A composite score combining waist circumference and body mass index more accurately predicts body fat percentage in 6- to 13-year old children

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ORIGINAL CONTRIBUTION

A composite score combining waist circumference and body mass index more accurately predicts body fat percentage in 6- to 13-year-old children

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Abstract
Purpose Body mass index (BMI) and waist circumference (WC) are widely used to predict % body fat (BF) and classify degrees of pediatric adiposity. However, both measures have limitations. The aim of this study was to evaluate whether a combination of WC and BMI would more accurately predict %BF than either alone.
Methods In a nationally representative sample of 2,303 6- to 13-year-old Swiss children, weight, height, and WC were measured, and %BF was determined from multiple skinfold thicknesses. Regression and receiver operating characteristic (ROC) curves were used to evaluate the combination of WC and BMI in predicting %BF against WC or BMI alone. An optimized composite score (CS) was generated.
Results A quadratic polynomial combination of WC and BMI led to a better prediction of %BF ($r^2 = 0.68$) compared with the two measures alone ($r^2 = 0.58$–0.62). The areas under the ROC curve for the CS [0.6 * WC-SDS + 0.4 * BMI-SDS] ranged from 0.962 ± 0.0053 (overweight girls) to 0.982 ± 0.0046 (obese boys) and were somewhat greater than the AUCs for either BMI or WC alone. At a given specificity, the sensitivity of the prediction of overweight and obesity based on the CS was higher than that based on either WC or BMI alone, although the improvement was small.
Conclusion Both BMI and WC are good predictors of %BF in primary school children. However, a composite score incorporating both measures increased sensitivity at a constant specificity as compared to the individual measures. It may therefore be a useful tool for clinical and epidemiological studies of pediatric adiposity.

Keywords Waist circumference · Body fat · Body mass index · Overweight · Children

Introduction

There has been a global increase in childhood obesity over the past 2–3 decades [15, 25]. Body mass index (BMI) is most often used to determine overweight and obesity in children because its determination is simple, and two BMI references are available and widely used [3, 19]. However, the use of BMI to identify overweight children at risk for metabolic disorders has several limitations: (a) reference cutoffs for overweight and, particularly, obesity may have low sensitivity, so a considerable number of children with high body fat may be misclassified as normal weight and children with high muscle mass may be classified as overweight or obese [27]; (b) it is not possible to distinguish between changes in fat and fat-free mass during treatment; and (c) it provides no indication on fat distribution [18].

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In adults, central (intra-abdominal) distribution of body fat increases risk of the metabolic syndrome more than peripheral distribution [20]. Waist circumference (WC) measurements have been used to estimate intra-abdominal fat in adults [17] and may also be useful in children [12]. Pediatric studies consistently show strong correlations of WC with components of the metabolic syndrome, including dyslipidemia and fasting insulin [4, 7, 8]. Therefore, WC could be a useful adjunct tool to BMI in the assessment of childhood obesity. In adults, BMI and WC are independent predictors of %BF and a combination may be valuable [16]. In children, it is uncertain whether these two indices are independent predictors of % body fat (%BF), and a combined index including both BMI and WC has not been proposed. Therefore, the aim of this study was to determine whether a formula combining WC and BMI would more precisely predict %BF in overweight children than either of the two alone.

Subjects and methods

Subjects

A probability-proportionate-to-size cluster sampling based on current census data was used to obtain a nationally representative sample of 2,500 children living in Switzerland and aged 6–13 years. This sample size represents about 1 in 250 children in this age group in Switzerland (Swiss Federal Department of Statistics, personal communication). By stratified random selection, 60 schools were identified across Switzerland. After acceptance of participation, 3 or 4 classes (depending on class sizes) were randomly selected from each school, and all students from the invited classrooms were invited to participate. The average number of participants per school was 38 students, but it varied according to class sizes and response rate. Data on the prevalence of overweight and obesity as well as percentiles for waist circumference and waist-to-height ratio from this sample have been published elsewhere [1, 2]. Ethical approval for the study was obtained from the Swiss Federal Institute of Technology, Zürich, Switzerland. Written informed consent was obtained from the all parents or guardians of the participating children, and oral assent was received from the children prior to the measurements.

