according to the AAP 2017 references [35], a HOMA-IR ≥90th percentile, a triglyceride level ≥90th percentile or an HDL cholesterol level ≤10th percentile according to the IDEFICS references for age and sex [40,41]. For clarity, cardiometabolic risk at 5 years of age was calculated by means of blood pressure at 5 years of age and anthropometric and biochemical measurements at 5.5 years of age.

2.3.5. Pubertal development

Pubertal development was self-assessed at 11 years of age by means of the Self-Administered Rating Scale for Pubertal Development [42], adapted by an interview-based puberty-rating scale by Petersen [43].

2.4. Ethics

The study was approved by the ethics committees of all the study centres (the Ethics Committee of Clinical Research of Hospital Universitari de Tarragona Joan XXIII; the Ethics Committee of Clinical Research of Hospital Universitari Sant Joan de Reus; the Ethics Committee of the Children's Memorial Health Institute Warsaw; the Ethics Committee of the Medical Faculty, Ludwig-Maximilians-Universität Munich; the Ethics Committee of the Medical Faculty, University of Milan Italy; Comité d'Ethique du CHVE, Liège; and Comité d'Ethique de l'Hôpital Universitaire des Enfants Reine Fabiola). Written parental consent was obtained for each participant. The study was carried out in compliance with the Declaration of Helsinki.

2.5. Statistics

The description of the continuous variables is presented as the median and interquartile range (25th −75th percentiles). The distribution of the categorical variables in different groups is presented as n (%).

Mann−Whitney U tests were used to compare the medians of the biochemical parameters and blood pressure according to the different obesity categories after assessing normality.

We conducted receiver operating characteristic analyses to determine the area under the curve (AUC) of the WHtR ratio to predict CMet risk. We calculated the sensitivity and specificity of the different cut-offs for predicting the different cardiovascular health outcomes.

Logistic binary regression analyses were performed to quantify the odds of having health risk factors and cardiometabolic risk by different abdominal obesity cut-offs (WHtR ≥ p90th, WHtR ≥0.50 and WHtR ≥0.55). Models were adjusted by sex and country at 5 and 8 years of age and by sex, country and pubertal development at 11 years of age.

Statistical significance was accepted at the level of $p < 0.05$.

Data management and statistical analyses were carried out with the software package SPSS Statistics version 26.0 (SPSS Inc., Chicago, IL, USA).

3. Results

Six hundred fifty-four 5-year-old children (309 boys, 47.2%) were included in the analysis. The following visits were performed in 589 8-year-old participants (47% male) and 583 11-year-old participants (47.5% male) from 5 European countries (approximately 14% from Germany, 15% from Belgium, 24% from Italy, 16% from Poland and 31% from Spain). The baseline information and characteristics of the participants with blood pressure measurements and biochemical analyses during follow-up are shown in Table 1. There were several dropouts from the first CHOP study visit to the 5-year, 8-year and 11-year visits, and the reasons for these dropouts were as follows: 24.3−28.2% of the participants did not fulfil the criteria for the original intervention; 51.9−52.3% of the participants refused to continue with the visits; 5.2−5.8% of the participants changed their contact details/address; 4.8% of the participants moved out of the study regions; 1.7−1.8% of the participants had an illness interfering with growth; and other/unknown reasons accounted for 7.3−11.5% of the dropouts.

According to the different criteria (WHtR ≥ p90th, WHtR ≥0.50 and WHtR ≥0.55), 3.1−22.0% of the children had abdominal obesity at 5 years of age, 5.3−30.6% had abdominal obesity at 8 years of age and 7.7−41.3% had abdominal obesity at 11 years of age. A total of 75% of the children with a WHtR≥0.55 at 5 years of age and 69.6% of the children at 8 years of age were also above this cut-off at 11 years of age.

Table 2 shows a comparison of the prediction of biochemical measurements (HDL cholesterol level, triglyceride level and HOMA-IR) and SBP by the different anthropometric measures that were evaluated, i.e., a BMI z-score ≥2SD, a WHtR≥0.5, a WHtR≥0.55 and a WHtR≥90th percentile at the ages of 5, 8 and 11. All four anthropometric measures predicted statistically worse HOMA-IR and SBP values at most ages. However, the WHtR ≥0.55 cut-off discriminated the best, especially at 5 and 8 years of age, when there were statistically significant differences between the children with or without obesity for all measurements, except for HDL cholesterol at 11 years of age. In contrast, a BMI z-score ≥2 SD, a WHtR≥0.5 and a WHtR ≥ p90 did not predict significant group differences for HDL cholesterol or triglyceride levels at several ages. The WHtR ≥0.55 cut-off predicted significantly

Table 1
Characteristics of the study sample.

