Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa Heart Study

David S Freedman, Henry S Kahn, Zuguo Mei, Laurence M Grummer-Strawn, William H Dietz, Sathanur R Srinivasan, and Gerald S Berenson

ABSTRACT

Background: Several investigators have concluded that the waist-to-height ratio is more strongly associated with cardiovascular disease risk factors than is the body mass index (BMI; in kg/m²).

Objectives: We examined the relation of the BMI-for-age z score and waist-to-height ratio to risk factors (lipids, fasting insulin, and blood pressures). We also compared the abilities of these 2 indexes to identify children with adverse risk factors.

Design: Children aged 5–17 y (n = 2498) in the Bogalusa Heart Study were evaluated.

Results: As assessed by the ability of the 2 indexes to 1) account for the variability in each risk factor and 2) correctly identify children with adverse values, the predictive abilities of the BMI-for-age z score and waist-to-height ratio were similar. Waist-to-height ratio was slightly better (0.01–0.02 higher R² values, P < 0.05) in predicting concentrations of total-to-HDL cholesterol ratio and LDL cholesterol, but BMI was slightly better in identifying children with high systolic blood pressure (0.03 higher R², P < 0.05) in predicting measures of fasting insulin and systolic and diastolic blood pressures. On the basis of an overall index of the 6 risk factors, no difference was observed in the predictive abilities of BMI-for-age and waist-to-height ratio, with areas under the curves of 0.85 and 0.86 (P = 0.30) and multiple R² values of 0.320 and 0.318 (P = 0.79). This similarity likely results from the high intercorrelation (R² = 0.78) between the 2 indexes.

Conclusions: BMI-for-age and waist-to-height ratio do not differ in their abilities to identify children with adverse risk factors. Although waist-to-height ratio may be preferred because of its simplicity, additional longitudinal data are needed to examine its relation to disease.

KEY WORDS BMI, body mass index, waist, height, waist-to-height ratio, children, lipids, blood pressure, insulin

INTRODUCTION

Vague (1) was the first to observe that women with android obesity had a high prevalence of diabetes and atherosclerosis. Subsequent studies have shown that abdominal obesity, as measured by the waist circumference or related indexes such as the waist-to-hip ratio, is associated with the subsequent development of type 2 diabetes (2–5) and ischemic heart disease (6–8), as well as with risk factors for cardiovascular disease (CVD) (9). Furthermore, despite the relatively low amount of intraabdominal fat among children (10), several indexes of abdominal obesity are associated with CVD risk factors among children and adolescents (11–16).

The waist-to-height ratio was first used in the Framingham Study (17), and several studies of children (13–15) and adults (18, 19) have concluded that this ratio is more strongly associated with CVD risk factors than is the body mass index (BMI; in kg/m²). In addition, waist-to-height ratio may be simpler to use. For example, because waist-to-height ratio is only weakly associated with age, measures among children do not have to be expressed relative to their sex and age peers [by using z scores (20)] as do measures of BMI. In addition, the same cutoff (eg, 0.5) could possibly be used to identify adverse measures of waist-to-height ratio among both children and adults (21, 22), which would simplify the expression of obesity-related disease risk. However, relatively few studies have examined the relation of waist-to-height ratio to CVD risk factors, and it is important to examine these associations in other data.

The current study compares the relation of BMI and waist-to-height ratio to measures of lipids, fasting insulin, and blood pressure among 5–17-y-olds (n = 2498) in the Bogalusa Heart Study. In addition, we examine the abilities of these 2 indexes to correctly identify children with adverse risk factors.

SUBJECTS AND METHODS

Study population

The Bogalusa (Louisiana) Heart Study is a community-based (Ward 4 of Washington Parish) study of CVD risk factors in early life (23). Seven cross-sectional examinations of schoolchildren were conducted since 1973, and the current analyses are based on...
the 1993–1994 examination. Written informed consent was obtained from all parents, and study protocols were approved by human subjects review committees at the Tulane University School of Public Health and Tropical Medicine.

