The Validity of BMI as an Indicator of Body Fatness and Risk Among Children

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abstract

PURPOSE OF REVIEW: Although the prevalence of childhood obesity, as assessed by BMI (kg/m^2), has tripled over the last 3 decades, this index is a measure of excess weight rather than excess body fatness. In this review we focus on the relation of BMI to body fatness and health risks, particularly on the ability of BMI for age ≥95th Centers for Disease Control and Prevention [CDC] percentile to identify children who have excess body fatness. We also examine whether these associations differ according to race/ethnicity and whether skinfold and circumference measurements provide additional information on body fatness or health risks.

RESULTS: The accuracy of BMI varies according to the degree of body fatness. Among relatively fat children, BMI is a good indicator of excess adiposity, but differences in the BMIs of relatively thin children can be largely due to fat-free mass. Although the accuracy of BMI in identifying children with excess body fatness depends on the chosen cut points, we have found that a high BMI-for-age has a moderately high (70%–80%) sensitivity and positive predictive value, along with a high specificity (95%). Children with a high BMI are much more likely to have adverse risk factor levels and to become obese adults than are thinner children. Skinfold thicknesses and the waist circumference may be useful in identifying children with moderately elevated levels of BMI (85th to 94th percentiles) who truly have excess body fatness or adverse risk factor levels.

CONCLUSION: A BMI for age at ≥95th percentile of the CDC reference population is a moderately sensitive and a specific indicator of excess adiposity among children. *Pediatrics* 2009;124:S23–S34

Although BMI (kg/m^2) is widely used as an index of body fatness, it is a measure of weight relative to height rather than of adiposity. BMI cannot distinguish between body fatness, muscle mass, and skeletal mass, and its use can result in large errors in the estimation of body fatness.[1] The weight and height changes that occur during growth (ages 5–18 years) result in substantial (~50%) increases in BMI, further complicating the interpretation of this index among children and adolescents. For example, increases in the BMI levels of boys during adolescence seem to be largely the result of increases in fat-free mass rather than body fatness.[2]

BMI has been characterized as being "almost useless as an estimator of percentage of body fat in normal-weight children,"[3] but much evidence indicates that a child with a high BMI relative to his or her gender and age peers (BMI for age) is likely to have excess body fatness. In this review we focus on the relation of childhood BMI to body fatness and health risks, particularly on the ability of a high BMI level to correctly identify a child with excess body fatness. In addition, we examine whether these associations differ according to race/ethnicity and whether skinfold and circumference measurements provide additional information on body fatness or health risks.

The term "obesity" is frequently used to refer to a high BMI among adults and children,[4,5] and the adult cut point for obesity (BMI ≥ 30 kg/m^2) is approximately the 95th percentile of BMI for age among 19-year-old boys and 17-year-old girls in the Centers for Disease Control and Prevention (CDC) reference population[6] (an SAS program for the CDC growth charts is available at www.cdc.gov/nccdphp/dnpa/growthcharts/resources/sas.htm). Although there are several reasons to prefer this terminology,[5] it can create confusion between high levels of BMI and high levels of body fatness. Because a main goal of this review is to quantify the ability of a high BMI (excess weight) to identify children who have a high level of body fatness, we specify the BMI cut points (eg, BMI for age ≥95th CDC percentile) that are used to classify overweight and obese children in addition to the descriptive terms. A high level of body fatness is termed "excess body fatness."

CHILDHOOD BMI AND BODY FATNESS

Measurement of Body Fatness

Although an ideal measure of body fatness would be accurate, precise, and accessible, with widely available population data, no existing measure satisfies all these criteria.[7] Reference methods are expensive and can be inaccessible, and the simpler, widely used anthropometric methods can be inaccurate.[3] The 4-compartment model, which incorporates independent estimates of mineral, total body water, body density, and body weight, is widely viewed as the most accurate method for calculating body fatness,[8] but it is time consuming, expensive, and available at few locations.

Although the initial costs are high, the speed and low operating costs of dual-energy radiograph absorptiometry (DEXA) has led to its use as a reference method in many studies that have examined the screening ability of BMI. These estimates of fat mass are highly correlated with those from 4-compartment models, but can be influenced by several factors including the hydration of the subjects and the equipment manufacturer, which creates the potential for systematic biases and large errors for a single subject.[3,8–10] A bias would not influence the relative ranking of subjects, but it could influence the proportion of children who are classified as having excess body fatness; this, in turn, would influence the ability of a high BMI to correctly identify children with excess fatness (positive predictive value). In addition, random errors in DEXA-estimated body fatness would reduce the (apparent) screening performance of BMI.

Body fatness is usually standardized for body weight and expressed as percent body fat [fat mass (kg)/body weight (kg)], but an alternative is to express fat mass relative to height squared. This leads to the use of fat mass index (FMI) (fat mass/height squared) and the fat-free mass index (FFMI) (fat-free mass/height squared).[11,12] Because FMI + FFMI = BMI, the use of these indices allows one to easily assess whether BMI differences (between subjects, ages, or time periods) are a result of fat or fat-free mass.

Although excess body fatness among children would ideally be defined on the basis of disease risk, this may be difficult. Almost all studies of health outcomes have examined the effects of excess weight rather than body fatness, and longitudinal studies spanning many decades would be necessary to have childhood body-fatness cut points to be based on associations with clinical outcomes. Furthermore, because the relation of childhood body fatness to disease outcomes is likely to be influenced by adult levels of body fatness, it would be necessary to have multiple measurements of body fatness throughout life. Even among adults, a World Health Organization expert committee concluded that "there is no agreement about cutoff points for the percentage of body fat that constitutes obesity."[13] The derivation and use of various cut points for excess body fatness are discussed below in "Classification of Excess Body Fatness."

Anthropometry

Anthropometry is a widely used, inexpensive method for assessing body fatness, but it can be inaccurate. The most frequent measurements are weight and height, and these are usually combined as weight/height^p; the power "p" can be chosen to minimize the correlation with height or to maximize the correlation with body fatness. BMI is a power index with $p = 2$.

Various skinfold and circumference (particularly the waist) measurements have also been used to assess fatness or fat distribution, but the errors associated with these measurements are larger than for weight and height.[14,15] (The use of self-reported weight and height may result in biased and imprecise estimates of BMI[16] and will not be discussed in this review.) Furthermore, it is uncertain if skinfold or circumference measurements provide a substantial amount of additional information on body fatness or health risks if BMI for age is already known (see "Additional Information From Skinfolds and Circumferences").