Methods

For the measurements, the subjects removed their shoes, emptied their pockets and wore light indoor clothing. Height and weight were measured using standard anthropometric techniques [26]. Body weight was measured to the nearest 0.1 kg by using a digital scale (BF 18; Breuer, Ulm, Germany) calibrated with standard weights. Height was measured to the nearest 0.1 cm by using a portable stadiometer (Seca 214, Seca Medizinische Waagen und Messsysteme, Hamburg, Germany). BMI was calculated as weight (kg) divided by height^2 (m). WC was measured using a nonstretchable measuring tape (prym tape measure junior yellow/white, William Prym GmbH & Co., Stolberg, Germany) midway between the lowest rib and the top of the iliac crest to the nearest 0.1 cm. Subjects were asked to stand erect with their abdomen relaxed and their weight equally divided over both legs. At the time of the measurement, they were further asked to gently breathe out [11]. The measurements were done in duplicate, and the mean was used for analysis. Skinfold thicknesses (SFT) were measured by two trained examiners (RA and MK) using a Harpenden Skinfold Caliper (HSC-5, British Indicators, West Sussex, United Kingdom) with a constant spring pressure of 10 g/mm, a resolution of 0.2 mm, and a measuring range of 80 mm. The measurements were performed at four different sites (triceps, biceps, subscapular, and suprailiac) [10]. For the measurements of the triceps skinfold, the midpoint of the back of the upper arm between the tips of the olecranal and acromial processes was determined by measuring with the arm flexed at 90° and marked with a soft pen. With the arm hanging freely at the side, the caliper was applied vertically above the olecranon at the marked level. Over the biceps, the SFT was measured at the same level as the triceps, again with the arm hanging freely and the palm facing outward. At the subscapular site, the SFT was picked up just below the inferior angle of the scapula at 45° to the vertical along the natural cleavage lines of the skin. The suprailiacal SFT was measured above the iliac crest, just posterior to the midaxillary line and parallel to the cleavage lines of the skin, with the arm lightly held forward. All sites were measured on the left side of the body in duplicate. For each site, 10% of the measurements were repeated by the second examiner to calculate interobserver variability. Mean interobserver variability for all skinfold measures was very low at 1.74%, while intra-observer variability was only 1.43%.

Using the mean of the repeated SFT measurements, body density (D) and %BF were calculated according to the following equations by Deurenberg et al. [6]:

$$D\,(boys)\,[g/ml] = 1.1690 - 0.0788 \cdot Log(Sum\ of\ four\ SFT)$$

$$D\,(girls)\,[g/ml] = 1.2063 - 0.0999 \cdot Log(Sum\ of\ four\ SFT)$$

$$body\,fat\ [\%] = \left(\frac{562 - 4.2 \cdot (age - 2)}{body\ density}\right) - (525 - 4.7 \cdot (age - 2))$$

Statistical analysis

Statistical analysis was performed using SPLUS (Version 8, Insightful Corporation, Seattle, WA, USA), SPSS 16.0 for windows (SPSS Inc, Chicago, IL, USA) as well as EXCEL 2003 (Microsoft Crop., Redmond, WA, USA). Percentiles for %BF and WC were calculated for boys and girls separately by the LMS method of cole and green (software LMSchartmaker pro version 2.43, http://www.healthforallchildren.co.uk). For the definition of overweight and obesity according to WC and %BF, the 85th and 95th percentiles of the sample population were used, respectively. To define overweight and obesity according to BMI, the 85th and 95th BMI for age CDC reference percentiles were used [19]. Because the distribution of BMI, %BF, and WC are age dependent, BMI SD scores (BMI-SDS), %BF SD scores (%BF-SDS), and WC SD scores (WC-SDS), which are adjusted for age, were used in subsequent calculations. These SDS are as calculated by LMSchartmaker and are based on the CDC reference data for BMI and on the sample itself for %BF and WC. All the calculations were done separately for boys and girls.