	5 years	5.5 years	8 years	11 years
Baseline characteristics				
n	654	641	589	583
Sex n (%)				
Male	309 (47.2)	304 (47.4)	277 (47.0)	277 (47.5)
Female	345 (52.8)	337 (52.6)	312 (53.0)	306 (52.5)
Birth weight (kg)	3.28 (3.05, 3.55)	3.28 (3.04, 3.55)	3.28 (3.03, 3.53)	3.28 (3.02, 3.53)
Infant feeding n (%)				
Low protein	227 (34.7)	224 (34.9)	204 (34.6)	197 (33.8)
High protein	227 (34.7)	212 (33.1)	192 (32.6)	186 (31.9)
Breastfeeding	200 (30.6)	205 (32.0)	193 (32.8)	200 (34.3)
Anthropometric measures				
n	654	641	589	583
Weight (kg)	19.0 (17.5, 20.5)	20.1 (18.5, 22.0)	27.3 (24.3, 30.70)	39.5 (34.0, 46.0)
Height (cm)	110.2 (106.9, 113.0)	114.1 (110.6, 116.8)	129.3 (125.4, 132.8)	147.6 (142.6, 152.2)
BMI (kg/m^2)	15.7 (14.9, 16.6)	15.5 (14.73 16.5)	16.3 (15.0, 18.0)	18.0 (16.2, 20.6)
BMI z-score	0.32 (−0.27, 0.89)	0.17 (−0.40, 0.88)	0.33 (−0.47, 1.24)	0.36 (−0.54, 1.32)
WC (cm)	52.4 (50.3, 55.2)	52.9 (50.5, 55.4)	57.3 (54.5, 62.1)	64.7 (60.4, 71.9)
WHtR	0.48 (0.46, 0.50)	0.47 (0.45, 0.49)	0.45 (0.43, 0.48)	0.44 (0.41, 0.49)
Blood pressure measurements				
n	536		556	569
SBP (mmHg)	97 (90, 104)	–	100 (93, 107)	108 (100, 115)
DBP (mmHg)	57 (52, 63)	–	58 (52, 62)	59 (55, 65)
SBP percentile	67 (39, 87)	–	62 (34, 82)	69 (38, 90)
DBP percentile	62 (44, 83)	–	46 (27, 63)	40 (26, 61)
Biochemical measurements				
n		429	376	484
Glucose (mg/dL)	–	83 (79, 87)	84 (79, 89)	86 (82, 91)
HDL -C (mg/dL)	–	53 (46, 63)	59 (49, 69)	56 (48, 63)
LDL-C (mg/dL)	–	99 (84, 114)	93 (76, 111)	102 (88, 119)
Total-C (mg/dL)	–	165 (147, 182)	165 (147, 184)	171 (155, 187)
TG(mg/dL)	–	51 (40, 70)	53 (42, 71)	62 (50, 78)
Insulin (μIU/mL)	–	5.8 (4.5, 7.5)	8.3 (6.7, 10.3)	11.3 (8.6, 15.0)
HOMA-IR	–	1.17 (0.92, 1.59)	1.71 (1.32, 2.19)	2.41 (1.81, 3.26)

Data is presented as median (interquartile range: 25th–75th percentile) BMI = body mass index; WC = waist circumference; WHtR = waist-to-height ratio; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; Total-C = total cholesterol; TG = triglycerides; HOMA-IR= Homeostatic Model Assessment for Insulin Resistance; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 2
Comparison of the biochemical measurements.