Of the 3135 children and adolescents (aged 5–17 y) examined, we excluded 9 girls who reported being pregnant, 7 children who were not white or black, 30 children who reported taking insulin (or were unsure), 13 children for whom we did not have a systolic (SBP) or diastolic (DBP) blood pressure measurement, and 14 children for whom information on measurements of waist, weight, or height was missing; these categories were not mutually exclusive. Of the remaining 3066 children, cholesterol (total, LDL, and HDL) and triacylglycerol determinations were available for 2961. Nonfasting children were excluded from the analyses of triacylglycerol and fasting insulin concentrations, and another 130 children did not have an insulin determination. After these exclusions, sample sizes for the various risk factors are 3066 (for SBP and DBP), 2961 (for LDL and HDL cholesterol), 2624 (for triacylglycerol), and 2494 (for insulin).

Because obesity is associated positively with LDL cholesterol and negatively with HDL cholesterol, we did not examine associations with total cholesterol. However, the ratio of total cholesterol to HDL cholesterol (total:HDL cholesterol) is included in the analyses.

General examinations

Height was measured to the nearest 0.1 cm with the use of an Iowa Height Board, and weight was measured to the nearest 0.1 kg with the use of a balance beam metric scale; BMI was calculated as a measure of relative weight. No adjustments were made for the weight of the gown, underpants, or socks that were worn during the examination.

BMI z scores were calculated from the 2000 Centers for Disease Control and Prevention (CDC) Growth Charts (20, 24) to account for the differences in BMIs by sex and age. These growth charts express the BMIs of children in the current study relative to their sex and age peers in the United States between 1963 and 1980; the calculated z scores are termed “BMI-for-age” in the current analyses. (BMIs among 5-y-olds in the CDC Growth Charts also include data from 1988–1994.) Overweight is defined as a BMI-for-age z score ≥ 1.645 (corresponding to the 95th percentile of normally distributed data) of these growth charts (25, 26). BMI-for-age z scores were used in all analyses in the current study. BMI-for-age percentiles are used only to classify children into 4 categories in one table that cross-classifies BMI-for-age and waist-to-height ratio.

The waist circumference was measured midway between the rib cage and the superior border of the iliac crest while the child was standing. Three measurements were obtained with a non-stretchable tape, and the mean value was used in the calculation of the waist-to-height ratio. In analyses that compared the abilities of BMI and waist-to-height ratio to correctly identify children with adverse risk factors, we dichotomized waist-to-height ratio at 0.512 (without considering the child’s sex or age) so that the same proportion (17%) of children would be overweight and have a “high” waist-to-height ratio.

On each examination day, a 10% sample of the children was randomly selected to be reexamined 2–3 h later by the same observer. We use these data to compare the reproducibilities of BMI and waist-to-height ratio.

Risk factors

Concentrations of serum total cholesterol and triacylglycerols were measured by using enzymatic procedures in a centralized laboratory that met the requirements of the CDC’s Lipid Standardization Program. For LDL- and HDL-cholesterol measurements, we used a combination of heparin-calcium precipitation and agar-agarose gel electrophoresis (27). Plasma insulin measurements were obtained with the use of a radioimmunoassay procedure (Phadebas Insulin Kit; Pharmacia Diagnostics AB, Uppsala, Sweden).

As previously described (23), sitting SBP and DBP in the right arm were measured 6 times by trained observers with a mercury sphygmomanometer (Baumanometer; WA Baum Co Inc, Copiague, NY). The cuff size was based on the length and circumference of the upper arm and was chosen to be as large as possible without having the elbow skin crease obstruct the stethoscope (28).

The distributions of lipid and lipoprotein concentrations in the Bogalusa Study were similar to those in the third National Health and Nutrition Examination (NHANES III) conducted from 1988 to 1994 (29). For example, the 90th percentiles of LDL cholesterol among 12–15-y-old white children (data were not cross-classified by race, sex, or age group) in NHANES III were 122 mg/dL (whites) and 133 mg/dL (blacks); corresponding values in the Bogalusa Study were 127 mg/dL (whites) and 133 mg/dL (blacks). Similarly, the 10th percentiles of HDL cholesterol were 35 mg/dL (boys) and 36 mg/dL (girls) among 12–15-y-olds in NHANES III and were 37 mg/dL among both boys and girls in the Bogalusa Study. However, because of differences in methods of measuring blood pressure (28), recorded measures of blood pressure are ≈5–10 mm Hg lower in the Bogalusa Study than in other studies.

