The body mass index (BMI), defined as weight/height², is often used to monitor childhood obesity. BMI values for 979 children (438 White, 283 Black, and 258 Hispanic) aged 3–18 years living in the Houston, Texas, metropolitan area from 1994 to 1998 were compared with percentage of fat (%Fat) measurements obtained by using dual-energy x-ray absorptiometry. The associations between %Fat and BMI were statistically significant ($r^2 = 0.34–0.70$, $p < 0.0005$) and were gender and ethnic dependent ($p < 0.0005$), indicating that BMI can provide a general description of the adiposity characteristics of a healthy pediatric population. However, BMI was a poor predictor for the individual child, with a standard error for %Fat of 4.7–7.3% of body weight. It is advantageous to identify accurately, as early as possible, those children who truly have excess adiposity, but this assessment should not be done at the risk of falsely mislabeling a significant number of healthy children as overweight or obese.

The purpose of the present study was to assess the adequacy of using BMI to classify overweight or obese children in a multiethnic population. Body fatness measurements were obtained by using dual-energy x-ray absorptiometry (DXA), which has been shown to provide a reliable measure of fat mass (20, 21). In particular, we wanted to determine the sensitivity and specificity rates when the recommended BMI cut-points were used, which are independent of ethnicity. We hypothesized that identification of overweight or obese children in minority populations can be improved when ethnicity is included in the selection of BMI limits to define the normal range.

MATERIALS AND METHODS

Subjects

A total of 979 children aged 3–18 years living in the Houston, Texas, metropolitan area from 1994 to 1998 participated in this study. The gender distribution was 573 females and 406 males from three ethnic groups: 438 European American (White), 283 African American (Black), and 258 Hispanic American (Hispanic). The protocol was approved by Baylor College of Medicine’s Institutional Review Board for Human Studies, and informed consent was obtained for each subject.

Anthropometry

Body weight was measured on a calibrated digital scale to ±0.1 kg while the child was wearing minimal...
clothing, typically a hospital gown. With the child in socks, height was recorded to the nearest ±0.5 cm by using a stadiometer. All measurements were performed by research nurses with training in anthropometric measurements. BMI was defined as weight/height$^2$ and was expressed in units of kg/m$^2$.

**Body composition**

DXA was used to assess body fat mass. Each subject’s whole body was scanned by using a Hologic QDR-2000 instrument operated in the pencil-beam mode; results were analyzed with body composition software, version 5.56 (Hologic, Inc., Waltham, Massachusetts). DXA measurement of fat mass in children has been shown to be reliable when compared with hydrodensitometry estimates (22), with an in vivo precision of 2–4 percent for children. Body fatness was based on the percentage of fat (%Fat) obtained by using DXA and was defined as 100 × fat mass/weight.

**Statistical analysis**

Statistical analyses were performed by using MINITAB software (Minitab Inc., State College, Pennsylvania). The standard error of the estimate (SEE) was obtained as part of linear regression analysis. Analysis of variance, using the general linear model, was used to test for gender and ethnic differences in the data. The BMI cutpoints were defined by an expert committee (16) and provided age-specific and gender-specific values for children aged 10–18 years. The three adiposity classifications for BMI were 1) normal (BMI < 85th percentile), 2) at risk (85th percentile ≤ BMI < 95th percentile), and 3) overweight (BMI ≥ 95th percentile).

To our knowledge, no reference ranges have been established for %Fat in children. Thus, for our classification scheme, the following procedure was used. First, the %Fat values for each gender were adjusted for variations with age by using linear regression, and the studentized residuals were obtained. These residual values were then rank ordered and were converted into percentile values. If the %Fat value was at or above the 85th percentile but below the 95th percentile, the subject was classified as having excess body fat. If the subject ranked at or above the 95th percentile, the subject was considered obese. If %Fat ranked below the 85th percentile, the subject was classified in the normal range.