Regressions of %BF-SDS on WC-SDS and BMI-SDS, separately and joint (including quadratic polynomials of WC and BMI), were calculated to describe their relations. Receiver-operating characteristic (ROC) curves were used to assess the performance of both WC-SDS and BMI-SDS for detecting overweight and obesity as compared to %BF-SDS. Because regression of %BF-SDS on WC-SDS together with BMI-SDS was improved compared with using WC-SDS or BMI-SDS alone (see Results and Table 4), we analyzed whether a simple linear combination of WC-SDS and BMI-SDS would yield better ROC curves. The linear combination α * WC-SDS + (1–α) * BMI-SDS were tried, for $\alpha = 0.1$–0.9 (step 0.1). It turned out that 0.6 * WC-SDS + 0.4 * BMI-SDS gave the highest AUC both for boys and girls in predicting overweight and obesity. The area under the ROC curve provides a numerical summary of the indicator's performance. The SE of the AUC was obtained by bootstrapping [5]. An AUC of 0.95 implies that a randomly selected overweight (or obese) child has a BMI-SDS greater than that of a randomly selected normal weight child 95% of the time [29]. The sensitivity and the specificity of the WC percentiles as calculated by LMSchartmaker and of the CDC BMI percentiles for overweight and obesity, as defined by the 85th and the 95th percentiles of %BF-SDS, were calculated. Student's t-test was used to compare genders. p-values <0.05 were considered significant.

Results

Subject characteristics are shown in Table 1. The final sample size recruited from 60 schools throughout Switzerland consisted of 2,303 children (1,128 boys and 1,175 girls) between the age of 6 and 13 years. In the 60 participating schools, a total of 3,188 children were invited to participate. Overall participation rate was 72.5%. Mean WC and %BF significantly differed between boys and girls ($p < 0.05$), while BMI did not. The prevalences of overweight and obesity according to the CDC references for boys and girls are shown in Table 2. There were no significant gender differences in overweight, but the prevalence of obesity was significantly higher in boys than in girls ($p < 0.05$).

Linear regressions of %BF as the dependent variable on WC(-SDS) or BMI(-SDS) showed an r^2 of 0.61–0.65 (compare Table 3). For both genders, the p-values for the prediction of %BF by either WC or BMI were <0.001. However, a thorough analysis indicated that a quadratic polynomial regression for BMI and WC together on %BF without interaction yielded a significantly better fit compared with BMI or WC alone as described in Table 3.

The ROC curves of WC-SDS and of BMI-SDS for the prediction of overweight and obesity in boys and girls on the basis of the 85th and the 95th percentiles for %BF calculated from skinfold thicknesses are displayed in Fig. 1 a–d. The areas under the ROC curves (± SE) of WC for prediction of overweight and obesity on the basis of the 85th and the 95th percentiles of %BF were 0.95 (±0.0067) and 0.98 (±0.0052) as well as 0.96 (±0.007) and 0.98 (±0.0059) for girls and boys, respectively. Whereas the areas under the ROC curves (±SE) of BMI for prediction of overweight and obesity on the basis of the 85th and the 95th percentiles of %BF were 0.94 (±0.0088) and 0.97 (±0.014) as well as 0.95 (±0.0079) and 0.97 (±0.006) for girls and boys, respectively.

As indicated by the regression results (Table 3), the prediction of BF% is significantly, if only slightly, improved by using both BMI and WC in a multiple regression. But it was unclear whether a composite score out of BMI and WC yields improved ROC curves as well as improved sensitivities and specificities. We defined, both for boys and girls, a composite score (CS) as 0.6 * WC-SDS + 0.4 * BMI-SDS. Figure 2 gives the corresponding ROC curves. Using the CS improved all eight AUCs (for BMI/WC, boys/girls, and overweight/obesity), particularly with respect to BMI alone, but the differences were marginally significant (boys and girls) for BMI and overweight ($p < 0.1$, Z test) and not significant for WC or obesity.

Table 1 Descriptive characteristics of a nationally representative sample of Swiss children aged 6–13 years

	Boys	Girls
N	1128	1175
Age (y)	10.2 ± 1.8[a]	10.1 ± 1.8
Height (m)	1.41 ± 0.12	1.41 ± 0.12
Weight (kg)	35.4 ± 9.6	35.2 ± 10.0
BMI (kg/m^2)	17.6 ± 2.7	17.5 ± 2.7
Body fat %	18.8 ± 8.7	21.1 ± 9.9[b]
Waist circumference (cm)	64.8 ± 8.1	63.9 ± 8.3[b]

[a] Mean ± SD (all such values)

[b] Significantly different from boys ($p < 0.01$), as determined by independent samples *t*-test

Table 2 Prevalence of overweight and obesity in a national sample of Swiss children aged 6–13 years using the BMI criteria of the US centers for disease control and prevention (CDC) [19]