Measures of adverse risk factors

Because measures of lipids, insulin, and blood pressures vary substantially by sex and age, we defined “adverse” measures in relation to a child’s sex and age peers in the Bogalusa Study sample. After log-transformation of measures of the risk factors to improve normality, each risk factor was regressed on sex, race, and age. Age was modeled with the use of restricted cubic splines with 5 knots (see Statistical analyses) (30), and we allowed for interactions with age (age × BMI and age × waist-to-height ratio) in the prediction of each risk factor. Regression models for SBP and DBP also included height (cubic splines) as a predictor. The standardized residuals (adjusted risk factor measures) from these models represent measures relative to children of the same sex, race, and age. All adjusted risk factors had a mean ± SD value of 0 ± 1.0. With the exception of HDL cholesterol (<10th percentile), adverse risk factor measures were defined as a measure ≥ 90th percentile.

Although the identification of children with adverse risk factors in the current study is based solely on the distribution of risk factors in the Bogalusa Study, the use of cutoffs from NHANES III (29) identified similar children with adverse concentrations of lipids and lipoproteins. For example, all of the 12–15-y-olds (whites and blacks combined; n = 106) in the current study who were classified as having a high LDL-cholesterol concentration (according to the Bogalusa Study cutoffs) also had a concentration >90th percentile (119 mg/dL) in NHANES III. However, 45 (5%) of the 950 children aged 12–15 y who we considered to have
The risk factor sum was used as a summary measure of the 6 risk factors and was derived by combining adjusted measures of triacylglycerols, LDL cholesterol, HDL cholesterol, fasting insulin, SBP, and DBP. Adjusted measures of most risk factors were simply added together, but adjusted measures of HDL cholesterol were subtracted from the total. In addition, because of the high correlation \( r = 0.66 \) between SBP and DBP, these 2 characteristics were first divided by 2. The resulting risk factor sum had a mean \( \pm SD \) value of \( 0 \pm 2.9 \) (range: 1–11). Correlations between the risk factor sum and the individual risk factors ranged from \( r = 0.37 \) (DBP) to \( r = 0.73 \) (triacylglycerols); the association with HDL cholesterol was \( r = -0.59 \).

The risk factor sum was highly correlated \( r = 0.97 \) with the first principal component (32) of the 6 risk factors. Furthermore, with the exception of LDL–cholesterol concentrations \( r = 0.39 \), the absolute value of the correlation coefficients with the first principal component ranged from 0.50 (HDL cholesterol) to 0.70 (triacylglycerols). (The second principal component was difficult to interpret because it contrasted measures of DBP, SBP, and HDL cholesterol with measures of triacylglycerols and fasting insulin, and it was not considered further.) Although risk factor summaries can be derived by adding together the number of adverse risk factors (16, 33), our method allows the risk factor sum to be used as a continuous variable.

**Statistical analyses**

The analyses, which were performed with the use of SAS software (version 9.1; SAS Institute Inc, Cary, NC) and R (version 2.4.1; R Foundation for Statistical Computing, Vienna, Austria (34)), first examined the ability of BMI-for-age and waist-to-height ratio to identify children with adverse measures of each risk factor. We calculated the positive predictive value (the proportion of children with a high BMI or waist-to-height ratio who actually have adverse risk factors) and the sensitivity (the proportion of children with adverse risk factors who have a high BMI or waist-to-height ratio) for each risk factor. Because these values depend on the cutoff used for BMI and waist-to-height ratio, we also examined the receiver operating characteristic curve for each risk factor. These curves are constructed by plotting the sensitivity at each value of BMI-for-age or waist-to-height ratio compared with the corresponding 1-specificity, and the area under the curve (AUC) quantifies the screening performance over all cutoffs. An AUC of 0.5 indicates that the screening test is no better than chance, and 1.0 indicates perfect classification. The statistical significance of the difference \( (35) \) in AUCs between BMI and waist-to-height ratio was calculated by using MEDCALC software (version 9.1.0.1; MedCalc Software, Mariakerke, Belgium).