Despite its widespread acceptance among adults, the use of BMI among children has sometimes been questioned because of its moderate association with height during growth and development ($r \sim 0.3$ after adjustment for age). However, height is correlated with the body fatness of children,[7,17] and the higher BMIs of taller children correctly identify their increased fatness. Furthermore, the correlation between childhood BMI and body fatness is close to the maximum that is possible for any power index,[17,18] and childhood BMI is more strongly correlated with adult skinfold thicknesses than are other weight-height indices.[17,19]

BMI-Classification Systems

Although BMI cut points of 25 and 30 kg/m^2 are used to identify adults who are at increased risk for various dis-

eases, the large increases in BMI that occur during growth and development require a "high" BMI to be defined relative to other children of the same gender and age. (Because body fatness also changes substantially with age, "excess body fatness" is also typically defined relative to a child's peers.) The use of a reference population to classify gender- and age-specific levels of BMI allows one to examine secular trends and compare the prevalence of overweight and obesity among children and adolescents across populations.

There is a "confusing multiplicity of child and adolescent obesity rates" in the literature,[20] largely based on the use of different reference populations and different percentile (or z-score) cut points. The 2 most widely used classification systems for BMI levels among children are the CDC growth charts[21] and the International Obesity Taskforce (IOTF) cut points.[4,22] Both classifications are based on cross-sectional, gender-specific distributions of BMI levels according to age, with the cut points for high BMI levels based on somewhat arbitrary decisions. The 85th and 95th percentiles of BMI for age are used in the CDC growth charts, and the IOTF classification used BMI levels at age 18.0 years (rather than at other ages) to represent levels among adults.

The CDC growth charts were based on data from 4 nationally (US) representative surveys of children and adolescents conducted from 1963–1965 to 1976–1980; 2- to 5-year-olds who were examined in 1988–1994 were also included in these growth charts.[7,21] BMI levels were expressed as gender-specific BMI-for-age z scores (SD scores) and percentiles, which allow the BMI of any child to be expressed relative to this reference population.

Most investigators now classify children who have a BMI for age at ≥95th

percentile of this reference population as obese, and children with BMI levels between the 85th and 94th percentiles as overweight. (These 2 BMI-for-age categories had originally been termed "overweight" and "at risk for overweight."[23,24]) Older adolescents with a BMI at ≥25 kg/m^2 (~85th percentile at ages 16–17 years in the reference population) are also considered to be overweight, whereas those with a BMI at ≥30 kg/m^2 (~95th percentile at ages 17–19 years) are also considered to be obese. These cut points were not based on associations with disease outcomes, but subsequent studies have shown that a high BMI for age is associated with increased body fatness, adverse levels of metabolic risk factors, and high levels of adult BMI.[25,26] On the basis of these cut points, 17% of 6- to 19-year-olds in the United States were obese in 2005–2006, and another 16% were overweight.

The IOTF cut points, based on data from 6 countries (including the United States), linked BMIs of 25 kg/m^2 (adult overweight) and 30 kg/m^2 (adult obesity) at age 18.0 years to BMIs at younger ages.[4] An 18-year-old boy in the United States with a BMI of 30 kg/m^2, for example, was at the 96.7th percentile, and the corresponding z score (1.84) was used as the cut point for obesity between the ages of 2.0 and 17.5 years. The estimated cut points for overweight (IOTF-25) and obesity (IOTF-30) were then averaged across the 6 countries. Although this classification linked childhood BMI cut points to the adult classifications, if the distribution of BMIs at ages 25 or 30 years (rather than age 18.0 years) had been used, the prevalence of childhood overweight and obesity would be increased, because the adult BMI distribution would have been shifted toward higher values. Furthermore, the data

used to derive these BMIs are largely from high-income countries.

Despite differences in the development of these 2 classification systems, the BMI levels corresponding to the IOTF-25 and 85th CDC percentile cut points are similar between the ages of 6 and 17 years. The IOTF-30 cut points are higher than the 95th CDC percentile and roughly correspond to the 97th CDC percentile among school-aged children. At younger ages (2–5 years), the CDC cut points are lower than the IOTF cut points, possibly reflecting the smaller secular increase in the BMI levels of preschool-aged (versus school-aged) children in the United States.[27] Differences in the BMI cut points used in these 2 classification systems to identify the highest BMI category (IOTF-30 versus 95th CDC percentile) can complicate comparisons across studies.[20,22,28]

The 99th percentile of BMI for age in the CDC growth charts has been suggested as a possible cut point for severe obesity,[26] identifying children who are at very high risk for severe adult obesity, excess body fatness, and biochemical abnormalities. However, the underling parameters[29] of the CDC growth charts were based on 10 selected percentiles of BMI for age (according to gender) between the 3rd and 97th percentiles, and it can be problematic to use these parameters to estimate the 99th percentile. For example, as compared with the 99th percentile of BMI in the CDC reference population, the 99th percentile estimated from the growth-chart parameters may be too low (~98th percentile in this reference population) among younger children and too high (~99.5th percentile) among older adolescent girls. It may be best to classify severe obesity among children by a BMI at or above (1) either the CDC 99th percentile or 35 kg/m^2 (class 2 adult obesity), (2) 120% of the CDC 95th percentile, or (3) 112% of the CDC 97th percentile.

Classification of Excess Body Fatness

Because of the lack of longitudinal data on the relation of body fatness among children to disease risk in adulthood, some investigators have derived cut points for excess body fatness among children from cross-sectional associations with metabolic risk factors.[30–32] (Associations with metabolic risk factors are discussed below in "Childhood BMI and Health Risks.") Of these classifications, the most widely used is based on the relation of skinfold-estimated percent body fat to adverse levels (upper quintile for a child's race, gender, and age) of lipids and blood pressures in the Bogalusa Heart Study.[30,33] The proposed cut points for excess body fatness differed according to gender (25% body fat among boys, 30% among girls) but not according to age among these 5- to 18-year-olds.

Although it is appealing to use a single cut point to identify children who have excess body fatness at all ages, a single cut point is unlikely to be optimal. An age-invariant cut point cannot account for the changes in body fatness that occur during growth and development and for age differences (interactions) in the relation of body fatness to risk factors. On the basis of the data from girls in the Pediatric Rosetta Study, 30% body fat is at ~95th percentile at the age of 7 years but is only slightly greater than the 50th percentile at the age of 15 years. Although the health effects of 30% body fat are likely to differ between 7- and 17-year-old girls, the possibility of age modification was not considered in the analyses that derived the 25% and 30% cut points.[30]

Despite the added complexity, it is likely that excess body fatness should be defined relative to a child's gender and age peers in much the same way that BMI cut points among children have been constructed. However, there is little agreement on the cut points that should be used to classify excess body fatness.[13]

Various techniques and samples have been used to estimate gender- and age-specific percentiles (eg, 85th, 90th, and 95th) of body fatness,[18,34–37] as well as age-specific levels that correspond to the percentage body fat of a typical 18-year-old with a BMI of 30 kg/m^2.[36,38] Children with body fatness above these cut points have been classified as having excess body fatness. Other studies[39,40] have used "prevalence matching," in which cut points were chosen so that the prevalence of children with excess body fatness (within gender and age groups) would be approximately equal to the prevalence of children considered to be obese or overweight on the basis of their BMI.