This procedure provided age-adjusted, gender-specific rank ordering for the total population, independent of ethnicity (total population model). The procedure was then repeated for each ethnic group separately to provide rank orderings that were then age adjusted and gender and ethnic specific (ethnic-adjusted model). To enable comparison of the results of the BMI classification and %Fat rank orderings, $3 \times 3$ tables were used to present the distribution of subjects. The Stuart-Maxwell chi-square ($\chi^2_{SM}$) statistic was used to test for similarities in the proportions among the three possible outcomes for the BMI and %Fat classifications (23). When this statistic was significant, an additional analysis of the ordered outcomes ($\chi^2_{OO}$) was performed to determine whether BMI tended to produce more responses at one end of the ordered scale and fewer at the other end compared with the %Fat models.

**RESULTS**

The mean (standard deviation) and range of values for age, weight, height, BMI, fat, and %Fat are given in table 1 for females and table 2 for males. The mean values for weight, height, BMI, and fat increased with age for both genders. The mean %Fat values also tended to increase with age for males, but the rate of increase between adjacent age groups was not consistent, and the mean %Fat values decreased for those in the oldest age group. The mean %Fat for the youngest White females and Black females was 20–21 percent, increasing to 24–28 percent for those aged 9–14 years; mean %Fat remained at about 27 percent for the White females but increased to 32 percent for the Black females aged 15–18 years. For the Black females, the groups aged 9–11 years ($p < 0.05$) and 15–18 years ($p < 0.003$) had a significantly higher %Fat than the age-matched White females. The Hispanic females also had a higher %Fat at all ages ($p < 0.005$) than the age-matched White females. For the males, the mean fat and %Fat values increased with age for the groups aged 3–5 to 12–14 years, followed by a decrease for those aged 15–18 years. The mean %Fat values for only the Black males aged 9–11 years were lower ($p < 0.05$) than those in the age-matched White group. On the other hand, the values for the Hispanic males were higher ($p < 0.05$–0.002) than those for the White males in the age groups 3–5 through 9–11 years. Based on the mean %Fat values, the average yearly increases for the females overall age range were 0.7 percent (White), 0.9 percent (Black), and 1.0 percent (Hispanic). The corresponding averages for $\Delta$%Fat per year for the males through age 15 years were 1.0 percent (White), 0.7 percent (Black), and 0.9 percent (Hispanic).

The relation between %Fat and BMI is shown in figure 1 for females and figure 2 for males. As expected, there was an increase in %Fat with increasing BMI for
both gender groups. The correlations of %Fat with BMI were statistically significant for both females (r² = 0.70, p < 0.0005) and males (r² = 0.34, p < 0.001; however, when a linear model was used, the ability of BMI to accurately predict %Fat for an individual child was poor (SEE = ±4.7 percent for females, SEE = 7.3