Regression models were also used to quantify the prediction of risk factor measures by both indexes. (The original, unadjusted measures of the risk factors were used as the dependent variable in these models.) These analyses compared the increases in the multiple \( R^2 \) values achieved by adding either BMI-for-age \( z \) score or waist-to-height ratio to a model already containing age, sex, and race. Continuous variables were modeled by using restricted cubic splines with 5 knots (30) to allow for nonlinearity, and we allowed for an interaction between each index and age. In contrast to the use of higher-order polynomials, models based on splines do not have peaks and valleys, and the fit in one region does not influence the fit in all other regions of the data.

To assess the differences between the \( R^2 \) values of models that contained either BMI-for-age or waist-to-height ratio, we first calculated predicted risk factor measures from each model. We then examined the statistical significance of the difference in the correlation between the actual risk factor measures and the 2 sets of predicted risk factor measures coefficients (36). We also examined whether the relation of BMI-for-age and waist-to-height ratio to each risk factor was nonlinear.

We then cross-classified categories of BMI-for-age (<50th percentile, 50th–84th percentile, 85th–94th percentile, and ≥95th percentile) and waist-to-height ratio. Cutoffs for the 4 categories of waist-to-height ratio were selected so that the number of children in each category would equal the number in the corresponding BMI-for-age category. We focused on measures of the risk factor sum among children whose BMI-for-age stratum was lower or higher (discordant) than the corresponding waist-to-height ratio stratum. We also show the relation of waist-to-height ratio to BMI-for-age by using lowess to smooth the data (37).

In addition to determining whether differences between BMI-for-age and waist-to-height ratio were statistically significant, we also focused on the magnitudes of the differences in the AUCs and \( R^2 \) values for each risk factor. It should be realized that a small difference between the 2 indexes, which indicates that their predictive abilities are similar, could be statistically significant. However, this small difference would have little practical importance.

**RESULTS**

Mean measures of various characteristics are shown in Table 1. The mean BMI-for-age \( z \) score was 0.46, and 17% of the children were overweight; BMIs did not differ significantly between boys and girls. The mean waist-to-height ratio was 0.458, and measures of waist, height, waist-to-height ratio, and SBP were slightly but significantly higher among boys than among girls. In contrast, girls had slightly but significantly higher concentrations of total cholesterol; HDL cholesterol, triacylglycerols, LDL cholesterol, and fasting insulin than did boys. Measures of the risk factor sum, an overall summary of the 6 age- and sex-adjusted risk factors, ranged from \(-9 \) to 11, with a mean value of 0. Age was associated with BMI \( r = 0.48 \), waist circumference \( r = 0.59 \), and height \( r = 0.90 \) but not with BMI-for-age \( r = 0.02 \) or waist-to-height ratio \( r = -0.01 \). Among the 276 children who were reexamined by the same observer, the intraclass correlations between the repeated measurements were 0.997 (BMI) and 0.949 (waist-to-height ratio), and the coefficients of variation were 1% (BMI) and 3% (waist-to-height ratio).

The abilities of BMI-for-age and waist-to-height ratio to correctly identify children with adverse risk factors are compared in Table 2. The AUCs, positive predictive values, and sensitivities varied substantially across risk factors, with the most accurate classification seen for fasting insulin concentrations. For each
TABLE 1
Characteristics of the subjects1

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 1501)</th>
<th>Girls (n = 1565)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>11 ± 3</td>
<td>11 ± 3</td>
</tr>
<tr>
<td>Black (%)</td>
<td>43</td>
<td>44</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>20.0 ± 4.8</td>
<td>20.2 ± 5.2</td>
</tr>
<tr>
<td>BMI-for-age z score</td>
<td>0.5 ± 1.1</td>
<td>0.4 ± 1.1</td>
</tr>
<tr>
<td>Overweight (%)</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>68 ± 14</td>
<td>66 ± 12</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>148 ± 20</td>
<td>145 ± 17</td>
</tr>
<tr>
<td>Waist-to-height ratio</td>
<td>0.46 ± 0.06</td>
<td>0.45 ± 0.06</td>
</tr>
<tr>
<td>Total-to-HDL cholesterol ratio</td>
<td>3.2 ± 0.8</td>
<td>3.4 ± 0.9</td>
</tr>
<tr>
<td>Triacylglycerols (mg/dL)</td>
<td>67 (52, 92)</td>
<td>73 (57, 98)</td>
</tr>
<tr>
<td>LDL cholesterol (mg/dL)</td>
<td>101 ± 25</td>
<td>104 ± 26</td>
</tr>
<tr>
<td>HDL cholesterol (mg/dL)</td>
<td>54 ± 12</td>
<td>53 ± 12</td>
</tr>
<tr>
<td>Fasting insulin (mU/L)</td>
<td>8.6 (6.4, 12.0)</td>
<td>10.0 (7.7, 14.0)</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>103 ± 10</td>
<td>102 ± 10</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>62 ± 9</td>
<td>62 ± 9</td>
</tr>
<tr>
<td>Risk factor sum</td>
<td>0 ± 3</td>
<td>0 ± 3</td>
</tr>
</tbody>
</table>

