ABSTRACT  The objectives of this study were 1) to examine interrelations among intraabdominal adipose tissue (IAAT) and other adiposity indexes; 2) to identify a visceral obesity index that is independent of total adiposity; and 3) to examine sex and ethnic (white compared with African American) differences in IAAT. We measured IAAT and subcutaneous abdominal adipose tissue (SAAT) using computed tomography, and total fat mass (FM) by dual-energy X-ray absorptiometry in a heterogeneous sample of 101 children aged 7.7 ± 1.6 y weighing 33.2 ± 12.6 kg. IAAT was highly variable (x ± SE: 31 ± 22 cm²; range: 7-107 cm²) and related to SAAT (r = 0.87) and FM (r = 0.81). The regression slope between IAAT and SAAT was significantly lower in African Americans (0.23 ± 0.02 cm² IAAT/cm² SAAT) than in whites (0.31 ± 0.02 cm² IAAT/cm² SAAT). Within each ethnic group there was no effect of sex on IAAT adjusted for SAAT (x ± SE: 40.2 ± 3.1 and 43.2 ± 2.7 cm² in white boys and girls, respectively; 26.4 ± 1.9 and 25.1 ± 1.6 cm² in African American boys and girls, respectively). We conclude that in children 1) there is wide variation in visceral fatness; 2) IAAT relative to SAAT is an index of visceral fat, independent of FM, allowing examination of the unique effects of IAAT; and 3) the relative distribution of adipose tissue in the intraabdominal compared with the subcutaneous abdominal region is significantly lower in African Americans than in whites.  

KEY WORDS  Visceral obesity, fat distribution, cardiovascular disease risk factor, ethnicity, African Americans, whites, adipose tissue, dual-energy X-ray absorptiometry, DXA

INTRODUCTION  

In adults, intraabdominal adipose tissue (IAAT), or visceral fat, has been identified as the specific fat depot related to negative health outcomes (1, 2). The relation between IAAT and adverse health, including dyslipidemia and glucose intolerance, has been described in obese children (3-5). IAAT also has been observed in healthy, nonobese children as young as 4-7 y (6) as well as in nonobese adolescents (7, 8). It is unclear whether the amount of visceral fat accumulation seen in children is appropriate for their body size, and whether the observed extremes are related to extremes of general body fatness. For example, some studies suggest that IAAT in children increases in proportion to overall fatness (6), as seen in adults (9), whereas others have shown that children with extremes of body mass index have similar amounts of IAAT (7). Thus, it is important to examine the normal variability in visceral fat accumulation as it occurs relative to other fat depots.

When assessing visceral fat accumulation, and when examining its relation with disease risk, it is important to consider the strong interrelations among IAAT, subcutaneous abdominal adipose tissue (SAAT), and total fat mass (9, 10). To perform comparative studies among subgroups of the population and to examine the unique effects of IAAT on adverse health effects, it is therefore important to identify an index of visceral fat accumulation that is independent of total and subcutaneous fat.

In adults there are sex (9) and ethnic (11) differences in IAAT. Men have greater amounts of IAAT than women, even after differences in total body fat are taken into account (9), and this difference is apparent during adolescence (7). However, it is unknown whether this dimorphism is apparent in prepubertal children. In terms of ethnic differences, anthropometric skinfold studies have suggested a greater central fat distribution in children of African American (12), Mexican American (12), and Native American (13) descent. This suggests that these ethnic groups may have greater visceral fat, placing them at higher risk from the negative health effects of obesity. However, it is not known whether there is greater visceral fat in these subgroups of the population. In 18 obese adults, African American women had less IAAT than white women who were matched for age, weight, and total body fat (105 ± 25 compared with 160 ± 70 cm²) (11). Additional studies using more sophisticated imaging techniques are needed in children to examine whether ethnic differences in visceral fat accumulation occur early in life.

Thus, our objectives were to examine the following in a heterogenous group of prepubertal children: 1) the interrela-
tions between IAAT and other adiposity indexes to identify a visceral obesity index that is independent of total adiposity; and 2) sex and ethnic (white compared with African American subjects) differences in IAAT.

SUBJECTS AND METHODS

Subjects

Children were recruited by newspaper and radio advertisements and by word of mouth. Subjects were screened by taking their medical history and were ineligible if they were 1) < 4 y of age; 2) beyond Tanner stage I, as assessed by physical examination by a pediatrician; Tanner stage I was defined based on breast stage and pubic hair development in girls and genitalia development in boys; 3) taking medications known to affect body composition or physical activity (eg, prednisone, ritalin, or growth hormone); 4) previously diagnosed with syndromes known to affect body composition or fat distribution (eg, Cushing syndrome, Down syndrome, insulin-dependent diabetes, or hypothyroidism) or, 5) diagnosed previously with any major illness. Because the intent was to recruit a heterogeneous group of children, there were no criteria for other characteristics such as obesity. This study was approved by the Institutional Review Board at the University of Alabama at Birmingham, and parents provided informed consent before testing began.