	BMI z-score ≥ 2SD		WHtR ≥ 0.50		WHtR ≥ 0.55		WHtR ≥ p90 IDEFICS	
	YES	NO	YES	NO	YES	NO	YES	NO
At 5y								
n	38	496	136	400	21	515	136	400
SBP	89 (58, 96)	65 (38, 86)‡	65 (37, 91)	68 (39, 86)	91 (66, 97)	65 (38, 86)‡	65 (37, 91)	68 (39, 86)
n	38	385	66	357	13	410	76	347
HDL-C	51 (43, 60)	54 (46, 64)	50 (42, 58)	54 (46, 64)§	44 (40, 52)	53 (46, 64)§	51 (43, 59)	54 (46, 64)§
TG	55 (39, 98)	51 (40, 69)	53 (35, 79)	51 (40, 69)	83 (54, 153)	51 (39, 70)†	52 (35, 76)	51 (40, 70)
HOMA-IR	1.49 (1.12, 1.84)	1.15 (0.90, 1.55)†	1.54 (1.19, 1.87)	1.12 (0.88, 1.48)‡	1.65 (1.28, 2.32)	1.16 (0.91, 1.55)†	1.50 (1.11, 1.75)	1.12 (0.88, 1.48)‡
At 8y								
n	56	497	78	477	29	526	164	391
SBP	84 (67, 92)	58 (33, 80)‡	84 (68, 92)	57 (32, 79)‡	85 (78, 95)	60 (33, 80)‡	78 (49, 90)	56 (31, 78)‡
N	39	333	50	323	20	353	111	262
HDL-C	55 (44, 62)	60 (50, 69)§	53 (43, 59)	61 (51, 70)‡	52 (44, 61)	59 (50, 69)§	56 (46, 64)	62 (51, 70)‡
TG	60 (42, 81)	53 (42, 70)	58 (44, 77)	53 (41, 70)	70 (44, 89)	53 (42, 70)§	53 (42, 71)	54 (42, 71)
HOMA-IR	2.31 (1.96, 3.22)	1.67 (1.30, 2.12)‡	2.28 (1.84, 3.10)	1.65 (1.29, 2.10)‡	2.91 (2.19, 3.32)	1.67 (1.30, 2.16)‡	2.17 (1.57, 2.70)	1.62 (1.28, 1.97)‡
At 11y								
n	64	505	122	447	45	524	195	373
SBP	88 (69, 97)	66 (35, 88)‡	88 (64, 96)	62 (34, 85)‡	89 (71, 97)	67 (35, 88)‡	83 (62, 95)	60 (32, 84)‡
n	55	412	106	362	37	430	158	309
HDL-C	54 (47, 62)	56 (49, 63)	55 (48, 63)	56 (48, 62)	53 (47, 59)	56 (48, 63)	55 (48, 62)	57 (49, 63)
TG	72 (55, 86)	61 (50, 77)§	68 (53, 84)	61 (50, 76)§	73 (56, 94)	62 (50, 77)§	66 (52, 84)	61 (50, 75)§
HOMA-IR	3.73 (3.03, 5.05)	2.31 (1.75, 3.09)‡	3.30 (2.67, 4.35)	2.23 (1.69, 2.96)‡	3.73 (2.84, 4.87)	2.37 (1.78, 3.16)‡	3.16 (2.49, 4.08)	2.13 (1.61, 2.78)‡

Data is presented as median (interquartile range: 25th–75th percentile) BMI = body mass index; WHtR = waist-to-height ratio; HDL-C = high-density lipoprotein cholesterol; TG = triglycerides; HOMA-IR= Homeostatic Model Assessment for Insulin Resistance; SBP = systolic blood pressure. §P < 0.05; †P < 0.01; ‡P < 0.001 for median differences between obesity categories (yes vs. no).

higher values for triglyceride levels and HOMA-IR compared to the other cut-offs. At 11 years of age, all cut-offs showed the same statistical significance between the groups (obesity *vs.* nonobesity). DBP was only significantly different between the WHtR cut-offs at 11 years of age and did not differ between the BMI groups at any of the ages.