1 The numbers of children with missing data for the individual risk factors ranged from 0 (SBP and DBP) to 572 (fasting insulin). There were 573 children with missing information on the risk factor sum. SBP, systolic blood pressure; DBP, diastolic blood pressure.

2 ± SD (all such values).

3 Significant difference for sex, P < 0.001 (t test).

4 Values are median; 25th and 75th percentiles in parentheses.

5 Significant difference for sex, P < 0.001 (t test, or Wilcoxon test for triacylglycerols or fasting insulin).

TABLE 2
Classification of adverse risk factor by BMI-for-age z score and waist-to-height ratio1

<table>
<thead>
<tr>
<th>Risk factor2</th>
<th>Subjects</th>
<th>BMI-for-age z score</th>
<th>Waist-to-height ratio</th>
<th>Area under the curve</th>
<th>Positive predictive value</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td>BMI-for-age z score</td>
<td>BMI-for-age z score</td>
<td>BMI-for-age z score</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.26</td>
<td>0.28</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.28</td>
<td>0.28</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
<td>0.18</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.21</td>
<td>0.22</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.34</td>
<td>0.33</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
<td>0.20</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.13</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.38</td>
<td>0.38</td>
<td>0.64</td>
</tr>
</tbody>
</table>

1 The area under the curve summarizes the sensitivity and specificity of BMI-for-age and waist-to-height ratio over all values of the index (see Subjects and Methods). Positive predictive value is the proportion of children with a high BMI-for-age (or waist-to-height ratio) who had an adverse risk factor. Sensitivity is the proportion of children with an adverse risk factor who had a high BMI-for-age (or waist-to-height ratio). SBP, systolic blood pressure; DBP, diastolic blood pressure.

2 The race-, sex-, and age-adjusted risk factors were used in the analyses.

3 The cutoff (0.512) for waist-to-height ratio was selected so that equal (17%) proportions of the children would be overweight and would have a high waist-to-height ratio.

4 Significant difference in area under the curve, P < 0.05 [as assessed by formulas in Hanely et al (35)]. The SE of each area under the curve difference was 0.01.
TABLE 3
Variability in risk factors that can be accounted for by BMI-for-age z-score or waist-to-height ratio in various regression models

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Subjects</th>
<th>Multiple $R^2$ values based on race, sex, and age</th>
<th>BMI-for-age z-score</th>
<th>Waist-to-height ratio</th>
<th>BMI-for-age z-score and waist-to-height ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-HDL cholesterol ratio</td>
<td>2961</td>
<td>0.05</td>
<td>0.14*</td>
<td>0.16*</td>
<td>0.16</td>
</tr>
<tr>
<td>Triacylglycerols</td>
<td>2961</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
<td>0.14</td>
</tr>
<tr>
<td>LDL cholesterol</td>
<td>2961</td>
<td>0.04</td>
<td>0.03*</td>
<td>0.04*</td>
<td>0.05</td>
</tr>
<tr>
<td>HDL cholesterol</td>
<td>2961</td>
<td>0.13</td>
<td>0.09</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Fasting insulin</td>
<td>2494</td>
<td>0.21</td>
<td>0.27*</td>
<td>0.24*</td>
<td>0.28</td>
</tr>
<tr>
<td>SBP</td>
<td>3066</td>
<td>0.29</td>
<td>0.08*</td>
<td>0.05*</td>
<td>0.09</td>
</tr>
<tr>
<td>DBP</td>
<td>3066</td>
<td>0.34</td>
<td>0.06*</td>
<td>0.03*</td>
<td>0.06</td>
</tr>
<tr>
<td>Risk factor sum</td>
<td>2493</td>
<td>0</td>
<td>0.32</td>
<td>0.32</td>
<td>0.34</td>
</tr>
</tbody>
</table>