It has been noted[36] that an important limitation of all published cut points for excess body fat is the lack of clinical correlates underlying the classification systems. However, because the relation of childhood body fatness to disease is likely to be influenced by the adult level of adiposity, it may be difficult to derive childhood cut points from longitudinal studies that would last many decades.

RELATION OF BMI TO BODY FATNESS

Among adults, BMI is moderately correlated with adiposity, frequently accounting for ~75% of the variability (multiple R^2) across subjects. The magnitudes of the observed associations among children have varied considerably, and relatively weak associations have been reported in several subgroups.[41–44] It is possible that these differences reflect the difficulties involved in using BMI to estimate the
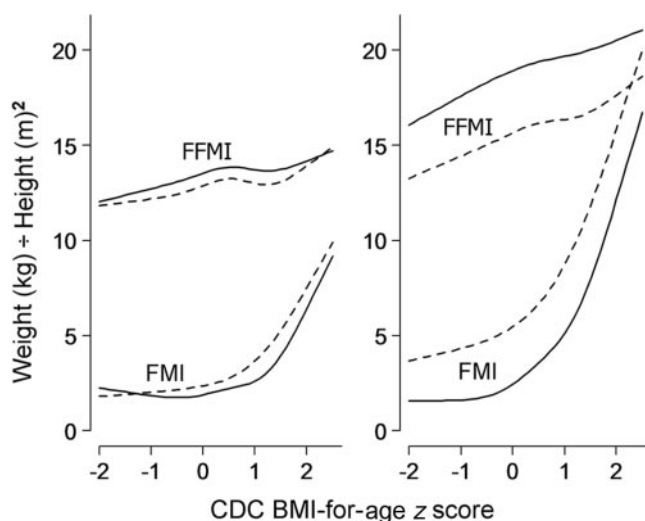
FIGURE 1
Predicted levels of FMI and FFMI at ages 6 (left) and 17 (right) years according to BMI-for-age *z* score in the Pediatric Rosetta Study; the solid lines represent boys, and the dashed lines represent girls. Regression models were based on 1196 children and included gender, age, BMI for age, race, and various interactions as predictor variables. A BMI-for-age *z* score of 1.0 is ~84th percentile, and a *z* score of 2.0 is ~98th percentile.

body fatness of relatively thin children. Although BMI is "almost useless as an estimator of percentage of body fat in normal-weight children,"[3] its accuracy increases with the degree of body fatness. One study,[42] for example, found the relation of BMI to skinfold thicknesses to be nonexistent ($r = 0.01$) among relatively thin boys but moderate ($r = 0.58$) among fatter boys. The differing associations between BMI and body fatness across studies may largely reflect differences in the fatness of examined subjects.

Analyses of the DEXA-estimated body fatness of children have confirmed that associations with BMI for age vary considerably according to the degree of body fatness. Fig 1 shows the estimated (cross-sectional) relation of BMI for age to levels of FMI and FFMI at ages 6 and 17 years among 1196 children in the Pediatric Rosetta Study.[25] The relation of BMI for age to FMI was nonlinear, with fat mass increasing substantially only at BMI-for-age *z* scores of >1.0 (~85th CDC percentile). In contrast, the relation of BMI for age to FFMI was fairly linear, with a positive association seen even among children who had a BMI at <50th CDC percentile.

Stratified analyses confirmed that the degree of fatness modified the relation of BMI for age to body fatness.[25] BMI levels among thin 5- to 8-year-old boys, for example, showed a much stronger association with FFMI ($r = 0.83$) than with FMI ($r = 0.22$), whereas BMI levels were strongly associated with body fatness ($r = 0.96$) among relatively heavy (BMI ≥ 85th CDC percentile) boys. Even in this relatively heavy subgroup, however, BMI for age was moderately correlated with FFMI ($r = 0.57$).

Longitudinal analyses have also shown that increases in the BMI of adolescent boys, but not girls, largely reflect increases in FFMI rather than in FMI.[2] Furthermore, these increases in FFMI were seen even among boys who had a BMI between the 85th and 94th CDC percentiles. BMI differences among normal-weight children (and BMI changes among these children) can largely reflect differences in fat-free, rather than fat, mass.

Identification of Excess Body Fatness by BMI

Although several investigators have examined the ability of a high BMI to identify children with excess body fatness,[18,35,45,46] the results are difficult to compare. There are differences in the (1) methods (skinfolds, DEXA, etc) used to estimate body fatness, (2) cut points used to classify high levels of both BMI and body fatness, and (3) statistics used to summarize the screening performance of BMI.

The accuracy of a high BMI in identifying children with excess body fatness has frequently been summarized by calculating the (1) sensitivity (proportion of children with excess body fatness who have a high BMI), (2) positive predictive value (proportion of children with a high BMI who have excess body fatness), and (3) specificity (proportion of children without excess body fatness who do not have a high BMI). It should be realized, however, that the cut points chosen for high levels of BMI and body fatness can strongly influence estimates of screening performance. For example, even if BMI for age and body fatness were perfectly correlated, if the prevalence of excess body fatness was 2 times higher than the prevalence of a high BMI, the maximum sensitivity would be 50% rather than 100%. In contrast, if the prevalence of a high BMI was twofold higher than that of excess body fatness, the positive predictive value could be no higher than 50%.