We analysed whether there were significant differences in cardiometabolic risk factors between children classified over the different obesity boundaries (children with a BMI z-score ≥2SD compared to a WHtR≥0.5, a WHtR≥0.55 and a WHtR≥90th percentile). At 5 years of age, the children classified as having a WHtR ≥0.55 had higher triglyceride levels and SBP than children classified as having a WHtR≥0.50 and a WHtR ≥ p90 ($p < 0.05$ for all comparisons). At 8 years of age, the children classified as having a WHtR≥0.55 had higher HOMA-IR and SBP than those classified as having a WHtR ≥ p90 ($p < 0.01$ and $p < 0.05$, respectively). Finally, at 11 years of age, the children classified in the BMI z-score ≥2SD group exhibited higher HOMA-IR compared to children in the WHtR ≥ p90 group ($p < 0.01$), and children in the WHtR ≥0.55 group exhibited higher HOMA-IR than children in the WHtR ≥ p90 group ($p < 0.05$). At this age, SBP did not differ between the children above the obesity boundaries, except for the BMI z-score ≥2SD group compared to the WHtR ≥ p90 group ($p < 0.05$). There were no differences between the groups for HDL or DBP levels (data not shown) at any age.

Among the obesity boundaries that were evaluated, a WHtR≥0.55 was the best predictor for classifying children with significantly worse cardiometabolic risk parameters for all parameters and at all ages, except for DBP at 5 and 8 years of age.

Table 3 shows the prevalence distribution of the altered cardiometabolic risk factors and the presence of CMet risk according to the different anthropometric measures. The capacity of each obesity criterion to predict altered parameters was analysed afterwards (Tables 4 and 5).

The AUCs for the WHtR and BMI to predict CMet risk were 0.642, 0.682 and 0.670 ($p < 0.001$) and 0.674, 0.710 and 0.709 ($p < 0.001$) at 5, 8 and 11 years of age, respectively. Table 4 shows the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) at 5, 8 and 11 years of age with the different obesity cut-offs (BMI z-score ≥2SD, WHtR≥0.50, WHtR≥0.55 and WHtR ≥ p90) for cardiometabolic risk. The WHtR≥0.55 cut-off showed the highest specificity but also the lowest sensitivity in all cases. Despite this low sensitivity, at 5 years of age, the WHtR≥0.55 cut-off obtained the most elevated PPV and NVP (for all the health outcomes and ages). In contrast, at 8 and 11 years of age, the predictive value of the different cut-offs to diagnose CMet risk was similar, especially between BMI and the WHtR≥0.55 cut-off.

Table 4
Diagnostic capacity of the different obesity cut-offs to predict cardiometabolic risk.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
At 5y (n = 329)				
BMI z-score ≥ 2SD	27	95	55	85
WHtR ≥ 0.5	37	88	41	86
WHtR ≥ 0.55	15	99	82	84
WHtR ≥ p90 IDEFICS	37	85	36	86
At 8y (n = 345)				
BMI z-score ≥ 2SD	26	92	39	87
WHtR ≥ 0.5	39	91	45	89
WHtR ≥ 0.55	19	97	53	87
WHtR ≥ p90 IDEFICS	61	75	31	91
At 11y (n = 443)				
BMI z-score ≥ 2SD	28	92	48	83
WHtR ≥ 0.5	46	82	41	85
WHtR ≥ 0.55	17	94	44	81
WHtR ≥ p90 IDEFICS	62	72	37	87

PPV = positive predictive value; NPV = negative predictive value; BMI = body mass index; WHtR = waist-to-height ratio.

Table 5 shows the binary logistic regression models with the cardiometabolic risk factors (normal/altered) as dependent variables, explained by the different anthropometric measures (having a BMI z-score ≥2SD, a WHtR≥0.55, a WHtR≥0.50 and a WHtR ≥ p90 or not) as independent variables. In all of our regression models at 5, 8 and 11 years of age, being categorized by any obesity marker was significantly associated with altered SBP, HOMA-IR or CMet risk. In contrast, DBP was not significantly associated with obesity markers in any regression model (data not shown). At 5 years of age, a WHtR≥0.55 predicted an increase in CMet risk with an odds ratio (OR) of 29.1 (95% CI: 5.6, 151.7) compared to a WHtR<0.55, while other obesity markers were associated with a lower OR.

At 8 years of age, the odds of having CMet risk was similar between the WHtR≥0.50 and WHtR≥0.55 groups, but the odds of having an altered HOMA-IR or high triglyceride level was much higher among the children classified in the WHtR≥0.55 abdominal

Table 3
Distribution of altered parameters according to obesity categories (n cases/total children within the abdominal obesity category).