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Body mass index (kg/m²)</th>
<th>Fat (kg)</th>
<th>%Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–5 (n = 19)</td>
<td>4.3 (0.7)</td>
<td>17.2 (1.9)</td>
<td>105.4 (5.7)</td>
<td>15.8 (1.0)</td>
<td>2.9 (0.6)</td>
</tr>
<tr>
<td>6–8 (n = 32)</td>
<td>7.1 (0.9)</td>
<td>23.8 (5.4)</td>
<td>121.9 (7.2)</td>
<td>15.9 (1.9)</td>
<td>4.0 (2.7)</td>
</tr>
<tr>
<td>9–11 (n = 43)</td>
<td>10.0 (0.9)</td>
<td>35.7 (10.0)</td>
<td>139.9 (7.5)</td>
<td>17.9 (3.3)</td>
<td>8.1 (5.8)</td>
</tr>
<tr>
<td>12–14 (n = 31)</td>
<td>12.9 (0.8)</td>
<td>53.8 (15.5)</td>
<td>158.7 (10.1)</td>
<td>21.1 (4.4)</td>
<td>13.2 (9.4)</td>
</tr>
<tr>
<td>15–18 (n = 44)</td>
<td>16.5 (1.2)</td>
<td>64.1 (12.0)</td>
<td>173.0 (7.9)</td>
<td>21.3 (3.2)</td>
<td>9.7 (5.7)</td>
</tr>
<tr>
<td>3–5 (n = 15)</td>
<td>4.4 (0.6)</td>
<td>18.0 (3.8)</td>
<td>105.9 (6.7)</td>
<td>15.9 (1.7)</td>
<td>2.7 (1.4)</td>
</tr>
<tr>
<td>6–8 (n = 26)</td>
<td>7.1 (0.8)</td>
<td>26.9 (7.5)</td>
<td>123.3 (6.7)</td>
<td>17.5 (3.4)</td>
<td>5.2 (4.8)</td>
</tr>
<tr>
<td>9–11 (n = 27)</td>
<td>10.1 (0.9)</td>
<td>38.0 (10.9)</td>
<td>141.5 (8.6)</td>
<td>18.7 (3.4)</td>
<td>7.1 (5.9)</td>
</tr>
<tr>
<td>12–14 (n = 20)</td>
<td>13.0 (1.0)</td>
<td>67.2 (20.9)</td>
<td>164.4 (9.8)</td>
<td>24.6 (6.4)</td>
<td>15.4 (12.8)</td>
</tr>
<tr>
<td>15–18 (n = 19)</td>
<td>16.6 (1.4)</td>
<td>76.4 (12.0)</td>
<td>175.8 (8.9)</td>
<td>24.9 (4.5)</td>
<td>11.7 (8.6)</td>
</tr>
<tr>
<td>3–5 (n = 23)</td>
<td>4.3 (0.8)</td>
<td>18.0 (3.9)</td>
<td>104.0 (8.7)</td>
<td>16.7 (2.6)</td>
<td>3.7 (2.1)</td>
</tr>
<tr>
<td>6–8 (n = 25)</td>
<td>7.1 (0.8)</td>
<td>26.0 (5.1)</td>
<td>121.6 (6.7)</td>
<td>17.5 (3.0)</td>
<td>5.9 (3.6)</td>
</tr>
<tr>
<td>9–11 (n = 26)</td>
<td>10.1 (0.8)</td>
<td>38.9 (10.1)</td>
<td>139.4 (7.9)</td>
<td>19.8 (3.7)</td>
<td>11.0 (6.4)</td>
</tr>
<tr>
<td>12–14 (n = 24)</td>
<td>12.8 (0.9)</td>
<td>55.7 (7.0)</td>
<td>158.5 (9.8)</td>
<td>22.0 (3.2)</td>
<td>14.4 (7.4)</td>
</tr>
<tr>
<td>15–18 (n = 32)</td>
<td>16.6 (1.2)</td>
<td>67.0 (14.0)</td>
<td>171.8 (6.4)</td>
<td>22.6 (4.0)</td>
<td>11.8 (9.6)</td>
</tr>
</tbody>
</table>

* p < 0.05; ** p < 0.01 (t-test comparison for Blacks and Hispanics versus Whites in each age group).
FIGURE 1. Relation between percentage of body fat and body mass index for females aged 3–18 years living in the Houston, Texas, metropolitan area from 1994 to 1998.

FIGURE 2. Relation between percentage of body fat and body mass index for males aged 3–18 years living in the Houston, Texas, metropolitan area from 1994 to 1998.
percent for males). The curvilinear shape of the relation for females prompted us to test for higher-order polynomial functions of BMI, but the SEE was reduced to only ±4.3 percent. When age, weight, height, and race were added separately and in combination with BMI as prediction parameters, the resultant SEE value for the females remained virtually unchanged (±4.3 percent), while that for the males was reduced to ±4.9 percent, mainly with the addition of race.