Although it is frequently stated that a high BMI is not a sensitive indicator of excess body fatness,[35,45–49] a low sensitivity may reflect a low prevalence of children with high BMI levels (relative to those considered to have excess body fatness) rather than the poor performance of BMI in detecting excess body fatness. For example, reported sensitivities of almost 0 in some subgroups are almost certainly a re-
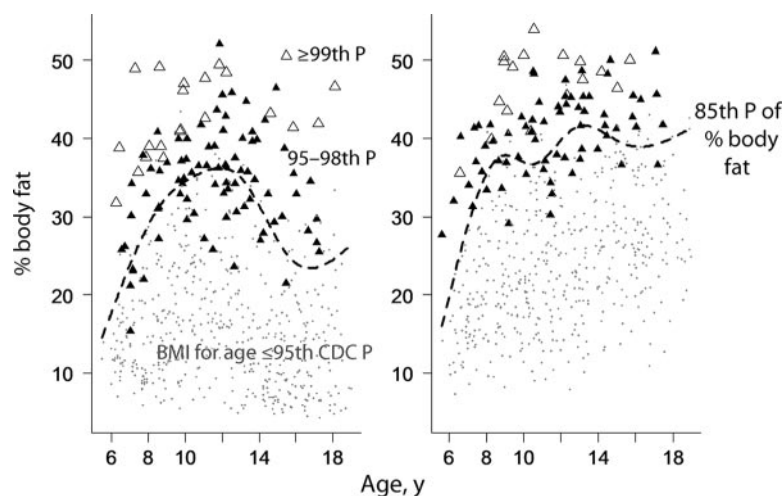
FIGURE 2
Levels of percent body fat among 626 boys (left) and 570 girls (right) in the Pediatric Rosetta Study. The solid triangles represent obese children who have a BMI for age between the 95th and 98.9th CDC percentiles, and the open triangles represent obese children who have a BMI for age at ≥99th CDC percentile. The gray dots represent nonobese (<95th CDC percentile) children, and the smoothed, dashed lines represent the 85th percentile of percent body fat according to age for each gender. Gray dots above the smoothed lines are false-negatives (nonobese children with excess body fatness), and triangles below the smoothed lines are false-positives (obese children who do not have excess body fatness). P indicates percentile.

TABLE 1 Identification of Excess Body Fatness According to Overweight in the Pediatric Rosetta Study

| | Excess Body Fat | | | |
| | Boys | | Girls | |
BMI for Age	Yes	No	Yes	No
≥95th CDC percentile				
Yes	75	28	63	21
No	27	496	21	465
≥99th CDC percentile				
Yes	22	0	17	0
No	80	524	67	486
n	102	524	84	486

sult of large differences in the prevalences of high BMI levels (<10%) and excess body fatness (up to 66% in some groups on the basis of a body-fatness cut point of 30%) among examined subjects.[45] Furthermore, differences in the performance of various BMI cut points,[49] including population-specific versus international cut points,[50] may also be largely due to differing prevalences of high BMI levels based on different classification systems. The potential influence of the cut points used for levels of BMI and body fatness on the screening performance of BMI can be large and must be considered when interpreting the results of various studies. It would be helpful if investigators consistently reported the prevalences of children with high BMIs and those with excess body fatness.

Analyses from the Pediatric Rosetta Project have indicated that a high BMI for age is a good index of excess body fatness,[37,51] and Fig 2 shows levels of percent body fat versus age for the 626 boys (left) and the 570 girls (right) in

this study. Because ~15% of the children were obese (≥95th CDC percentile), the 85th percentile of percent body fat (in the sample) was used for the classification of excess body fatness; these percent-body-fat cut points were estimated at each age by using quantile regression.[52] If a high BMI could perfectly classify excess body fatness, all obese children (triangles) would be above the smoothed lines and all nonobese children (gray points) would be below the lines. Despite the obvious errors, the classification is fairly good: most children with a BMI at ≥95th CDC percentile had excess body fatness, and most nonobese children did not. Additional analyses (not shown) indicated that ~80% of the false-positives (obese children who did not have excess body fatness) had a BMI for age between the 95.0th and 96.9th percentiles of the CDC reference population.

The ability of obesity (BMI ≥ 95th CDC percentile) to correctly identify children with excess body fatness can be summarized in 2 × 2 tables (Table 1).

Of the 103 obese boys (2 upper-left cells), 75 had excess body fatness (positive predictive value = 73%), whereas the sensitivity was 74% (75 of 102). There were similar estimates (75%) of the positive predictive value and sensitivity among girls, and the specificity was high (~95%) among both boys (496 of 524) and girls (465 of 486). Analyses based on the 85th percentile of FMI, rather than percent body fat, yielded slightly higher (81%–86%) positive predictive values but similar estimates of sensitivity and specificity (not shown). The use of the 99th CDC percentile of BMI for age (bottom of Table 1) increased the specificity and positive predictive value to 100% (all children with these high BMI levels, represented by the open triangles in Fig 2, had excess body fatness). However, most children with excess body fatness did not have a BMI for age at ≥99th CDC percentile, resulting in a sensitivity of only 20% (22 of 102 and 17 of 84; Table 1).

In contrast to obese children, most children who have a BMI for age between the 85th and 94th percentiles (overweight) do not have excess body fatness.[40] For example, of the 200 overweight children in the Pediatric Rosetta Study, only 18% (positive predictive value) had a percent-body-fat level at or above the age-specific 85th percentile. (The corresponding positive predictive value for the 95th CDC per-

centile was >70%.) Another 50% of overweight children in the Pediatric Rosetta Study had a moderately elevated body-fatness level, with levels of percent body fat corresponding to their moderately elevated BMI levels (85th–94th percentiles), whereas ~30% of overweight children had a body-fatness level that was comparable to that among normal-weight children.[40] Analyses from the Bogalusa Heart Study have also shown that relatively few (13%) overweight children have elevated skinfold thicknesses.[26] It is likely that BMI levels considered to be "overweight" on the basis of the 2000 CDC growth charts can be a result of moderate increases in levels of either fat or fat-free mass.[25]

The screening accuracy of BMI can also be summarized by the area under the receiver operator characteristic curve (AUC).[53] This statistic accounts for the inherent trade-offs between sensitivity and specificity obtained with various BMI cut points and can be interpreted as the probability that the BMI for age of a randomly selected child who has excess body fatness would be higher than the BMI for age of a child without excess body fatness. On the basis of this statistic, BMI for age was a good indicator (AUC ~ 0.95; the maximum is 1.0) of excess body fatness among both boys and girls in the Pediatric Rosetta Study. Although the AUC can be somewhat difficult to interpret, it provides a more complete representation of the screening performance of BMI for age than do estimates of sensitivity, positive predictive value, and specificity obtained from a single BMI cut point.