Protocol

Children were admitted to the General Clinical Research Center (GCRC) in the late afternoon for an overnight visit. On arrival, anthropometric measurements were obtained and dinner was served at ~1700. An evening snack was allowed but only water and energy-free, noncaffeinated beverages were permitted after 2000 until after the morning testing. Between 1850 and 1950 a single-slice computerized tomography (CT) scan was taken at the level of the umbilicus. The following morning blood was drawn while subjects were in a fasted state for measurement of lipids, hormones, and other metabolic factors (data not reported). Two weeks later, the children arrived at the Energy Metabolism Research Unit at 0700 while in a fasted state and body composition was determined by dual-energy X-ray absorptiometry (DXA).

Measurement of abdominal adipose tissue distribution

SAAT and IAAT were measured by CT as described previously (6). A single-slice CT scan of the abdomen was performed at the level of the umbilicus and analyzed for cross-sectional area of adipose tissue. Adipose tissue area was measured by using the density contour program of the scanner software as described previously (6). All scans were analyzed by the same investigator (TRN) and data are expressed in cm² of tissue. The test-retest reliability for IAAT was 1.7% when five scans in children were reanalyzed by the same investigator (6).

Measurement of body composition by DXA and anthropometry

Total and regional body composition were measured by DXA with a Lunar DPX-L densitometer (Lunar Corp, Madison, WI) that we validated previously in the pediatric body weight range (14, 15). Subjects were scanned while wearing light clothing and lying flat on their backs with arms by their sides. DXA scans were performed and analyzed by using pediatric software (version 1.5e; Lunar Corp) as described previously (14, 15). The DPX-L densitometer was calibrated on the day of each test according to procedures provided by the manufacturer. Height was measured with a stadiometer in subjects without shoes and weight with an electronic scale with subjects wearing minimal clothing.

Statistical analysis

Differences in physical characteristics, body composition, and fat distribution among African American and white boys and girls were examined in a two-way (sex and ethnic group) analysis of variance. The interrelations among IAAT, SAAT, and total fat were examined by using correlations and partial correlations. The nature of the relation between IAAT and SAAT among white and African American boys and girls was examined by using a two-way analysis of covariance, with IAAT as the dependent variable, SAAT as the covariate, and sex and ethnic group as the main-effects variables. Similarity of regression slopes among the subgroups was examined by the significance of the interaction between the covariate and each of the two grouping variables. Data were analyzed by using SAS software version 6.10 (SAS Institute Inc, Cary, NC), with significance set at P < 0.05 for all tests.

RESULTS

Physical characteristics are described in Table 1. On average, African American children were younger by ~1 y and girls were heavier than boys because of a greater fat mass in limbs and trunk. Percentage body fat was significantly higher in girls than in boys, but was similar in the two ethnic groups (24.0 ± 12.0% and 23.3 ± 10.6% in white and African American boys, respectively; 33.3 ± 8.1% and 32.7 ± 10.6% in white and African American girls, respectively). The four subgroups were similar in terms of height and soft lean tissue mass. Absolute SAAT was higher in girls and tended to be higher in white than in African American children (P = 0.05). Absolute IAAT was higher in girls and in whites than in African American children; the ethnic effect was more pronounced in girls. The distribution of IAAT in these children is shown in Figure 1. The distribution was skewed to the right. The distribution of IAAT was unrelated to the distribution of percentage body fat. IAAT was strongly correlated with SAAT (r = 0.87, P < 0.001) and total fat mass (r = 0.81, P < 0.001), and SAAT and total fat mass were also highly correlated (r = 0.93, P < 0.001), as shown in Table 2. The relation between IAAT and SAAT persisted, though at a diminished level, after the effects of total fat mass were removed (r = 0.53, P < 0.001), whereas there was no significant relation between IAAT and total fat mass after the effects of SAAT were removed. Thus, the residual of IAAT from its relation with SAAT was independent of total body fat mass.

The relation between IAAT and SAAT is shown in Figure 2. The regression slope for IAAT versus SAAT was significantly influenced by ethnicity (Figure 2 and Table 3), with a significantly lower regression slope in African American than in white children (0.17 ± 0.02 cm² IAAT/cm² SAAT and 0.23 ±
TABLE 1
Physical characteristics, body composition, and body fat distribution