1 Age, BMI-for-age, and waist-to-height ratio were modeled by using restricted cubic splines with 5 knots. Regression models also contained the interaction between BMI-for-age z-score or waist-to-height ratio with age. SBP, systolic blood pressure; DBP, diastolic blood pressure.

2 The original, unadjusted risk factors were used as the dependent variable. The multiple $R^2$ for the model predicting the risk factor sum from race, sex, and age is 0 because the risk factor sum is based on standardized measures of the risk factors.

3 Significant $P < 0.05$ difference in multiple $R^2$ values of a model containing BMI-for-age z-score and a model containing waist-to-height ratio in the prediction of risk factor measures, $P < 0.05$. To calculate statistical significance, predicted measures of each risk factor were first calculated from the 2 regression models. The difference in the correlations between these predicted and actual measures was assessed as suggested by Meng et al (36).

yielded multiple $R^2$ values that were only slightly higher than those obtained with the use of either index. For example, the multiple $R^2$ for the risk factor sum based on both BMI-for-age and waist-to-height ratio was 0.34, whereas the $R^2$ for each index alone was 0.32.

Despite the similarity of the multiple $R^2$ values for the 2 indexes, additional analyses indicated that associations with BMI-for-age were more curvilinear than those with waist-to-height ratio. Predicted measures of several risk factors based on regression models containing either BMI-for-age (left panels) or waist-to-height ratio (right panels) for an 11-y-old white girl are shown in Figure 1. (Predicted measures for boys and black children would be shifted vertically, but they would parallel the curves in Figure 1.) Nonlinearity was most evident in the relation of BMI-for-age to concentrations of triacylglycerol (upper left panel), fasting insulin, and the risk factor sum (bottom left panel) but was also observed for SBP and HDL cholesterol. Furthermore, for each risk factor, the strength of the association increased (steeper slope) at higher measures of BMI-for-age. Associations with waist-to-height ratio (right panels), in contrast, were more linear, and the difference between the 2 indexes was particularly evident for triacylglycerol concentrations. Although waist-to-height ratio showed a nonlinear association ($P < 0.001$) with fasting insulin concentrations, the change in slope was less marked than with BMI-for-age.

We then examined measures of the risk factor sum among children after a cross-classification of categories of BMI-for-age and waist-to-height ratio (Table 4). Waist-to-height ratio measures were categorized so that equal numbers of children would be in each waist-to-height ratio and BMI group. Despite the small number of children in some of the discordant categories (cells above and below the shaded diagonal), the mean risk factor sum tended to increase with measures of both BMI-for-age and waist-to-height ratio. Because of residual confounding, however, these apparent “independent effects” should be interpreted cautiously. A comparison of measures of the risk factor sum in the 2 discordant groups indicated that the mean measure among those who had a high BMI-for-age relative to waist-to-height ratio (6 upper right cells; $\bar{x} = -0.21$) was almost identical to the mean measure among children who had a high waist-to-height ratio relative to BMI-for-age (6 lower left cells; $\bar{x} = -0.19$; $P = 0.88$). Comparable analyses for the individual risk factors indicated that children with a relatively high waist-to-height ratio had slightly

![Figure 1](https://academic.oup.com/ajcn/article-abstract/86/1/33/4754390/1)

**FIGURE 1**. The relation of BMI-for-age z-score (left) and waist-to-height ratio (right) to risk factor (RF) measures. Predicted measures (for an 11-y-old white girl) were calculated from regression models that included BMI-for-age or waist-to-height ratio, in addition to age, sex, and the interaction of BMI-for-age (or waist-to-height ratio) with age. Continuous variables were modeled by using splines with 5 knots, and the nonlinear effect of BMI-for-age was statistically significant ($P < 0.001$) for each of the 5 RFs. So that the RF sum and fasting insulin could be plotted in the same figure, 9.0 was added to the former. The units for each RF are shown in parentheses. SBP, systolic blood pressure; TG, triacylglycerols.
higher concentrations of total cholesterol: HDL cholesterol and LDL cholesterol, whereas those with a high BMI-for-age had slightly higher concentrations of fasting insulin ($P < 0.05$ for each difference).