Racial Differences in BMI and Body Fatness

The body fatness of adults differs according to race/ethnicity: at equivalent levels of BMI and age, white adults
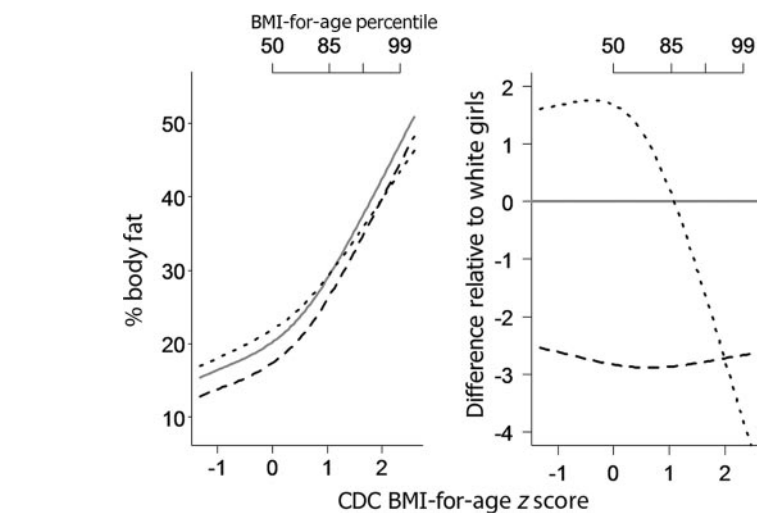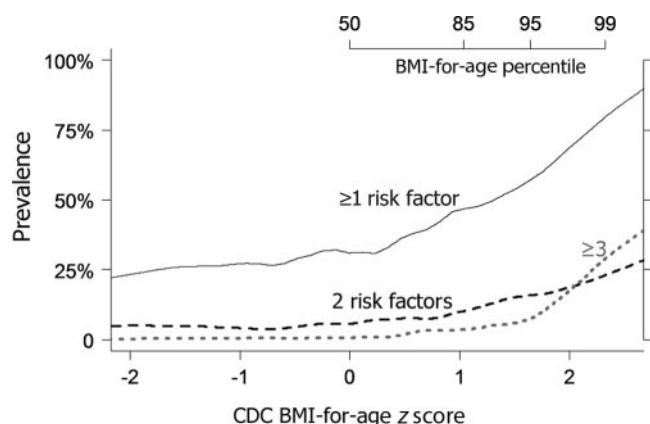

FIGURE 3

Predicted levels of percent body fat among girls based on BMI for age, race, age, and the interaction between race and BMI for age in the Pediatric Rosetta Study. The lines represent white (gray line), black (dashed black line), and Asian girls (dotted black line). Left, predicted levels of body fatness (at age 12 years) according to levels of BMI for age; the multiple R^2 was 0.82. Right, Differences in body fatness of black and Asian girls relative to white girls.

have less body fat than Asian adults[54] but more than black adults.[55] On the basis of these findings, along with possible differences in the relation of body fatness to disease risk, it has been suggested that BMI cut points be lowered among Asian adults[56] and raised among black adults.[55] This could result in BMI cut points identifying similar levels of body fatness (and possibly, risk) across race/ethnicity groups. There have been fewer studies of differences in the body composition of children, but black/white differences in body fatness have been noted by several investigators.[55,57]

Analyses from the Pediatric Rosetta Study[58] have confirmed that there are differences in the DEXA-estimated body fatness of white, Asian, and black children (Fig 3). At comparable levels of BMI for age, the estimated body fatness of black girls (and boys) was ~3% less than that of white children, but the white/Asian difference varied substantially across levels of BMI for age (Fig 3, right). Among relatively thin (BMI < 50th CDC percentile) girls, for example, Asians had a mean (ad-

justed) level of body fatness that was ~2% higher than that of whites. In contrast, obese white girls had ~2% to 3% more body fatness (at the same BMI level) than did obese Asian girls. Some results have also suggested that the increased body fatness of Asian (versus white) adults may be most evident at low BMI levels.[59]

These racial differences in body fatness, however, are much smaller than is the mean (15%–20%) difference in percent body fat between nonobese and obese children. Therefore, the influence of race/ethnicity on the ability of high BMI levels to identify excess body fatness is uncertain. (An additional complication is that the association between child and adult BMI levels may differ according to race/ethnicity.) The interaction between BMI for age and race/ethnicity in the estimation of body fatness, however, suggests that it may be difficult to identify equivalent levels of body fatness by simply adjusting BMI for the average difference in body fatness across race/ethnicity groups.

FIGURE 4
Relation of BMI for age to the proportion of children in the Bogalusa Heart Study with the specified number of risk factors. The maximum number of risk factors was 5 and included adverse levels of triglycerides, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, fasting insulin, and either systolic or diastolic blood pressure. Curves were smoothed by using LOWESS (locally weighted scatterplot smoothing).

CHILDHOOD BMI AND HEALTH RISKS

Cross-Sectional Associations With Cardiovascular Disease Risk Factors

Several reviews have focused on the short-term and long-term consequences of childhood obesity,[19,60–62] and high BMI levels have consistently been found to be associated with cardiovascular disease risk factors such as insulin resistance, dyslipidemia, and increased blood pressure. The relation of BMI for age to the clustering of multiple risk factors was recently analyzed in a large ($n \sim 10\,100$) sample of children and adolescents from the Bogalusa Heart Study.[26] On the basis of these associations, the proportion of children with at least 2 (of 5) risk factors increased from 5% (<25th CDC percentile) to 59% (≥99th CDC percentile) with increasing levels of BMI for age (Fig 4). Furthermore, the observed associations were markedly nonlinear, with substantial increases in the prevalence of multiple risk factors seen only at high levels of BMI for age. Of the 226 children who had a BMI for age at ≥99th CDC percentile, 84% had an adverse level of at least 1 risk factor.

Tracking of Childhood BMI Into Adulthood

An important criterion of the validity of childhood BMI is its relation to adult obesity, and almost all longitudinal studies have found that BMI levels track throughout life. Children with high BMI levels are more likely to become obese adults than are thinner children.[60–64] Although some negative findings have been reported, these may be a result of the relative thinness of the examined children (eg, children born in the United Kingdom in 1947[65]), and it is likely that these results are not applicable to the current levels of body fatness seen among US children. Differences in the BMIs of relatively thin children are likely to reflect differences in fat-free mass rather than fat mass.[25]

The strength of the association between levels of BMI in childhood and adulthood increases with childhood age,[19] and positive predictive values of childhood obesity (≥95th CDC percentile) for adult obesity have ranged from ~0.35 (BMI assessed at the age of 5 years) to 0.57 (assessed at the age of 15 years).[66] These estimates, however, are strongly influenced by the prevalences of obesity among children

and adults and were based on only 347 subjects. A much larger longitudinal study[67] revealed that, even when childhood BMI was assessed between the ages of 6 and 8 years, the prevalence of adult obesity was >10 times greater (78% vs 6%) among obese (≥95th CDC percentile) children than among those with a BMI at ≤50th percentile. As assessed by the correlation between childhood BMI for age and adult BMI, the magnitude of the association was only slightly weaker among subjects who were initially examined at the ages of 6 to 8 years ($r \sim 0.6$) than at the ages of 15 to 17 years ($r \sim 0.7$).

