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 y[1–3]

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ABSTRACT

Background: A central fat pattern has adverse health implications in both children and adults. Because adiposity tracks from childhood into adulthood, the ability of simple anthropometric techniques to correctly measure truncal adiposity in childhood needs to be assessed.

Objectives: We sought to assess the validity of waist circumference, waist-to-hip ratio (WHR), and the conicity index as indicators of trunk fat mass in children and adolescents.

Design: Trunk fat mass (kg) was measured with dual-energy X-ray absorptiometry in 278 girls and 302 boys aged 3–19 y. Receiver operating characteristic (ROC) curves and areas under the curves (AUCs) for the ROCs were calculated to compare the relative abilities of the anthropometric measures to correctly identify children with high trunk fat mass (*z* score for our study population of ≥1).

Results: The 80th percentile for waist circumference correctly identified 89% of girls and 87% of boys with high trunk fat mass (sensitivity) and 94% of girls and 92% of boys with low trunk fat mass (specificity). Waist circumference performed significantly better as an index of trunk fat mass than did WHR or the conicity index, as shown by the AUCs in girls and boys, respectively: waist circumference AUCs = 0.97 and 0.97, conicity index AUCs = 0.80 and 0.81, and WHR AUCs = 0.73 and 0.71. Our cutoffs for high trunk fat mass and high waist circumference are provided for both sexes for each year of age.

Conclusion: Waist circumference provides a simple yet effective measure of truncal adiposity in children and adolescents. *Am J Clin Nutr* 2000;72:490–5.

KEY WORDS Waist-to-hip ratio, conicity index, trunk fat, dual-energy X-ray absorptiometry, receiver operating characteristic curve, children, adolescents, body fat, anthropometry

INTRODUCTION

In adults, it is well established that a more central fat distribution is associated with an increased risk of ill health (1). Recent studies in children also showed that a greater deposition of central fat is correlated with less favorable patterns of serum lipoprotein concentrations (2–5) and blood pressure (2). Because adiposity (6, 7) and cardiovascular risk factors (7) track from childhood into adulthood, early identification of children with high central adiposity is important.

Although computed tomography (CT) and magnetic resonance imaging (MRI) are considered the gold standards for assessing central fat distribution, their high cost, radiation dose (with CT), and unsuitability for use in young children have often precluded their use on a broad scale. In contrast, dual-energy X-ray absorptiometry (DXA) is a relatively simple technique for evaluating total and regional adiposity in children of all ages (8, 9). Although DXA cannot distinguish between intraabdominal and subcutaneous fat, research in adults (10) and children (11) showed strong correlations between trunk fat mass measured with DXA and intraabdominal fat measured with CT or MRI.

Routine evaluation of regional fat distribution on a wide scale requires methods that are simpler than DXA, CT, or MRI. However, studies on the efficacy of anthropometric techniques for identifying children with high central adiposity are scarce (11–13). The waist-to-hip ratio (WHR) has been used extensively in adults; however, studies published in the 1990s suggest that waist circumference alone may be a more useful and accurate tool in adults (14–17) and children (11–13). The conicity index, which evaluates waist circumference in relation to height and weight, appears to have a prognostic value similar to that of WHR in adults (18), but its ability to assess truncal adiposity has not been evaluated in children as far as we know. Therefore, the aim of our study was to assess the relative abilities of waist circumference, the WHR, and the conicity index to correctly identify children with high trunk fat mass as measured by DXA.

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SUBJECTS AND METHODS

Subjects

We studied 580 white children and adolescents (278 girls and 302 boys) recruited by using advertisements about studies on nutrition and bone health. The studies were approved by the Ethics Committee of the Southern Regional Health Authority. We obtained written, informed consent from each parent or guardian (for children <16 y) or from the children themselves (for those ≥16 y). A brief medical history was obtained with use of a questionnaire. Height was measured to the nearest millimeter with a wall-mounted Harpenden stadiometer (Holtain Ltd, Croswell, Crymych, United Kingdom) and weight was measured with electronic scales (model 1609N; Tanita Corp, Tokyo, Japan) to the nearest 0.1 kg. Body mass index (BMI; in kg/m^2) was calculated; no child was excluded on the basis of BMI. Waist and hip circumferences (cm) were measured in duplicate with an anthropometric tape while the subjects were wearing light clothing. Waist circumference was measured at the minimum circumference between the iliac crest and the rib cage. Hip circumference was measured at the maximum protuberance of the buttocks, and the WHR was calculated. The conicity index was calculated as follows:

$$\text{Conicity index} = \text{waist circumference}/(0.109 \times \text{square root of weight/height}) \qquad (1)$$

where waist circumference and height were measured in meters and weight was measured in kg.