	BMI		WHtR		WHtR		WHtR percentile	
	<2SD	≥2SD	<0.50	≥0.50	<0.55	≥0.55	<90th	≥90th
At 5y								
SBP ≥ p90 (n = 536)	71/412 (17.2%)	42/121 (34.7%)	76/400 (19.0%)	37/136 (27.2%)	101/515 (19.6%)	12/21 (57.1%)	76/400 (19.0%)	37/136 (27.2%)
HDL-C ≤ p10 (n = 423)	19/334 (5.7%)	7/89 (7.9%)	19/357 (5.3%)	7/66 (10.6%)	26/410 (6.4%)	0/13	19/347 (5.5%)	7/76 (9.2%)
Triglycerides ≥ p90 (n = 423)	45/334 (13.5%)	18/89 (20.2%)	49/357 (13.7%)	14/66 (21.2%)	57/410 (13.9%)	6/13 (46.2%)	49/347 (14.1%)	14/76 (18.4%)
HOMA-IR ≥ p90 (n = 423)	89/328 (27.1%)	44/85 (51.8%)	96/350 (27.4%)	37/63 (58.7%)	124/401 (30.9%)	9/12 (75.0%)	94/339 (27.7%)	39/74 (52.7%)
CMet Risk (n = 329)	33/258 (12.8%)	27/71 (38.0%)	38/274 (13.9%)	22/54 (40.7%)	51/317 (16.1%)	9/11 (81.8%)	38/267 (14.2%)	22/61 (36.1%)
At 8y								
SBP ≥ p90 (n = 556)	41/389 (10.5%)	46/164 (28.0%)	61/478 (12.8%)	26/78 (33.3%)	76/527 (14.4%)	11/29 (37.9%)	42/392 (10.7%)	45/164 (27.4%)
HDL-C ≤ p10 (n = 373)	18/255 (7.1%)	12/117 (10.3%)	22/323 (6.8%)	8/50 (16.0%)	27/353 (7.6%)	3/20 (15.0%)	19/262 (7.3%)	11/111 (9.9%)
Triglycerides ≥ p90 (n = 373)	28/258 (10.9%)	15/118 (12.7%)	36/326 (11.0%)	7/51 (13.7%)	37/357 (10.4%)	6/20 (30.0%)	30/265 (11.3%)	13/112 (11.6%)
HOMA-IR ≥ p90 (n = 359)	83/245 (33.9%)	75/113 (66.4%)	119/310 (38.4%)	39/49 (79.6%)	141/340 (41.5%)	17/19 (89.5%)	86/252 (34.1%)	72/107 (67.3%)
CMet Risk (n = 345)	18/233 (7.7%)	36/111 (32.4%)	33/298 (11.1%)	21/47 (44.7%)	44/326 (13.5%)	10/19 (52.6%)	21/240 (8.8%)	33/105 (31.4%)
At 11ys								
SBP ≥ p90 (n = 569)	69/383 (18.0%)	76/186 (40.9%)	90/447 (20.1%)	55/122 (45.1%)	125/524 (23.9%)	20/45 (44.4%)	69/374 (18.4%)	76/195 (39.0%)
HDL-C ≤ p10 (n = 467)	5/312 (1.6%)	8/155 (5.2%)	9/361 (2.5%)	4/106 (3.8%)	10/430 (2.3%)	3/37 (8.1%)	7/309 (2.3%)	6/158 (3.8%)
Triglycerides ≥ p90 (n = 467)	42/312 (13.5%)	28/155 (18.1)	47/361 (13.0%)	23/106 (21.7%)	60/430 (14.0%)	10/37 (27.0%)	36/309 (11.7%)	34/158 (21.5%)
HOMA-IR ≥ p90 (n = 458)	81/304 (26.6%)	115/154 (74.7%)	113/352 (32.1%)	83/106 (78.3%)	168/422 (39/8%)	28/36 (77.8%)	83/301 (27.6%)	113/157 (72.0%)
CMet Risk (n = 443)	38/292 (13.0%)	56/151 (37.1%)	51/338 (15.1%)	43/105 (41.0%)	78/407 (19.2%)	16/36 (44.4%)	36/287 (12.5%)	58/156 (37.2%)

Data is presented as n (%). BMI = body mass index; WHtR = waist-to-height ratio; SBP = systolic blood pressure; HDL-C = high-density lipoprotein cholesterol; CMet Risk: Cardiometabolic Risk.