As is evident from figures 1 and 2, there was a wide variation in BMI values for a given %Fat, and vice versa. Analysis of variance showed that there were ethnic differences in the relation between %Fat and BMI for females \( p < 0.0005 \) but not for males. In general, the Black children tended to have a lower %Fat value than the White children with the same BMI value, whereas the opposite was observed for the Hispanic female population. A substantial subset of the Hispanic male population had %Fat values in the 5–20 percent range and BMI values in the 20–25 kg/m\(^2\) range and was displaced below the general curve for %Fat versus BMI. A smaller number of the Black males and a few of the White males were similarly displaced.

The relative percentile rank ordering of an adiposity index, such as BMI or %Fat, is often used to classify a subject as overweight or obese. A comparison of a BMI classification scheme proposed by an expert committee (16) with that based on %Fat for the present population is provided in table 3 for each gender. Of the 487 females and 345 males classified as normal by %Fat, 83 percent of each gender were similarly identified by using BMI, while 12–14 percent were considered at risk and 4 percent were defined as overweight. Of the 57 females and 40 males in the excess %Fat classification, 49 percent of the females and 35 percent of the males also received an at-risk BMI rank ordering; 9 percent and 15 percent, respectively, were still identified as normal; and 42 percent and 50 percent, respectively, were in the overweight BMI groups. Of the 29 females and 21 males in the obese %Fat groups, 90 percent of the females and 71 percent of the males

<p>| TABLE 3. Comparison of body mass index and percentage of body fat rankings for the total population of 979 White, Black, and Hispanic children living in the Houston, Texas, metropolitan area, 1994–1998* |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Females         |                 |                 |                 |                 |                 |</p>
<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>At risk†</th>
<th>Overweight‡</th>
<th>Total</th>
<th>Normal</th>
<th>At risk†</th>
<th>Overweight‡</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>402</td>
<td>67</td>
<td>18</td>
<td>487</td>
<td>288</td>
<td>42</td>
<td>15</td>
<td>345</td>
</tr>
<tr>
<td>Excess§</td>
<td>5</td>
<td>28</td>
<td>24</td>
<td>57</td>
<td>6</td>
<td>14</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Obese‖</td>
<td>0</td>
<td>3</td>
<td>26</td>
<td>29</td>
<td>0</td>
<td>6</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>407</td>
<td>98</td>
<td>68</td>
<td>573</td>
<td>294</td>
<td>62</td>
<td>50</td>
<td>406</td>
</tr>
<tr>
<td>White</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Black</td>
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<tr>
<td>Hispanic</td>
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<tr>
<td>Total</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At risk or overweight (%)#</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True positive</td>
<td>94.4</td>
<td>97.1</td>
<td>91.2</td>
<td>77.3</td>
<td>100.0</td>
<td>61.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False positive</td>
<td>13.1</td>
<td>22.5</td>
<td>21.3</td>
<td>11.6</td>
<td>22.3</td>
<td>18.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missed positive</td>
<td>5.6</td>
<td>2.9</td>
<td>8.8</td>
<td>22.7</td>
<td>0.0</td>
<td>39.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False negative</td>
<td>0.5</td>
<td>0.9</td>
<td>3.9</td>
<td>3.7</td>
<td>0.0</td>
<td>15.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight only (%)**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True positive</td>
<td>100.0</td>
<td>92.0</td>
<td>95.0</td>
<td>90.0</td>
<td>100.0</td>
<td>56.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False positive</td>
<td>1.9</td>
<td>4.6</td>
<td>5.6</td>
<td>1.6</td>
<td>8.4</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missed positive</td>
<td>0.0</td>
<td>8.0</td>
<td>5.0</td>
<td>10.0</td>
<td>0.0</td>
<td>44.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False negative</td>
<td>0.0</td>
<td>1.4</td>
<td>1.0</td>
<td>0.6</td>
<td>0.0</td>
<td>8.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The cutpoints for the percentage of body fat groups were obtained for each gender population, independent of ethnicity, and those for body mass index were based on the expert committee's recommendations (16).
† 85th percentile ≤ BMI < 95th percentile for age and gender.
‡ BMI ≥95th percentile for age and gender.
§ 85th percentile ≤ percentage of fat ranking < 95th percentile for gender.
‖ Percentage of fat ranking ≥95th percentile for gender.
# At-risk and overweight subjects were combined in a single group.
** At-risk subjects were combined with the normal BMI group.
were also judged overweight, while the remaining 10 percent of the females and 29 percent of the males were considered at risk. For the total population, the sensitivity and specificity for the BMI clinical guidelines were 94 percent and 83 percent, respectively, for females and 90 percent and 83 percent, respectively, for males. That is, 6 percent of the females and 10 percent of the males whose %Fat was above the 85th percentile were not identified as being at risk or overweight on the basis of their BMI values, while 17 percent of the females and 17 percent of the males with a normal %Fat were incorrectly classified as at risk or overweight.