	CDC	
	Overweight (>85th and <95th percentile)	Obese (>95th percentile)
Boys ($n = 1128$)	11.3 (0.94)	5.41 (0.67)
Girls ($n = 1175$)	9.87 (0.87)	3.23 (0.52)[a]

In percentage (SE)

[a] Significantly different from boys as determined by χ^2 test ($p < 0.05$)

Table 3 Residuals and r^2 of the regression models of %BF on BMI and WC alone, linear, and of %BF on BMI and WC combined (quadratic polynomials) by gender

	Residual SD	r^2
Girls BMI alone, linear	0.62	0.61
Girls WC alone, linear	0.65	0.58
Girls quadratic polynomials in BMI and WC	0.57	0.68
Boys BMI alone, linear	0.61	0.62
Boys WC alone, linear	0.66	0.58
Boys quadratic polynomials in BMI and WC	0.56	0.68

The sensitivity and specificity of the WC cutoffs as well as the BMI cutoffs proposed by the centers for disease control and prevention [19] compared with %BF are displayed in Table 4. With a range of 0.95–0.99, the specificity of all the cutoff points used is high, while the sensitivity varies from 0.54 to 0.76. For overweight, the WC cutoffs show a higher sensitivity compared with the BMI cutoffs in girls, while for boys, it is the opposite. For obesity, the sensitivity is consistently higher for the WC cutoffs in both boys and girls. The lowest sensitivity (0.54) was found for the BMI obesity cutoffs in girls. The slight superiority of the composite score (CS) 0.6 * WC-SDS + 0.4 * BMI-SDS, as indicated by the AUC, is confirmed in Table 5, where the sensitivity of WC, BMI, and CS is compared for specificity 0.90 for overweight and 0.95 for obesity. Compared with classification by %BF, the number of false positives by BMI was 79, while it was 86 for WC. In both cases, there were 109 false negatives. In total, 254 children were classified as overweight/obese by both the BMI and the WC percentiles, while 96 were classified as overweight/obese by only WC and 89 by only BMI.

Discussion

Our data indicate both WC and BMI are good predictors of %BF in 6–12-year-old children in Switzerland, but a combination of the two measures in a composite score is a better predictor. To accurately define excess fatness in children using simple anthropometric measures is challenging. The most widely used tool for defining overweight and obesity in epidemiological studies and most clinical settings remains the BMI. Even though it is a simple measurement and generally shows good agreement with body fat measurements, there are several limitations to this technique including the impossibility to distinguish between different distribution patterns of body fat [9].

There is a clear link between intra-abdominal fat and metabolic abnormalities, such as plasma cholesterol, triglyceride, and insulin concentrations [4, 7, 8, 12]. In the most recent definition of the metabolic syndrome in children issued by the IDF in 2007, increased WC (>90th percentile) is used as the sine qua nonfactor for diagnosing the syndrome [28]. Several recent review papers have tried to conclude which of the two measures, WC or BMI, is better suited for the diagnosis of childhood overweight and obesity; however, there is no consensus [9, 21, 22]. In their review of ten studies, Reilly et al. [22] found no improved identification of adverse cardiometabolic risk profiles from WC over that provided by BMI [22]. Similarly, our data on the two individual measures show no conclusive evidence for one of the two measures being superior in predicting %BF in all groups.

WC is a useful predictor of metabolic disorders in children [12], and in our data, the areas under the ROC curves for WC showed slightly better performance compared with BMI for predicting %BF. BMI is also a good proxy measure for body fatness in children [27], and the specificity of proposed cutoff points to define overweight and obesity is high, at 0.95–0.99. However, the sensitivity of the cutoffs shows much wider variation and may