DXA scanning

All DXA measurements were obtained with a Lunar DPX-L scanner (software version 1.3z; Lunar Corporation, Madison, WI). The scanner determines total fat mass in kg and as a percentage of body mass; the latter is calculated as [fat mass/(fat mass + lean tissue mass + bone mineral content)] × 100. Regional adiposity is estimated by using automatic default regions (arms, legs, and trunk). The trunk region consists of the area bordered by a horizontal line below the chin, vertical borders lateral to the ribs and oblique lines passing through the femoral necks. The leg region includes all tissue below these oblique lines (8). Our CVs for scanning precision on the basis of 10 consecutive scans of an adult subject were 2.6% for total fat mass in kg, 2.5% for total fat mass as a percentage of body mass, and <3.5% for all regional measurements. Other researchers reported a CV of 3.6% for total trunk mass in 61 prepubertal girls when duplicate scans were performed 6 wk apart (19).

Statistical analyses

Statistical analyses were performed with SPSS 6 for the Macintosh (Language Systems Corp, Chicago) and STATA STATISTICAL SOFTWARE (release 6; StataCorp, College Station, TX). Results are presented as means ± SDs for normally distributed data and as geometric means with 95% CIs for data that required log transformation. Receiver operating characteristic (ROC) curves determine the efficacy of a screening measure for correctly identifying subjects on the basis of their classification by a reference test (16, 20). Sensitivity (true-positive rate, or the proportion of reference-test-positive subjects who test positive with the screening test) and specificity (true-negative rate, or the proportion of reference-test-negative subjects who test negative with the screening test) are calculated for a range of cutoffs for the screening measure. By plotting the sensitivity against the false-positive rate (1 − specificity), we can identify the optimal point at which most subjects are correctly classified and a minimum of subjects are incorrectly classified. This optimal point is usually chosen as the point closest to 1 (top left-hand corner) on the ROC curve (16). However, different cutoffs may be selected depending on whether the consequences of many subjects classified as false positive are more (or less) important than are the consequences of many subjects classified as false negative. Minimizing either misclassification may be considered more important than minimizing the total number of subjects who are misclassified.

Sex-specific ROC curves were constructed by using the reference measurement of trunk fat mass (in kg) as measured by DXA. The anthropometric measurements were waist circumference, WHR, and the conicity index. All measurements were adjusted for age by linear regression. If the square of age significantly increased the R^2 of the model, this was also included in the regression; z scores for each variable were calculated as follows:

$$z \text{ score} = (\text{actual value} - \text{predicted value from regression}) / \text{root mean square error of the regression} \qquad (2)$$

A z score ≥1 for DXA-measured trunk fat mass identified a subject as true positive. For the anthropometric measures, the z scores were ranked and converted to percentiles so that each child's z score (age-adjusted anthropometric measurement of interest) was ranked relative to the rest of the group. The sensitivity and specificity of each screening measure were calculated at 19 percentile cutoffs (5th, 10th, 15th, … 95th) and ROC curves were constructed. For each measure of sensitivity and specificity, 95% CIs were calculated by using exact binomials (STATA software).

The areas under the curves (AUCs) for the ROCs and their 95% CIs were calculated to determine the validity of each anthropometric measure in estimating trunk fat deposition measured by DXA as described previously (16). The AUCs were calculated by using the logistic procedure in STATA, which determines AUCs by an integration analysis. A bootstrapping procedure was used 1000 times to estimate the 95% CIs of the AUCs and to test for differences between the areas of particular curves (21). Bias-adjusted 95% CIs were provided by the bootstrapping procedure and are presented for both the AUCs and the differences of interest. Values for each AUC can be between 0 and 1, with a value of 0.5 indicating that the screening test is no better than chance. Therefore, values >0.5 are desirable, with 1 implying perfect performance, although this is rarely observed in practice (22). In our study, the point closest to 1 on the ROC curves (80th percentile) was selected as the most appropriate anthropometric cutoff. Actual values for these cutoffs were calculated for each year of age (by using the midpoint of each year, eg, 8.5 for 8 y) with the regression equations. Positive (sensitivity/1 − specificity) and negative (1 − sensitivity/specificity) likelihood ratios were also calculated. A likelihood ratio expresses the odds that a given value of a diagnostic test result would be expected in an individual with (as opposed to an individual without) the target disorder (23).