Table 5
Logistic regression models of the different abdominal obesity criteria on health outcome measures at different ages.

	SBP ≥ p90		HDL-C ≤ p10		TG ≥ p90		HOMA-IR ≥ p90		CMet Risk	
	OR (95% CI), R^2%	p-value	OR (95% CI), R^2%	p-value	OR (95% CI), R^2%	p-value	OR (95% CI), R^2%	p-value	OR (95% CI), R^2%	p-value
At 5y										
n	536		423		423		423		329	
BMI z-score ≥ 2SD	6.8 (3.2, 14.8), 27.9	<0.001	1.3 (0.3, 4.7), 17.4	0.736	3.0 (1.3, 7.2), 22.1	0.012	2.7 (1.3, 5.4), 6.2	0.007	9.0 (3.7, 21.6), 24.7	<0.001
WHtR ≥ 0.5	4.1 (2.3, 7.4), 27.9	<0.001	2.4 (0.9, 6.3), 19.0	0.090	2.2 (1.0, 4.7), 21.4	0.039	3.6 (2.0, 6.3), 9.8	<0.001	7.1 (3.3, 15.3), 25.6	<0.001
WHtR ≥ 0.55	8.4 (3.1, 22.4), 26.6	<0.001	–	–	6.0 (1.7, 21.5), 22.4	0.006	7.5 (1.9, 29.4), 6.9	0.004	29.1 (5.6, 151.7), 23.7	<0.001
WHtR ≥ p90	4.1 (2.3, 7.4), 27.9	<0.001	2.0 (0.8, 5.3), 18.5	0.161	1.8 (0.9, 3.8), 20.8	0.111	2.7 (1.6, 4.6), 8.0	<0.001	5.3 (2.5, 10.9), 23.1	<0.001
At 8y										
n	556		373		373		359		345	
BMI z-score ≥ 2SD	4.7 (2.4, 9.0), 13.4	<0.001	1.7 (0.6, 4.9), 9.0	0.330	1.6 (0.6, 4.4), 13.6	0.344	8.0 (3.2, 20.1), 16.9	<0.001	5.7 (2.5, 13.2), 16.2	<0.001
WHtR ≥ 0.5	4.7 (2.6, 8.6), 14.8	<0.001	3.1 (1.2, 7.7), 11.4	0.018	1.2 (0.7, 4.8), 14.0	0.190	6.5 (3.1, 14.0), 18.0	<0.001	10.8 (4.8, 24.1), 24.7	<0.001
WHtR ≥ 0.55	5.1 (2.2, 12.1), 11.5	<0.001	2.7 (0.7, 10.4), 9.5	0.147	6.7 (2.1, 21.9), 17.5	0.002	13.6 (3.0, 62.4), 14.7	0.001	11.8 (4.1, 33.8), 18.0	<0.001
WHtR ≥ p90	4.5 (2.7, 7.7), 17.4	<0.001	1.6 (0.7, 3.7), 9.3	0.240	1.3 (0.6, 2.8), 13.5	0.441	4.5 (2.7, 7.5), 20.1	<0.001	7.9 (3.9, 16.0), 25.4	<0.001
At 11y										
n	569		467		467		458		443	
BMI z-score ≥ 2SD	3.7 (2.0, 6.8), 20.7	<0.001	2.1 (0.5, 8.3), 22.0	0.308	2.1 (1.0, 4.2), 8.5	0.047	10.7 (4.8, 23.9), 22.5	<0.001	5.7 (2.9, 11.1), 17.2	<0.001
WHtR ≥ 0.5	4.7 (2.9, 7.5), 23.2	<0.001	1.3 (0.4, 4.7), 21.3	0.659	1.7 (1.0, 3.1), 8.4	0.065	9.8 (5.6, 17.2), 30.3	<0.001	4.4 (2.6, 7.5), 18.5	<0.001
WHtR ≥ 0.55	3.3 (1.7, 6.4), 16.8	<0.001	3.2 (0.8, 13.2), 23.1	0.111	2.2 (1.0, 5.0), 8.4	0.051	5.6 (2.6, 13.7), 16.2	<0.001	3.6 (1.7, 7.7), 12.3	0.001
WHtR ≥ p90	4.4 (2.8, 7.0), 26.2	<0.001	1.2 (0.4, 4.1), 21.3	0.672	2.0 (1.1, 3.4), 9.3	0.014	8.5 (5.2, 13.8), 32.7	<0.001	5.5 (3.2, 9.4), 22.2	<0.001