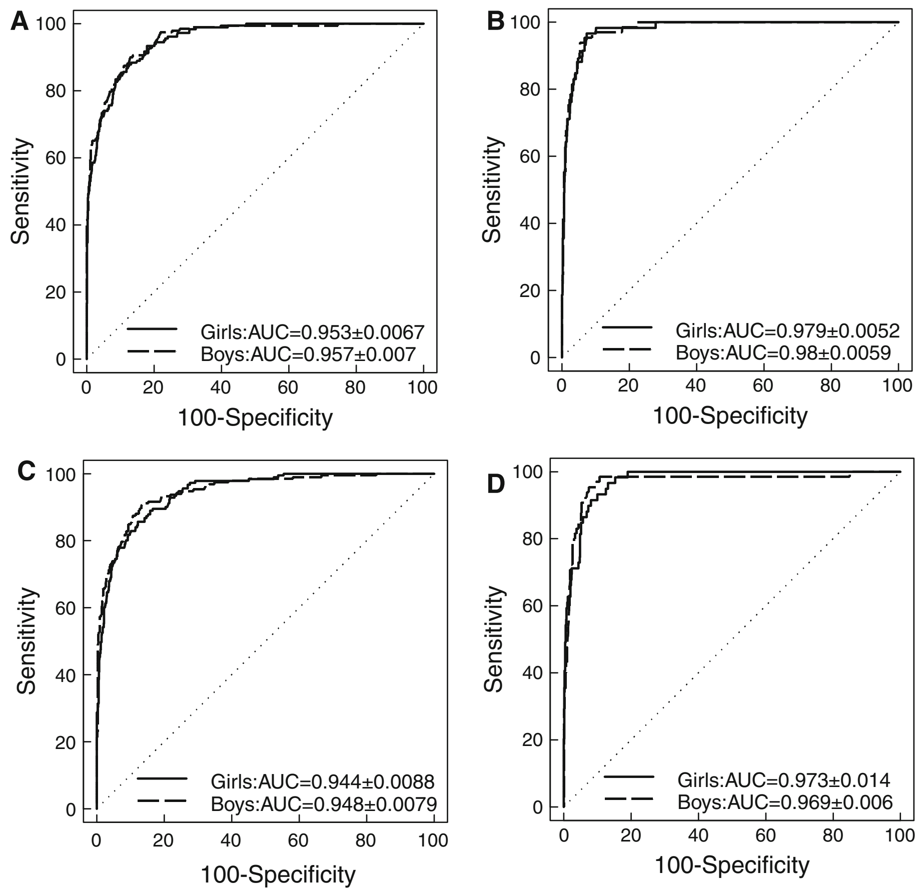

Fig. 1 Receiver-operating characteristic (ROC) curves of WC (**a** and **b**) and BMI (**c** and **d**) SD scores for prediction of overweight (**a** and **c**) and obesity (**b** and **d**) in boys and girls on the basis of percentiles (85th and 95th for overweight and obesity, respectively) for percentage body fat calculated from skinfold thicknesses in a national sample of 2303 6–13-year-old children in Switzerland. The area under the curve (AUC) ± standard error is indicated for each curve

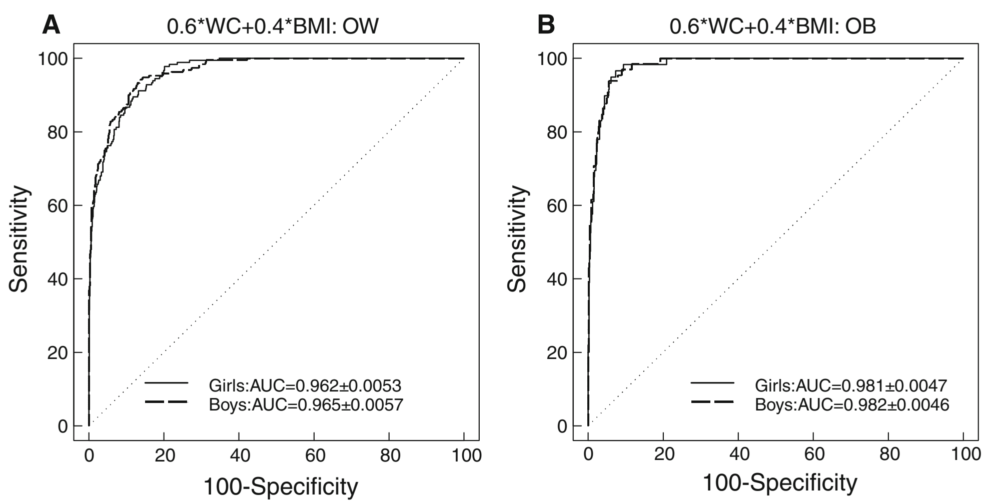

Fig. 2 Receiver-operating characteristic (ROC) curves for the combination of waist circumference (WC) and body mass index (BMI) by the equation: 0.6 * WC + 0.4 * BMI, for prediction of overweight (**a**) and obesity (**b**) in boys and girls on the basis of the 85th (**a**) and 95th (**b**) percentile for percentage body fat calculated from skinfold thicknesses in a national sample of 2303 6–13-year-old children in Switzerland. The area under the curve (AUC) ± standard error is indicated for each curve