The percentages of children in the true-positive, false-positive, missed-positive, and false-negative classifications for each ethnicity and gender are also shown in table 3. The \( \chi^2_{SM} \) values were highly robust for females (Hispanic: 18.9, \( p < 0.001 \); White: 31.0, \( p < 0.0001 \); Black: 35.5, \( p < 0.00001 \) ) and males (Hispanic: 17.0, \( p < 0.001 \); White: 8.6, \( p < 0.02 \); Black: 25.9, \( p < 0.0001 \) ), indicating significant differences in the overall classification schemes. Furthermore, the \( \chi^2_{CO} \) statistics (18.4–34.8, \( p < 0.001–0.0001 \) ) indicated that the BMI scheme also differed from the %Fat method at the two ends of the scale (normal vs. normal, obese vs. overweight) for each ethnic group.

The results of the %Fat ranking scheme based on each ethnic group separately are provided in table 4. That is, the %Fat percentile rank orderings were based on a comparison with a child’s own ethnic peers, not the total population. As our results indicated, the number of subjects in each row or column of the %Fat x BMI classification table remained unchanged; hence, the overall sensitivity and specificity rates also did not change. However, within an ethnic group, the distribution among the three classifications could be expected to change, which is shown by the results of the true-positive, false-positive, missed-positive, and false-negative classifications for each ethnic group. For the female population, the ethnic-specific percentile rank orderings of %Fat resulted in increased \( \chi^2_{SM} \) values for the Black (42.7, \( p < 0.00001 \) ) and Hispanic (38.9, \( p < \)

\[ \begin{array}{|c|c|c|c|}
\hline
\text{Body mass index (BMI)} & \text{Females} & \text{Males} \\
\hline
\text{Normal} & \text{At risk‡} & \text{Overweight§} & \text{Total} \\
\hline
\text{Normal} & 400 & 65 & 22 & 487 & 289 & 40 & 16 & 345 \\
\text{Excess} & 7 & 24 & 26 & 57 & 5 & 17 & 18 & 40 \\
\text{Obese} & 0 & 9 & 20 & 29 & 0 & 5 & 16 & 21 \\
\hline
\text{Total} & 407 & 89 & 68 & 573 & 294 & 62 & 50 & 406 \\
\hline
\text{Percentage of body fat} & \text{White} & \text{Black} & \text{Hispanic} & \text{White} & \text{Black} & \text{Hispanic} \\
\text{True positive} & 82.5 & 100.0 & 100.0 & 80.0 & 100.0 & 100.0 \\
\text{False positive} & 7.4 & 25.5 & 29.4 & 9.7 & 21.5 & 20.4 \\
\text{Missed positive} & 17.5 & 0.0 & 0.0 & 20.0 & 0.0 & 0.0 \\
\text{False negative} & 3.2 & 0.0 & 0.0 & 3.7 & 0.0 & 0.0 \\
\hline
\text{Overweight only} & \text{White} & \text{Black} & \text{Hispanic} & \text{White} & \text{Black} & \text{Hispanic} \\
\text{True positive} & 58.8 & 90.9 & 100.0 & 75.0 & 100.0 & 86.7 \\
\text{False positive} & 1.2 & 6.5 & 8.0 & 0.6 & 8.4 & 6.1 \\
\text{Missed positive} & 41.2 & 9.1 & 0.0 & 25.0 & 0.0 & 13.3 \\
\text{False negative} & 2.7 & 1.4 & 0.0 & 1.9 & 0.0 & 1.8 \\
\hline
\end{array} \]