Measures of BMI-for-age and waist-to-height ratio for each child, with the triangles representing children who had a high risk factor sum, are shown in Figure 2. The strong association between the 2 indexes is evident, and regression models indicated that measures of BMI-for-age could account for 78% of the variability in measures of waist-to-height ratio. Furthermore, the identification of high measures of the risk factor sum by waist-to-height ratio (horizontal line) and BMI-for-age (vertical line) did not differ. Of the 250 children with a high risk factor sum, 145 (58%) had high measures of both indexes (upper right), 14 (6%) had high measures of BMI-for-age only (lower right), 15 (6%) had high measures of waist-to-height ratio only (upper left), and 76 (30%) did not have high measures of either (lower left).

**DISCUSSION**

Our results show that there is little difference in the abilities of BMI-for-age and waist-to-height ratio to identify children with adverse CVD risk factors. In general, waist-to-height ratio showed slightly stronger associations with lipid and lipoprotein concentrations, whereas BMI-for-age showed slightly stronger associations with measures of fasting insulin and blood pressures. Although some of the differences between the 2 indexes were statistically significant, the AUCs, positive predictive values, sensitivities, and multiple $R^2$ values were similar for each risk factor. Furthermore, the use of both BMI-for-age and waist-to-height ratio resulted in only slightly better prediction of risk factors than that achieved with only one index. The strong association between BMI-for-age and waist-to-height ratio ($R^2 = 0.78$) probably accounts for their similar predictive abilities, as well as for the small amount of additional information obtained by using the 2 indexes together.

Various indexes of abdominal obesity (such as waist circumference, waist-to-hip ratio, and waist-to-height ratio) are associated with adverse risk factors among children (13–15) and adults (18, 19). The limitations of these indexes, however, should be considered. For example, although waist circumference is correlated with the amount of intraabdominal visceral fat, which may be the most detrimental fat depot (9), it is also associated with subcutaneous abdominal fat and with total body fat (38, 39). In addition, a recent study of adults found that waist-to-height ratio and BMI were more strongly associated with each other ($r = 0.85–0.91$) than with percentage of body fat ($r = 0.69–0.76$), as determined by air-displacement plethysmography (19). These associations emphasize the potential problems in using waist-to-height ratio and BMI as indexes of abdominal and generalized adiposity, respectively. The interpretation of associations with BMI and waist-to-height ratio is further complicated by the possible relation of disease risk to height (40), which is in the denominator of both indexes.

Some investigators have concluded that, compared with BMI, waist-to-height ratio is more strongly associated with CVD risk factors among children (13–15) and adults (18, 19). It has been emphasized, however, that many of the differences between waist-to-height ratio and BMI are relatively small (19). For example, Hara et al (14) reported that the logarithm of a risk factor score showed correlations of $r = 0.50$ (waist-to-height ratio) and $r = 0.45$ (BMI), and Hsieh et al (33) reported correlations of $r =$...
forcing the association with concentrations of fasting insulin to for-age were constrained to be linear (14–16, 19). We found that insulin resistance was more strongly associated with total fat mass than with visceral abdominal fat (41). The weaker associations with BMI that were found in previous studies of children may be due to the investigators’ use of BMI rather than BMI-for-age (13, 14) or due to the fact that associations with BMI-for-age were constrained to be linear (14–16, 19). We found that forcing the association with concentrations of fasting insulin to be linear reduced the \( R^2 \) for BMI-for-age from 0.48 (nonlinear) to 0.43 (linear), whereas the \( R^2 \) for waist-to-height ratio decreased from 0.45 only to 0.44. These nonlinear associations may arise because BMI-for-age is a good indicator of adiposity among relatively fat children, but it is an index of both fat and fat-free mass among thinner children (42). If BMI-for-age differences among some relatively thin (eg, BMI-for-age \( z \) score < 1.0) children largely reflect differences in fat-free mass, it would be expected that the relation of BMI-for-age to risk factor measures would be “flatter” (Figure 1) among these children.