Each line represents a model adjusted by sex, country and pubertal development (at 11 years). BMI = body mass index; WHtR = waist-to-height ratio; SBP = systolic blood pressure; HDL-C = high-density lipoprotein cholesterol; TG = triglycerides; HOMA-IR= Homeostatic Model Assessment for Insulin Resistance; CMet Risk: Cardiometabolic Risk; R^2 Nagelkerke. There were no subjects with WHtR≥0.55 and HDL-C ≤ p10 at 5 years.

obesity group. At 11 years of age, all the cut-offs showed similar predictive capacity, and the WHtR≥0.55 cut-off showed lower odds for altered SBP, HOMA-IR or CMet risk compared to other criteria.

4. Discussion

This study assessed the power of different obesity markers to predict an elevated cardiometabolic risk in European children who were not selected for increased risk. In our sample, an elevated BMI and markers of central obesity were associated with less favourable values for SBP, HOMA-IR and cardiometabolic risk from the early age of 5 years and older. This confirms findings in previous studies that found similar associations between obesity indicators and CV risk parameters in children [44,45].

Among the different obesity markers that were evaluated, the WHtR≥0.55 cut-off had the best discrimination power. Our results differ from those of Sijtsma et al. [46], who compared WC, the WHtR and BMI as indicators of cardiometabolic risk factors in children aged 3–7 years. They found that all these predictors were similarly positively correlated with SBP, HOMA-IR and triglyceride levels in children with overweight or obesity. Buchan et al. [47] evaluated the ability of BMI, WC and the WHtR to identify cardiometabolic risk in children aged 9–12 years and found that a BMI ≥ $p85^{th}$, WC ≥ $p85^{th}$ and WHtR≥0.5 significantly increased the odds of a composite score of cardiometabolic risk. However, they did not find increased risks of having elevated triglycerides, HDL cholesterol, SBP or impaired fasting glucose levels. These results may reinforce the idea extracted from our results, that a WHtR≥0.5 cut-off might not be sensitive enough to detect children at cardiovascular risk compared to a WHtR≥0.55 cut-off.

The use of a WHtR≥0.5 cut-off as an abdominal obesity criterion associated with CV disease risk was first proposed in adults. In several studies, a WHtR≥0.5 cut-off was strongly related to CV risk and metabolic syndrome and was a significantly better predictor for CV outcomes, such as diabetes or hypertension, than BMI or WC. Furthermore, it was useful for the screening and early diagnosis of patients at risk [26,48–50]. The use of this cut-off had been extrapolated to children and used in this younger population [51,52]. However, as body shape and proportions in children change during growth and puberty [53,54], it is necessary to explore whether this cut-off is appropriate in children of different ages. Mehta, based on the association between the WHtR and BMI, proposed using a WHtR≥0.55 as the cut-off for abdominal obesity in children [28]. Recently, Arellano et al. [55] proposed specific cut-offs depending on the risk factors (e.g., a WHtR ≥0.57 to predict risk of high blood pressure, a WHtR ≥0.52 to predict elevated triglyceride levels and a WHtR ≥0.51 to predict metabolic syndrome). In this study, Arellano et al. evaluated the association of the WHtR and WC with the risk of metabolic syndrome, which was defined through the sum of internal z scores for various parameters (e.g., insulin, triglycerides, etc.) in which an overall result ≥1 SD was considered a risk marker in children aged 8–11 years. In a different way, we used external references for the identification of a possible altered parameter (≥90 percentile from the AAP references for blood pressure and European references from the IDEFICS study for biochemical parameters) as a criterion for increased risk. We chose the IDEFICS study cohort as an external reference because its sampling characteristics were similar to ours [39], since it consisted of 18,169 European children aged 2–10.9 years, with an average prevalence of obesity of 7.3%.