Other characteristics such as the length of follow-up, race/ethnicity, parental fatness, birth weight, timing of sexual maturation, socioeconomic status, and physical activity may influence the tracking of childhood BMI.[63] Although an early adiposity rebound has also been suggested to increase the risk for adult obesity, a young age at the BMI nadir may simply identify children whose BMI for age is high or moving upward.[68] It is likely that equivalent information can more easily be obtained from a single BMI measurement at the age of 7 years.[69]

ADDITIONAL INFORMATION FROM SKINFOLD AND CIRCUMFERENCE MEASUREMENTS

Skinfold Measurements

Skinfold thicknesses have often been considered an attractive, noninvasive tool for estimating the amount of subcutaneous fat. Although a single measurement (or set of skinfolds) provides a more accurate estimate of body fatness than does BMI for age, relatively small differences in the relation of percent body fat to BMI versus skinfold thicknesses have been reported.[17] Furthermore, skinfolds can be subject to large measurement errors, which makes their interpretation

problematic if examiners have not been trained extensively.[14] The optimal sites for skinfold-thickness measurements are also uncertain, and some sites require disrobing. These measurements have not been recommended as part of a routine examination,[5] but it has been suggested[23,70] that skinfolds may help determine if an overweight child may have excess body fatness.

Recent results, however, suggest that skinfold measurements may only slightly improve the estimation of body fatness among children who are obese (BMI ≥95th CDC percentile).[37,71] For example, information on the triceps and subscapular skinfolds significantly improved the prediction of DEXA-calculated body fatness in the Pediatric Rosetta Study among all children, but there were only relatively small (8%) improvements among the obese children.[71] Approximately 75% of children with a BMI at ≥95th CDC percentile have excess body fatness (Fig 2, Table 1), and this positive predictive value can be increased by simply using a higher BMI cut point. Other analyses indicate that BMI levels among children are as strongly correlated with various cardiovascular disease risk factors (lipid and insulin levels, blood pressure), as is the sum of the subscapular and triceps skinfold thicknesses.[72] Although skinfold thicknesses may be useful in identifying nonobese children who truly have excess body fatness, the large measurement errors may preclude their widespread use.

Circumferences

Body-fat patterning influences the risk of type 2 diabetes and cardiovascular disease among adults, and abdominal obesity is associated with metabolic disorders among children and adolescents. However, because of the strong intercorrelation between fat patterning and the amount of body fatness, the additional information conveyed by body-fat distribution remains uncertain.

Several recent studies of children and adolescents focused on the waist-to-height ratio (WHtR), an index of abdominal obesity that seems to be (at least) as strongly correlated with various metabolic complications as is BMI.[73,74] The use of WHtR also has the potential to simplify the assessment of obesity-related risk.[75] Whereas a child's BMI must be expressed relative to his or her gender and age peers, it may be possible to use a single WHtR cut point (0.5) to identify children and adults at increased risk, because levels vary only slightly according to gender and age. It is also possible that the concept of a large waist relative to height, both of which are expressed in the same units, may be easier to explain to children and parents than is the division of weight (kg) by height (m)^2 (or 703 times the division of pounds by inches squared).

There are, however, several limitations of WHtR: there have been few longitudinal studies on the relation of childhood WHtR to adult levels; numerous locations have been recommended for the measurement of the waist circumference[15,76]; and the measurement error for waist circumference is greater than those for weight and height.[14,74] In addition, we have found that WHtR provides relatively little additional information (among all children) on risk-factor levels if BMI is already known.[74]

CONCLUSIONS

The accuracy of BMI as an indicator of adiposity varies substantially according to the degree of body fatness. Among relatively fat children, BMI is a good indicator of excess adiposity, but differences in the BMIs of relatively thin children (eg, BMI for age <85th CDC percentile) can be largely due to differences in fat-free mass. If appropriate cut points for both BMI and body fatness are selected, so that the prevalences of high levels of each characteristic are approximately equal, a BMI for age at ≥95th CDC percentile has moderately high (70%–80%) sensitivity and positive predictive value, along with high specificity (95%), for identifying children with excess body fatness. As compared with thinner children, overweight children (85th–94th CDC percentiles) are also more likely to have adverse levels of multiple risk factors and to become obese adults; their risks, however, are lower than those of obese children.

Skinfold-thickness and circumference measurements require additional training and may be difficult to standardize, and there is little information to support their use in the general assessment of body fatness and health risks. The additional information supplied by these measurements among overweight children, beyond that conveyed by BMI for age, is uncertain.

REFERENCES

1. Prentice AM, Jebb SA. Beyond body mass index. *Obes Rev*. 2001;2(3):141–147

2. Demerath EW, Schubert CM, Maynard LM, et al. Do changes in body mass index percentile reflect changes in body composition in children? Data from the Fels Longitudinal Study. *Pediatrics*. 2006;117(3). Available at: www.pediatrics.org/cgi/content/full/117/3/e487

3. Bray GA, DeLany JP, Volaufova J, Harsha DW, Champagne C. Prediction of body fat in 12-y-old

African American and white children: evaluation of methods. *Am J Clin Nutr.* 2002;76(5): 980–990

4. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ.* 2000;320(7244):1240–1243

5. Krebs NF, Himes JH, Jacobson D, Nicklas TA, Guilday P, Styne D. Assessment of child and adolescent overweight and obesity. *Pediatrics.* 2007;120(suppl 4):S193–S228

6. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Adv Data.* 2000;(314):1–27

7. Cole TJ, Rolland-Cachera MF. Measurement and definition. In: Lissau I, Burniat W, Poskitt EME, et al, eds. *Child and Adolescent Obesity: Causes, Consequences, Prevention and Management.* Cambridge, United Kingdom: Cambridge University Press; 2002:1–27

8. Fields DA, Goran MI. Body composition techniques and the four-compartment model in children. *J Appl Physiol.* 2000;89(2):613–620

9. Wong WW, Hergenroeder AC, Stuff JE, Butte NF, Smith EO, Ellis KJ. Evaluating body fat in girls and female adolescents: advantages and disadvantages of dual-energy x-ray absorptiometry. *Am J Clin Nutr.* 2002;76(2):384–389