RESULTS

In **Table 1** we show the heterogeneous nature of our study population; wide ranges were observed for all variables. Because we did not exclude any subject on the basis of body size, considerable variability was noted in the height and weight SD

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TABLE 1
Characteristics of the study participants[1]

	Girls (n = 278)	Boys (n = 302)	Girls (n = 278)	Boys (n = 302)
Age (y)	12.4 ± 4.2	11.9 ± 4.2	3.1–19.8[2]	3.3–19.9
Height (cm)	146.7 (141.2, 149.2)	149.9 ± 23.5	95.6–177.9	98.6–194.0
Weight (kg)	47.1 ± 18.8	41.9 (39.8, 44.2)	14.5–112.8	14.5–106.0
BMI (kg/m^2)	20.0 (19.5, 20.5)	19.2 (18.8, 19.5)	14.1–39.7	13.8–33.8
Body fat (%)	25.1 (24.0, 26.3)	16.9 (16.1, 17.7)	9.4–52.3	7.1–53.1
Trunk fat mass (kg)	4.0 (3.6, 4.5)	2.5 (2.3, 2.8)	0.4–29.2	0.4–25.1
Waist girth (cm)	65.9 (64.6, 67.2)	67.2 (65.9, 68.6)	46.5–112.6	45.8–113.0
WHR	0.79 (0.78, 0.80)	0.83 (0.82, 0.84)	0.61–1.12	0.69–1.12
Conicity index[3]	1.12 (1.11, 1.12)	1.16 (1.15, 1.17)	0.97–1.41	1.01–1.52

[1] Normally distributed data are presented as $\bar{x}$ ± SD; data requiring log transformation are presented as geometric means with 95% CIs in parentheses. WHR, waist-to-hip ratio.

[2] Range.

[3] Calculated as waist girth in meters/(0.109 × square root of weight in kg/height in meters).

scores (24). The height and weight SD scores, respectively, ranged from −3.28 to 4.25 and −2.79 to 7.52 in girls and from −2.13 to 3.58 and −1.73 to 8.48 in boys.

Correlations between trunk fat (in kg) and waist circumference were significantly higher (r = 0.92, P < 0.0001) in both girls and boys than were correlations between trunk fat and WHR (r = −0.40 and r = −0.04 in girls and boys, respectively) or between trunk fat and the conicity index (r = 0.01 and r = 0.30 in girls and boys, respectively). These differences among correlations remained similar after adjustment for age. The age-adjusted correlations between trunk fat and waist circumference, WHR, and the conicity index, respectively, were r = 0.83, r = 0.21, and r = 0.31 for girls and r = 0.84, r = 0.34, and r = 0.46 for boys.

The ROC curves for trunk fat mass in girls and boys are shown in **Figure 1**. Waist circumference performed significantly better than did either WHR or the conicity index in identifying high trunk fat mass in both sexes, as indicated by the AUCs (**Table 2**). For each anthropometric measure, AUCs did not differ significantly by sex (data not shown). In both boys and girls, the point closest to 1 on the ROC curves was denoted by a waist circumference cutoff at or above the 80th percentile for age. This cutoff resulted in 89% sensitivity (95% CI: 77%, 96%) with 94% specificity (91%, 97%) for girls and 87% sensitivity (74%, 95%) with 92% specificity (88%, 95%) for boys. By contrast, the 80th percentile for WHR correctly identified only 47% (95% CI: 32%, 62%) of girls with high trunk fat mass, with a specificity of 85% (80%, 90%), and 46% (31%, 61%) of boys, with a specificity of 85% (80%, 89%). The ability of the conicity index to correctly classify subjects was intermediate between that of the WHR and waist circumference [sensitivity of 57% (95% CI: 42%, 72%) and specificity of 88% (83%, 92%) in girls and sensitivity of 61% (45%, 75%) and specificity of 88% (83%, 91%) in boys].