Elizondo-Montemayor et al. [56] identified a cut-off of 0.59 for the WHtR in children aged 6–12 years as a strong predictor of metabolic syndrome, and Khoury et al. [57], using the NHANES study data, proposed the point of 0.60 as a cut-off for children and adolescents. The NHANES sample and the study from Elizondo-Montemayor had obesity prevalences of 27% and 35.6%, respectively, which were much higher than those in our study sample.

A study conducted in young children aged 3–4 years [58] did not find significant differences between the accuracy of the WHtR compared to BMI and WC to identify preschool children with cardiovascular risk. Asif et al. [59], in children aged 5–12 years, found that the optimal cut-off for the WHtR was 0.47 and 0.48 for boys and girls, respectively, without stratifying by age. For Gomes et al. [60], WC and BMI were better associated with cardiometabolic risk than the WHtR in adolescents aged 10–17 years, and the optimal WHtR cut-off for this age group was 0.47.

A systematic review [26] and a meta-analysis [52] proposed using a cut-off of 0.5 for the WHtR in children and adolescents, the same as in adults, to detect children with increased cardiometabolic risk. As mentioned above and as identified by a recent meta-analysis from 2018 [61], there is considerable heterogeneity in the optimal cut-offs to predict cardiovascular risk in children, which makes the selection of a unique threshold difficult. Part of this heterogeneity could be increased by the different age ranges included in each study, as well as the different actual obesity prevalence.

The strengths of our study are that we analysed a general European population with an obesity prevalence similar to that from the European region according to data from the World Obesity Observatory [62]. Furthermore, we performed separate analyses for three different ages (5, 8 and 11 years), and thus, we could observe that the WHtR≥0.55 cut-off might be more specific to younger ages, whereas in older children (at 11 years) the different cut-offs had a similar capacity to predict cardiometabolic risk, so a WHtR≥0.50 cut-off, as recommended in adults, could be suitable as well. This seems sensible, since at younger ages, it might be less likely to detect altered cardiovascular conditions, and so, the degree of obesity to appear these alterations should be higher. Consistently, the likelihood of onset of metabolic alterations may increase with age, and therefore, the cut-off that is able to identify these alterations may decrease, becoming more similar to the cut-off recommended for adults.

A WHtR≥0.55, as we proposed, is in the range of values proposed for children by other investigators (approximately 0.47–0.60) [51,52,56,57,59,60]. A WHtR of approximately 0.60 would be even more specific than a WHtR of 0.55; however, this high degree of abdominal obesity is uncommon in European children. The WHtR≥0.60 cut-off was proposed to predict cardiometabolic risk in studies that were based on the NHANES cohort, with an almost threefold higher obesity prevalence than in our European cohort.

A possible limitation of our study is that we evaluated a normal child population with an average obesity prevalence of 9.6% at the ages from 5 to 11 years, where it is unlikely to find a high frequency of altered CV risk parameters. However, this limitation is also a strength in indicating that a WHtR≥0.55 predicts increased SBP, triglyceride levels, HOMA-IR and cardiometabolic risk in a general child population. The replication of our results in other populations of children is desirable. We cannot disregard a potential interaction between abdominal obesity and diet, familial predisposition or physical activity (which was not the focus of the present work) in relation to cardiometabolic risk [13].

Further research is needed to understand whether the WHtR may be a good marker of abdominal visceral fat in children and whether the proposed cut-offs for the WHtR differ for different ethnicities.

5. Conclusion

BMI and the WHtR are useful predictors for metabolic syndrome and cardiovascular risk in children aged 5–11 years. All the analysed cut-offs (a BMI ≥ z-score ≥2 SD, a WHtR≥0.5, a WHtR≥0.55 and a WHtR ≥ p90th percentile) were related to altered risk markers at 5, 8 and 11 years of age. A WHtR ≥0.50 could be an appropriate cut-off to predict cardiometabolic risk in children, but a WHtR ≥0.55 better discriminated between the subjects with altered risk parameters at younger ages. Since the WHtR is a simple measure to perform and to interpret with a fixed cut-off for children, it seems suitable for application in clinical practice. The results of our study support the well-known message “Keep your waist to less than half your height”, proposed by several authors for children and adolescents [51]. In young children, a higher cut-off of a WHtR≥0.55 could be necessary to be associated with cardiometabolic risk.

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Author contributions

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Conflict of interest

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