generate many false negatives. For classifying overweight, WC seems to be the better predictor in girls and BMI in boys, but for obesity the sensitivity of WC is consistently higher in both genders. This is especially true for obese girls, where the performance of BMI is poor, with a sensitivity of only 0.54 compared with 0.66 for WC. It should be noted, however, that the sensitivity is poorly estimated in our sample of obese subjects due to their relative small frequency (3–5%, Table 1). The number of false-positive or false-negative classifications by WC or BMI compared with %BF in our sample revealed very similar numbers. Also, in terms of the number of children classified as overweight/obese by WC but not BMI, or by BMI but not WC, neither of the two measures was clearly superior.

Because both WC and BMI have advantages and limitations, a combination of the two may be beneficial in

Table 4 Sensitivity and specificity of age- and sex-specific waist circumference and BMI cutoff points compared with percentage body fat

	Overweight (>85th)[a]				Obesity (>95th percentile)[a]			
	Boys		Girls		Boys		Girls	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
WC	0.68	0.96	0.74	0.95	0.76	0.98	0.66	0.99
BMI	0.74	0.95	0.67	0.97	0.66	0.98	0.54	0.99

[a] The 85th and 95th percentiles of body fat% were used to define overweight and obesity, respectively. For waist circumference and body fat%, the newly created percentiles and, for BMI, the reference criteria from the US centers for disease control and prevention (CDC) were used

Table 5 Sensitivity of age- and sex-specific cutoff points for WC and BMI and for the composite score (0.6 * WC-SDS + 0.4 * BMI-SDS; CS) compared with percentage body fat calculated with a specificity fixed at 0.9 for overweight and 0.95 for obesity

	Overweight[a] spec = 0.9		Obesity[a] spec = 0.95	
	Boys	Girls	Boys	Girls
WC	0.85	0.85	0.89	0.88
BMI	0.84	0.82	0.86	0.78
CS	0.87	0.87	0.89	0.90

[a] The 85th and 95th percentiles of body fat% were used to define overweight and obesity, respectively. For waist circumference and body fat%, the newly created percentiles and, for BMI, the reference criteria from the US centers for disease control and prevention (CDC) were used

accurately predicting % BF. In adults, it has been proposed to combine WC and BMI for the prediction of fat mass in clinical practice [16], but this has not yet been done for children. In our data, a combination of WC and BMI for the prediction of fat mass has been shown to be as good and for most comparisons even slightly better as evidenced by both the regressions and the AUC in the ROC curves. Thus, this CS may provide a simple and useful algorithm to assess pediatric overweight and obesity. For use in clinical practice, it would be necessary to create percentile curves.

A potential limitation of our data is that %BF was determined by using skinfold thickness measures. Although not as objective a measure as DXA, skinfold thicknesses are a valid measure of %BF when done by experienced examiners; %BF values obtained by skinfold thickness measures show good agreement with measurements by DXA [13, 23] and are particularly useful in large population-based studies like ours. Combining multiple skinfold thicknesses, as in our study, results in greater accuracy and precision than single site measurements [14, 24]. To ensure data quality, all skinfold thickness measurements were carried out by the same two expert examiners and precision was high, with inter- and intra-observer variability <2%. Another potential limitation of the study is possible bias introduced during sampling. To recruit, we used a probability proportionate to size cluster sampling and, as described previously [2], we were able to follow the sampling scheme in nearly all schools, and the participation rate in all regions was similar. However, we do not know whether the children who declined participation were equally distributed among the entire BMI or WC range.

In conclusion, both WC and BMI are good predictors of %BF in our study population. But both measures have limitations, and, particularly for BMI, sensitivity tends to be poor. The combination of the two indicators using the proposed composite score can more accurately predict %BF, providing increased sensitivity at a constant specificity as compared to the individual measures in this age group. The composite score may therefore be a useful new tool for clinical and epidemiological studies of pediatric adiposity when BMI and WC measurements are available.

Nevertheless, further studies are required, especially because the clinical relevance of our results may well be more evident for specific subgroups than for the essentially 'normal' healthy child.

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