Positive likelihood ratios showed that children with waist circumference values above the 80th percentile for age were 11.1 times (boys) to 15.9 times (girls) more likely to have a high trunk fat mass than were children with waist circumference values below the 80th percentile for age. In comparison, lower likelihood ratios were calculated for the conicity index (4.7 and 4.9 in girls and boys, respectively) and WHR (3.2 and 3.0 in

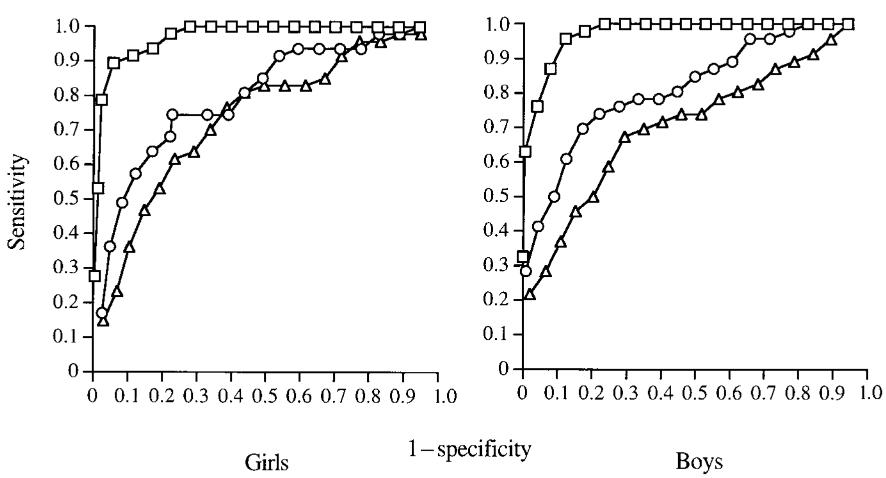

FIGURE 1. Receiver operating characteristic curves for trunk fat mass in girls (n = 278) and boys (n = 302) aged 3–19 y. Compared are the relative abilities of waist circumference (□), the conicity index (○), and the waist-to-hip ratio (△) to correctly identify children with high trunk fat mass (z score ≥1), as measured by dual-energy X-ray absorptiometry.

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TABLE 2
Areas under the receiver operating characteristic (ROC) curves[1]

ROC curve	Area	95% CI
1: Waist girth and trunk fat mass in girls	0.97	0.95, 0.99
2: Conicity index and trunk fat mass in girls	0.80	0.72, 0.86
3: WHR and trunk fat mass in girls	0.73	0.64, 0.81
4: Waist girth and trunk fat mass in boys	0.97	0.95, 0.99
5: Conicity index and trunk fat mass in boys	0.81	0.74, 0.88
6: WHR and trunk fat mass in boys	0.71	0.62, 0.80

[1] WHR, waist-to-hip ratio. Differences between pairs of curves (95% CIs for the difference) were as follows: curves 1 and 2 = 0.18 (0.12, 0.25), curves 2 and 3 = 0.06 (0.01, 0.12), curves 1 and 3 = 0.24 (0.17, 0.32), curves 4 and 5 = 0.16 (0.10, 0.23), curves 5 and 6 = 0.10 (0.06, 0.14), curves 4 and 6 = 0.26 (0.18, 0.35).

girls and boys, respectively). Negative likelihood ratios showed that children with waist circumferences above the 80th percentile for age were only approximately one-tenth (0.11 in girls and 0.14 in boys) as likely to have low trunk fat mass as were children with low waist circumferences (below the 80th percentile). Higher negative likelihood ratios were calculated for the conicity index (0.48 and 0.45 in girls and boys, respectively) and WHR (0.62 and 0.64, respectively).

In **Table 3** we show the 80th-percentile waist-circumference cutoffs calculated for each 1-y age group in boys and girls. These were somewhat higher in boys, particularly in late adolescence. In Table 3 we also show the estimated cutoffs for trunk fat mass (*z* score of 1) for each 1-y interval. In contrast with waist circumference, these were higher in girls at all ages, reflecting their higher total fat mass compared with boys (data not shown). This sex difference is further illustrated in **Figure 2**, which highlights the large variability in trunk fat mass observed in both sexes.

DISCUSSION

Our study showed that waist circumference performs well as an index of central adiposity in children and adolescents of both sexes over a wide age range. In contrast, we showed for the first time that the conicity index is not an accurate indicator of central fat distribution in youths. Other researchers (11–13) suggested previously that WHR correlates poorly with central adiposity. However, their studies were conducted in small samples of children with a limited age range. In contrast, we used more rigorous statistical analyses in a large sample of both boys and girls ranging in age from 3 to 19 y. Our results showed clearly the superiority of waist circumference as an anthropometric indicator of regional fat distribution. The use of ratios such as WHR to assess obesity may not be appropriate because they are highly age dependent (25) and may obscure stronger relations that may be present with separate circumference measurements (26). Furthermore, differences in skeletal structure may confound the results (27).