10. Williams JE, Wells JC, Wilson CM, Haroun D, Lucas A, Fewtrell MS. Evaluation of Lunar Prodigy dual-energy x-ray absorptiometry for assessing body composition in healthy persons and patients by comparison with the criterion 4-component model. *Am J Clin Nutr.* 2006;83(5):1047–1054

11. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. *Am J Clin Nutr.* 1990;52(6):953–959

12. Wells JC. A critique of the expression of paediatric body composition data. *Arch Dis Child.* 2001; 85(1):67–72

13. World Health Organization, Expert Committee on Physical Status. *Physical Status: The Use and Interpretation of Anthropometry.* Geneva, Switzerland: World Health Organization; 1995:420. WHO technical report 854

14. Ulijaszek SJ, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. *Br J Nutr.* 1999;82(3):165–177

15. Wang J, Thornton JC, Bari S, et al. Comparisons of waist circumferences measured at 4 sites. *Am J Clin Nutr.* 2003;77(2):379–384

16. Sherry B, Jefferds ME, Grummer-Strawn LM. Accuracy of adolescent self-report of height and weight in assessing overweight status: a literature review. *Arch Pediatr Adolesc Med.* 2007; 161(12):1154–1161

17. Freedman DS, Thornton JC, Mei Z, et al. Height and adiposity among children. *Obes Res.* 2004;12(5): 846–853

18. Mei Z, Grummer-Strawn LM, Pietrobelli A, Goulding A, Goran MI, Dietz WH. Validity of body mass index compared with other body-composition screening indexes for the assessment of body fatness in children and adolescents. *Am J Clin Nutr.* 2002;75(6):978–985

19. Whitlock EP, Williams SB, Gold R, Smith PR, Shipman SA. Screening and interventions for childhood overweight: a summary of evidence for the US Preventive Services Task Force. *Pediatrics.* 2005; 116(1). Available at: www.pediatrics.org/cgi/content/full/116/1/e125

20. Sweeting HN. Measurement and definitions of obesity in childhood and adolescence: a field guide for the uninitiated. *Nutr J.* 2007;6:32

21. Ogden CL, Kuczmarski RJ, Flegal KM, et al. Centers for Disease Control and Prevention 2000 growth charts for the United States: improvements to the 1977 National Center for Health Statistics version. *Pediatrics.* 2002;109(1):45–60

22. Chinn S. Definitions of childhood obesity: current practice. *Eur J Clin Nutr.* 2006;60(10):1189–1194

23. Himes JH, Dietz WH. Guidelines for overweight in adolescent preventive services: recommendations from an expert committee. The Expert Committee on Clinical Guidelines for Overweight in Adolescent Preventive Services. *Am J Clin Nutr.* 1994;59(2):307–316

24. Kuczmarski RJ, Flegal KM. Criteria for definition of overweight in transition: background and recommendations for the United States. *Am J Clin Nutr.* 2000;72(5):1074–1081

25. Freedman DS, Wang J, Maynard LM, et al. Relation of BMI to fat and fat-free mass among children and adolescents. *Int J Obes (Lond).* 2005;29(1):1–8

26. Freedman DS, Mei Z, Srinivasan SR, Berenson GS, Dietz WH. Cardiovascular risk factors and excess adiposity among overweight children and adolescents: the Bogalusa Heart Study. *J Pediatr.* 2007;150(1):12.e2–17.e2

27. Freedman DS, Khan LK, Serdula MK, Ogden CL, Dietz WH. Racial and ethnic differences in secular trends for childhood BMI, weight, and height. *Obesity (Silver Spring).* 2006;14(2):301–308

28. Flegal KM, Tabak CJ, Ogden CL. Overweight in children: definitions and interpretation. *Health Educ Res.* 2006;21(6):755–760

29. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med.* 1992;11(10):1305–1319

30. Williams DP, Going SB, Lohman TG, et al. Body fatness and risk for elevated blood pressure, total cholesterol, and serum lipoprotein ratios in children and adolescents. *Am J Public Health.* 1992; 82(3):358–363

31. Dwyer T, Blizzard CL. Defining obesity in children by biological endpoint rather than population distribution. *Int J Obes Relat Metab Disord.* 1996;20(5):472–480

32. Higgins PB, Gower BA, Hunter GR, Goran MI. Defining health-related obesity in prepubertal children. *Obes Res.* 2001;9(4):233–240

33. Lohman TG, Going SB. Assessment of body composition and energy balance. In: Lamb D, Murray R, eds. *Exercise, Nutrition, and the Control of Body Weight.* Carmel, IN: Cooper Publishing Group; 1998:61–99

34. Lazarus R, Baur L, Webb K, Blyth F. Body mass index in screening for adiposity in children and adolescents: systematic evaluation using receiver operating characteristic curves. *Am J Clin Nutr.* 1996;63(4):500–506

35. Zimmermann MB, Gubeli C, Puntener C, Molinari L. Detection of overweight and obesity in a national sample of 6–12-y-old Swiss children: accuracy and validity of reference values for body mass index from the US Centers for Disease Control and Prevention and the International Obesity Taskforce. *Am J Clin Nutr.* 2004;79(5):838–843

36. McCarthy HD, Cole TJ, Fry T, Jebb SA, Prentice AM. Body fat reference curves for children. *Int J Obes (Lond).* 2006;30(4):598–602

37. Mei Z, Grummer-Strawn LM, Wang J, et al. Do skinfold measurements provide additional information to body mass index in the assessment of body fatness among children and adolescents? *Pediatrics.* 2007;119(6). Available at: www.pediatrics.org/cgi/content/full/119/6/e1306

38. Taylor RW, Jones IE, Williams SM, Goulding A. Body fat percentages measured by dual-energy x-ray absorptiometry corresponding to recently recommended body mass index cutoffs for overweight and obesity in children and adolescents aged 3–18 y. *Am J Clin Nutr.* 2002;76(6):1416–1421

39. Flegal KM, Shepherd JA, Looker AC, et al. Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. *Am J Clin Nutr.* 2009;89(2):500–508

40. Freedman D, Wang J, Thornton J, et al. The classification of body fatness by BMI-for-age categories among children. *Arch Pediatr Adolesc Med.* 2009; In press

41. Daniels SR, Khoury PR, Morrison JA. The utility of body mass index as a measure of body fatness in children and adolescents: differences by race and gender. *Pediatrics.* 1997;99(6):804–807

42. Schaefer F, Georgi M, Wuhl E, Scharer K. Body mass index and percentage fat mass in healthy German schoolchildren and adolescents. *Int J Obes Relat Metab Disord.* 1998;22(5):461–469