* The cutpoints for the percentage of body fat groups were obtained for each gender and ethnicity population, while those for body mass index were based on the expert committee's recommendations (18).
† 85th percentile ≤ BMI < 95th percentile for age and gender.
‡ BMI ≥95th percentile for age and gender.
§ 85th percentile ≤ percentage of fat ranking < 95th percentile for gender.
¶ Percentage of fat ranking ≥95th percentile for gender.
# At-risk and overweight subjects were combined in a single group.
** At-risk subjects were combined with the normal BMI group.
0.00001) groups, while the value for the White group (4.6, p > 0.10) decreased dramatically. For the male population, inclusion of ethnicity in the determination of %Fat rank orderings resulted in no substantial changes in the χ²SM and χ²00 values for the Black (22.6, p < 0.00001) or Hispanic (25.8, p < 0.00001) groups, but the value for the White group (4.3, p > 0.10) decreased significantly.

**DISCUSSION**

We found gender and ethnic differences in the %Fat values over the full age range of the study, confirming similar observations reported in other pediatric population studies (24–29). We also found that the relation between %Fat and BMI was gender dependent, which indicates that BMI alone is not an equivalent measure of adiposity for both genders. For a given BMI value, the females consistently had higher fat mass and %Fat values than the males. Furthermore, we observed that within a gender group, the %Fat versus BMI associations also were ethnic dependent. In general, the Black females had lower %Fat values than the White females at a similar BMI, while the Hispanic females usually had a higher %Fat. For the males, the relation between BMI and %Fat was not as well defined as that for females. Many of the males, independent of ethnicity, had high BMI values without evidence of elevated %Fat values.

There is an implicit presumption that subjects with the same BMI value should have similar levels of adiposity. In the present study, we clearly showed that this premise is not true for children, confirming similar observations reported for adults (30–33). On the basis of our observations, we conclude that use of BMI alone is a poor indicator for assessing the true degree of adiposity (%Fat) of an individual child, especially males.

As part of our evaluation of BMI as a classification index, we determined its level of sensitivity and specificity by using BMI cutpoints recommended by an expert committee (16). To ensure that a marker for an individual subject was reliable, one would want to achieve a high sensitivity (true-positive rate) without losing specificity (true-negative rate), while maintaining a low rate of false-positive classifications. In the present study, use of the recommended BMI cutpoints resulted in 28.5 percent of the total pediatric population being labeled as at risk or overweight. Yet, only about half of this group (81 females, 55 males) was identified similarly on the basis of their %Fat rank ordering. Adjusting for ethnic differences in the percentile distribution in the %Fat ranking model did improve the classification for children in the minority groups but reduced the accuracy for the White children.

Many epidemiologic studies use BMI as an anthropometric measure of adiposity within the total population being examined. Our results suggest that age-, gender-, and ethnic-specific BMI rank orderings may provide a general description of the adiposity characteristics for a pediatric population. However, BMI values also are often used to evaluate the individual child in the clinical setting (16). We believe that this application may provide a false classification if BMI alone is used to assess degree of adiposity, because children who have the same BMI can have markedly different %Fat values, as we clearly demonstrated. We recommend that, at a minimum, not only gender and age but also ethnicity must be considered.

The worldwide prevalence of obesity in children continues to increase (1–4). Therefore, it is highly desirable to have some measure of adiposity that will not miss those children with true excess stores of body fat but at the same time will not falsely mislabel a needless number of healthy children as overweight or obese. We conclude that BMI has not adequately achieved this status for use in children.

**ACKNOWLEDGMENTS**

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**REFERENCES**