The current study has several potential limitations that should be considered. Although the sample was not randomly selected, measures of BMI, lipids, and lipoproteins were fairly comparable to those reported in national studies (29). However, because of differences in methods of measuring blood pressure (28), few children in the Bogalusa Study had an SBP or a DBP > 90th percentile of the National High Blood Pressure Education Program (31). Furthermore, although it can be difficult to compare the magnitudes of the observed associations across studies because of differences in statistical modeling techniques, age ranges, and the specific anthropometric index examined, the magnitudes of the associations that we observed between BMI-for-age and the examined risk factors agree well with those of other studies (43).

Although several prospective studies found the indexes of abdominal obesity to be stronger predictors of CVD and type 2 diabetes than is BMI (4–7), there are conflicting findings. For example, the predictive abilities of BMI and waist-to-height ratio for type 2 diabetes among Pima Indians were almost identical (3), and several studies found that various indexes of abdominal obesity predict disease no better than does BMI (2, 8, 17). For example, the relative risk for coronary heart disease among men in the upper quintile of waist circumference in the Physicians’ Health Study was 1.60, whereas the corresponding relative risk for BMI was 1.73 (8).

Some investigators have suggested that, even if the predictive abilities of waist-to-height ratio and BMI-for-age are similar, waist-to-height ratio may be preferred as an indicator of obesity-related risk (15, 21, 22). The concept of a large waist relative to height may be easier to explain than is the division of weight by the square of height, particularly for people accustomed to using pounds and inches. Furthermore, because waist-to-height ratios vary only slightly by age and by sex among children, it is not necessary to express measures as percentiles or \( z \) scores, relative to a reference population, as is the case for BMI. (The correlation between unadjusted and sex- and age-adjusted measures of waist-to-height ratio was \( r = 0.99 \), and the use of either adjusted or unadjusted measures yielded virtually identical results.) The calculation of waist-to-height ratio is also simpler, requiring only the division of numbers in the same units. Furthermore, the possible use of a single cutoff (0.5) to identify adverse measures among both children and adults (21) would result in a simple public health message: “Keep your waist circumference to less than half your height.” In the current study, 85% of overweight children had a waist-to-height ratio \( \geq 0.5 \).

However, the disease risks associated with BMI have been studied much more extensively than those for waist-to-height ratio, and additional longitudinal data on waist-to-height ratio are needed. Furthermore, although the relation of childhood BMIs to those in adulthood was examined in numerous studies (reviewed in reference 44), we know of no study that has examined the tracking of waist-to-height ratios. In addition, although the reproducibility of waist circumference measurements is high (45), we and others have found that it is lower than that of BMI (19). This difference may limit the ability of waist-to-height ratio to detect small changes in obesity-related risk. Furthermore, waist circumference has been measured at numerous sites between the lowest rib and iliac crest, and there are differences between the recommendations of the Anthropometric Standardization Reference Manual (46), the World Health Organization, and the National Institutes of Health (reviewed in reference 45). Small changes in the location of the waist measurement can alter associations with risk factor measures (47–49) and possibly with disease risk.

In summary, we found that waist-to-height ratio and BMI-for-age showed similar associations with CVD risk factors. Although the use of waist-to-height ratio among children has the potential to simplify the assessment of obesity-related risk, additional information is needed on the tracking of waist-to-height ratio from childhood to adulthood, as are data relating waist-to-height ratio to morbidity and mortality.

The author’s responsibilities were as follows—DSF: analyzed data, interpreted results, and wrote the manuscript; HSK: interpreted results; ZM and LMG-S: analyzed data, interpreted results, and formulated study objectives; WPD: analyzed data; and all authors: revised the manuscript. None of the authors had a personal or financial conflict of interest.

REFERENCES


5. Schulze MB, Heidemann C, Schienkiewitz A, Bergmann MM, Hoffmann K, Boeing H. Comparison of anthropometric characteristics

Downloaded from https://academic.oup.com/ajcn/article-abstract/86/1/33/4754390 by guest on 21 August 2018