43. Bray GA, DeLany JP, Harsha DW, Volaufova J, Champagne CC. Evaluation of body fat in fatter and leaner 10-y-old African American and white children: the Baton Rouge Children's Study. *Am J Clin Nutr.* 2001;73(4):687–702

44. Kerruish KP, O'Connor J, Humphries IR, et al. Body composition in adolescents with anorexia nervosa. *Am J Clin Nutr.* 2002;75(1):31–37

45. Wickramasinghe VP, Cleghorn GJ, Edmiston KA, Murphy AJ, Abbott RA, Davies PS. Validity of BMI as a measure of obesity in Australian white Caucasian and Australian Sri Lankan children. *Ann Hum Biol.* 2005;32(1):60–71

46. Neovius M, Rasmussen F. Evaluation of BMI-based classification of adolescent overweight and obesity: choice of percentage body fat cutoffs exerts a large influence. The COMPASS Study. *Eur J Clin Nutr.* 2008;62(10):1201–1207

47. Reilly JJ, Dorosty AR, Emmett PM. Identification of the obese child: adequacy of the body mass index for clinical practice and epidemiology. *Int J Obes Relat Metab Disord.* 2000;24(12):1623–1627

48. Gaskin PS, Walker SP. Obesity in a cohort of black Jamaican children as estimated by BMI and other indices of adiposity. *Eur J Clin Nutr.* 2003;57(3):420–426

49. Neovius MG, Linne YM, Barkeling BS, Rossner SO. Sensitivity and specificity of classification systems for fatness in adolescents. *Am J Clin Nutr.* 2004;80(3):597–603

50. Fu WP, Lee HC, Ng CJ, et al. Screening for childhood obesity: international vs population-specific definitions. Which is more appropriate? *Int J Obes Relat Metab Disord.* 2003;27(9):1121–1126

51. Freedman DS, Ogden CL, Berenson GS, Horlick M. Body mass index and body fatness in childhood. *Curr Opin Clin Nutr Metab Care.* 2005;8(6):618–623

52. Wei Y, Pere A, Koenker R, He X. Quantile regression methods for reference growth charts. *Stat Med.* 2006;25(8):1369–1382

53. Fletcher RW, Fletcher SW. *Clinical Epidemiology: The Essentials*. 4th ed. Baltimore, MD: Lippincott, Williams & Williams; 2005

54. Deurenberg-Yap M, Schmidt G, van Staveren WA, Deurenberg P. The paradox of low body mass index and high body fat percentage among Chinese, Malays and Indians in Singapore. *Int J Obes Relat Metab Disord*. 2000;24(8):1011–1017

55. Wagner DR, Heyward VH. Measures of body composition in blacks and whites: a comparative review. *Am J Clin Nutr*. 2000;71(6):1392–1402

56. Misra A. Revisions of cutoffs of body mass index to define overweight and obesity are needed for the Asian-ethnic groups. *Int J Obes Relat Metab Disord*. 2003;27(11):1294–1296

57. Harsha DW, Frerichs RR, Berenson GS. Densitometry and anthropometry of black and white children. *Hum Biol*. 1978;50(3):261–280

58. Freedman DS, Wang J, Thornton JC, et al. Racial/ethnic differences in body fatness among children and adolescents. *Obesity (Silver Spring)*. 2008;16(5):1105–1111

59. Swinburn BA, Ley SJ, Carmichael HE, Plank LD. Body size and composition in Polynesians. *Int J Obes Relat Metab Disord*. 1999;23(11):1178–1183

60. Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord*. 1999;23(suppl 2):S2–S11

61. Reilly JJ, Methven E, McDowell ZC, et al. Health consequences of obesity. *Arch Dis Child*. 2003;88(9):748–752

62. Power C, Lake JK, Cole TJ. Measurement and long-term health risks of child and adolescent fatness. *Int J Obes Relat Metab Disord*. 1997;21(7):507–526

63. Parsons TJ, Power C, Logan S, Summerbell CD. Childhood predictors of adult obesity: a systematic review. *Int J Obes Relat Metab Disord*. 1999;23(suppl 8):S1–S107

64. Singh AS, Mulder C, Twisk JW, van Mechelen W, Chinapaw MJ. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev*. 2008;9(5):474–488

65. Wright CM, Parker L, Lamont D, Craft AW. Implications of childhood obesity for adult health: findings from thousand families cohort study. *BMJ*. 2001;323(7324):1280–1284

66. Guo SS, Wu W, Chumlea WC, Roche AF. Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *Am J Clin Nutr*. 2002;76(3):653–658

67. Freedman DS, Khan LK, Serdula MK, Dietz WH, Srinivasan SR, Berenson GS. The relation of childhood BMI to adult adiposity: the Bogalusa Heart Study. *Pediatrics*. 2005;115(1):22–27

68. Cole TJ. Children grow and horses race: is the adiposity rebound a critical period for later obesity? *BMC Pediatr*. 2004;4:6

69. Freedman DS, Kettel Khan L, Serdula MK, Srinivasan SR, Berenson GS. BMI rebound, childhood height and obesity among adults: the Bogalusa Heart Study. *Int J Obes Relat Metab Disord*. 2001;25(4):543–549

70. Barlow SE, Dietz WH. Obesity evaluation and treatment: Expert Committee recommendations. The Maternal and Child Health Bureau, Health Resources and Services Administration and the Department of Health and Human Services. *Pediatrics*. 1998;102(3). Available at: www.pediatrics.org/cgi/content/full/102/3/e29

71. Freedman DS, Wang J, Ogden CL, et al. The prediction of body fatness by BMI and skinfold thicknesses among children and adolescents. *Ann Hum Biol*. 2007;34(2):183–194

72. Freedman DS, Katzmarzyk PT, Dietz WH, Srinivasan SR, Berenson GS. Relation of body mass index and skinfold thicknesses to cardiovascular disease risk factors in children: the Bogalusa Heart Study. *Am J Clin Nutr*. 2009;90(1):210–216

73. Kahn HS, Imperatore G, Cheng YJ. A population-based comparison of BMI percentiles and waist-to-height ratio for identifying cardiovascular risk in youth. *J Pediatr*. 2005;146(4):482–488

74. Freedman DS, Kahn HS, Mei Z, et al. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa Heart Study. *Am J Clin Nutr*. 2007;86(1):33–40

75. Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *Int J Food Sci Nutr*. 2005;56(5):303–307

76. Rudolf MC, Walker J, Cole TJ. What is the best way to measure waist circumference? *Int J Pediatr Obes*. 2007;2(1):58–61

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