The conicity index was found to relate to atherogenic risk factors to an extent similar to that of WHR in adults, but it has the advantage of accounting for total adiposity without requiring measurement of hip circumference (18). This may contribute to the superior performance of the conicity index compared with WHR for identifying children with high trunk fat in our study. However, our results show that the conicity index is not as accurate a measure of central adiposity as is waist circumference in children, in that it correctly identified fewer than two-thirds of children with high trunk fat mass. This may be due in part to the reasons, discussed above, that ratios may not be appropriate for assessing obesity. It is also not known whether the relations between cardiovascular risk factors and conicity that are observed in adults also are present in children.

In contrast, waist circumference performed well in identifying children with high trunk fat as measured with DXA. Waist circumference correctly identified >90% of children as being truly

TABLE 3
Suggested cutoffs for identifying high trunk fat mass and waist circumference in growing children

Age[1]	Girls *n*	Girls Trunk fat mass[2]	Girls Waist circumference[3]	Boys *n*	Boys Trunk fat mass[2]	Boys Waist circumference[3]
y		*kg*	*cm*		*kg*	*cm*
3	3	0.94	50.3	5	0.93	53.1
4	10	1.29	53.3	10	1.21	55.6
5	14	1.75	56.3	17	1.56	58.0
6	11	2.32	59.2	17	1.97	60.4
7	12	3.03	62.0	21	2.46	62.9
8	11	3.88	64.7	15	3.02	65.3
9	28	4.87	67.3	13	3.64	67.7
10	14	5.99	69.6	17	4.34	70.1
11	18	7.24	71.8	25	5.08	72.4
12	15	8.59	73.8	25	5.86	74.7
13	29	9.99	75.6	36	6.65	76.9
14	25	11.40	77.0	22	7.43	79.0
15	23	12.76	78.3	27	8.18	81.1
16	26	14.02	79.1	19	8.86	83.1
17	17	15.10	79.8	14	9.45	84.9
18	11	15.97	80.1	6	9.92	86.7
19	11	16.57	80.1	13	10.25	88.4

[1] Cutoffs were calculated for the midpoint ages (ie, 8.5 y for 8-y-old children).
[2] *z* score of 1 for each age (year) and sex.
[3] Best waist circumference cutoff (80th percentile) chosen as the point closest to 1 (top left-hand corner) on the corresponding receiver operating characteristic curve (*see* Figure 1).

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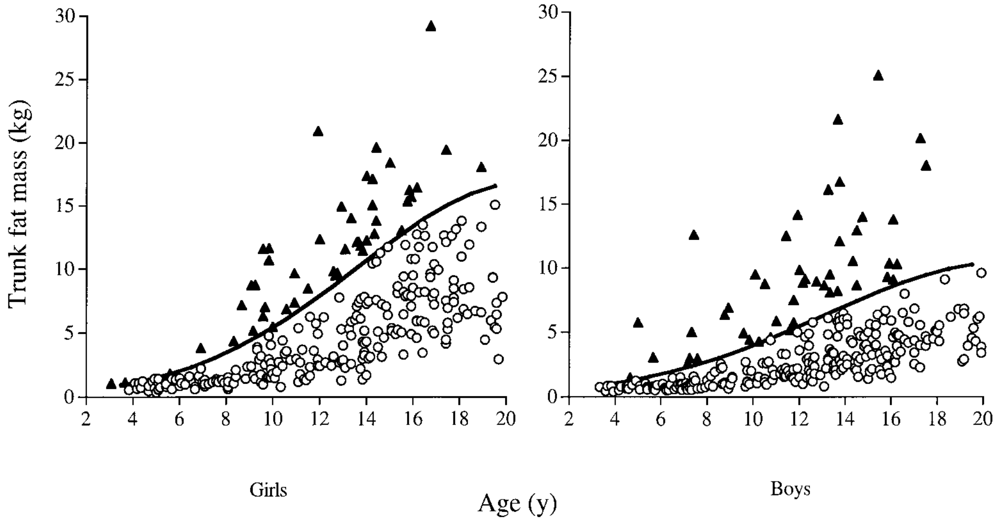

FIGURE 2. Trunk fat mass according to *z* score group allocation (○, *z* score < 1; ▲, *z* score ≥ 1). *n* = 278 girls and 302 boys.

positive (high waist circumference and high trunk fat mass) or truly negative (low waist circumference and low trunk fat mass) and resulted in high AUCs of 0.97 in both girls and boys. In our entire sample, 5 girls and 6 boys were classified as false negative (low waist circumference but actual high trunk fat) and 13 girls and 20 boys were classified as false positive (high waist circumference but actual low trunk fat). Furthermore, our waist circumference cutoffs for 19-y-old youths closely resemble published figures denoting increased metabolic risk in adults (80 cm for women and 94 cm for men; 14). Katzmarzyk et al (28) showed recently that waist circumference tracks reasonably well in childhood; 25–90% of children and adolescents who were in the highest quintile at baseline remained in that quintile 7 y later. Therefore, children who are identified waist circumference as being at high risk of excess truncal adiposity could be encouraged to make lifestyle changes, such as increased physical activity, to improve their body composition. Owens et al (29) showed recently that children who participated in a 4-mo physical-training program accumulated less visceral fat than did children who did not participate.

One difficulty with this area of research is that, despite increasing interest in the measurement of regional fat distribution, commonly accepted cutoffs for classifying subjects with high central adiposity do not yet exist with any assessment method. We chose an arbitrary cutoff to define high trunk fat mass (*z* score ≥1); the appropriate cutoff may differ slightly for other population groups. Because we did not collect blood samples or measure blood pressure, we cannot say whether these cutoffs are associated with increased metabolic risk. However, it is apparent from the data in Table 3 that these cutoffs do identify children with high amounts of trunk fat. Moreover, a *z* score of 1 in our population closely approximated the 85th percentile for both girls and boys. This percentile cutoff was chosen recently to define children at risk of overweight on the basis of BMI in the United States (30). In addition, we tested the possible efficacy of a more conservative cutoff for high trunk fat mass in our population, a *z* score ≥1.5. This cutoff actually increased the sensitivity of waist circumference in both sexes (95% for girls at the 80th percentile for waist circumference and 96% for boys at the 85th percentile), whereas the specificity was lower in girls (86%) but remained similar in boys (93%). However, a *z* score of 1.5 resulted in very high cutoffs for trunk fat mass (eg, 17.0 kg for a 15-y-old girl, which corresponds to a total fat mass at that age of 36 kg, on the basis of our data). The adverse associations between obesity and blood lipid concentrations in children are observed at body fat levels considerably below this amount (31).

We recognize that DXA measures trunk fat and cannot differentiate between intraabdominal and subcutaneous fat. On the other hand, it is encouraging to note that trunk fat mass as measured by DXA is strongly correlated with intraabdominal fat in young children (32). In addition, researchers reported similar correlations between fat distribution and adverse plasma lipid profiles in children, whether fat distribution was measured with MRI as visceral adipose tissue (5) or was assessed with DXA as central fat (2). Others (27, 33) have suggested using smaller, more specific central abdominal regions (defined by anatomical bony landmarks) to assess fat distribution by DXA, rather than using the default region of trunk fat mass. We showed recently in adults that this improved the predictive ability of waist circumference as a screening measure of central adiposity (16). However, we did not observe a similar effect in the children in the present study (data not shown). The AUCs for waist circumference in comparison with trunk fat mass were already very high in our study population (0.97 in both sexes), which limited the possibility of gaining any significant improvement by using specific abdominal regions of interest.

Because we recruited by advertisement, we did not have a random population sample. However, our study population was large, included both sexes, and covered a wide age range (3–19 y). Moreover, the mean height and weight SD scores of our subjects were similar to representative norms (24). Because our subjects were not recruited on the basis of adiposity, they were a very heterogeneous population in terms of body composition. Our findings are specific to white children, and further research will be required to determine whether waist circumference also performs well as an index of central adiposity in children from other racial groups.

Screening for adiposity in childhood is somewhat controversial at present because there is limited research directly relating body composition in childhood to adult health outcomes. However,

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central obesity in children is correlated with a less favorable metabolic profile (2–5), and research has shown that lifestyle interventions can improve the body composition of young people (29). If we encourage children with high waist circumferences to eat healthy diets and be more physically active, they may realize benefits in addition to improved body composition, including enhanced social interactions and well-being.

In conclusion, waist circumference correctly identified a high proportion of children and adolescents with high trunk fat mass (z score ≥1) as measured by DXA. Waist circumference is a simple technique that could be used to screen for high central adiposity in children. Our waist circumference cutoffs, which correctly identified most of the children with high trunk fat mass while minimizing misclassification, are presented here for girls and boys of each year of age from 3 to 19 y.

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