<table>
<thead>
<tr>
<th></th>
<th>Combined (n = 101)</th>
<th>White Boys (n = 16)</th>
<th>Girls (n = 20)</th>
<th>African American Boys (n = 27)</th>
<th>Girls (n = 38)</th>
<th>Significant effects by two-way ANOVA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>7.7 ± 1.6</td>
<td>8.2 ± 1.6</td>
<td>8.2 ± 1.2</td>
<td>7.3 ± 1.6</td>
<td>7.4 ± 1.8</td>
<td>Ethnicity</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>5.0-10.0</td>
<td></td>
<td></td>
<td>4.2-10.0</td>
<td></td>
<td>Sex</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>129 ± 12</td>
<td>130 ± 10</td>
<td>132 ± 12</td>
<td>128 ± 16</td>
<td>128 ± 14</td>
<td>NS</td>
</tr>
<tr>
<td>Soft lean mass (kg)</td>
<td>21.2 ± 5.5</td>
<td>20.5 ± 3.8</td>
<td>23.5 ± 5.0</td>
<td>20.2 ± 4.2</td>
<td>21.0 ± 6.9</td>
<td>NS</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>10.8 ± 7.6</td>
<td>7.0 ± 4.3</td>
<td>15.0 ± 7.8</td>
<td>7.8 ± 6.9</td>
<td>12.2 ± 7.6</td>
<td>Sex</td>
</tr>
<tr>
<td>Limb fat mass (kg)</td>
<td>5.6 ± 4.0</td>
<td>3.5 ± 2.0</td>
<td>7.1 ± 3.6</td>
<td>4.2 ± 3.7</td>
<td>6.7 ± 4.3</td>
<td>Sex</td>
</tr>
<tr>
<td>Trunk fat mass (kg)</td>
<td>4.1 ± 3.4</td>
<td>2.6 ± 2.1</td>
<td>6.7 ± 3.9</td>
<td>2.6 ± 2.7</td>
<td>4.4 ± 3.1</td>
<td>Sex</td>
</tr>
<tr>
<td>SAAT (cm²)</td>
<td>100 ± 93</td>
<td>65 ± 67</td>
<td>172 ± 102</td>
<td>61 ± 86</td>
<td>106 ± 82</td>
<td>Sex and ethnicity3</td>
</tr>
<tr>
<td>IAAT (cm²)</td>
<td>31 ± 22</td>
<td>27 ± 16</td>
<td>54 ± 27</td>
<td>22 ± 17</td>
<td>28 ± 17</td>
<td>Sex × ethnicity4</td>
</tr>
</tbody>
</table>

1 ± SD; range in parentheses. SAAT, subcutaneous abdominal adipose tissue; IAAT, intraabdominal adipose tissue.
2 P < 0.05, except where otherwise noted.
3 P = 0.05 for ethnicity.
4 Significant interaction between sex and ethnicity.

DISCUSSION

The purpose of this study was to examine the pattern of abdominal fat accumulation in a heterogenous sample of children. Our analysis revealed that the degree to which visceral fat accumulation occurs is highly variable. IAAT, SAAT, and total

FIGURE 1. Distribution of intraabdominal adipose tissue (IAAT). Top: the amount of IAAT for each of the 101 subjects, arranged in increasing order. Empty bars represent white children; filled bars represent African American children. Note the extreme and skewed variability in IAAT among these children. Bottom: the percentage body fat for the corresponding child from the top panel. The inset on the upper panel shows the lack of relation between IAAT and percentage body fat.
TABLE 2
Correlations and partial correlations among intraabdominal adipose tissue (IAAT), subcutaneous abdominal adipose tissue (SAAT) and total body fat

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAAT versus SAAT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.87</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Partial correlation, adjusted for total fat</td>
<td>0.53</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IAAT versus total fat mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.81</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Partial correlation, adjusted for SAAT</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>SAAT versus total fat mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.93</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Partial correlation, adjusted for IAAT</td>
<td>0.80</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

'TAAT and SAAT determined by computerized tomography at the umbilicus level.

value should be derived by using separate regressions in each subgroup.

A valid index of visceral obesity is an important prerequisite for examining its relation with disease risk. For example, in previous studies in children (3, 5), IAAT was related to fasting triacylglycerol concentrations (r = 0.3-0.4). However, it is also likely that SAAT and total body fat would be related to triacylglycerol concentrations and it is difficult to conclude which compartment of body fat is specifically related to triacylglycerol concentration. Thus, future studies examining the effects of IAAT on disease risk should consider the colinearity that exists among the different fat depots.

In previous studies reporting IAAT in children, the absolute amount of IAAT is generally lower than in adults, suggesting that IAAT is of little significance in children. However, other studies have shown that IAAT in obese children is related to disease risk factors (3, 5). Also, it is difficult to interpret the smaller magnitude of IAAT in children because of scaling problems (eg, it would be inappropriate to conclude that a 40-kg child is underweight because their reference weight is lower than that in adults). Obviously, children are going to have less IAAT than adults because they are smaller. Fox et al (7) found that differences in adiposity in obese children are predominately found subcutaneously. Our study challenges this view because we found significant relations between IAAT and SAAT (r = 0.87, P < 0.001) as well as between IAAT and total body fat (r = 0.83, P < 0.001).

The finding of a lower amount of visceral fat in African American than in white children is consistent with previous findings in obese adult women (11). Our findings support those of this previous study by showing that the lower visceral fat accumulation in African Americans occurred early in life, occurred across the spectrum of fatness, and was similar between the sexes (Figure 3). In addition, our findings suggest that the ethnic difference in visceral fat was due to a differential partitioning of adipose tissue within the abdominal region.

FIGURE 2. Relation between intraabdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) in white (O, dotted line) and African American (●, solid line) children. The lines represent best-fit linear regressions (IAAT = 0.23 x SAAT + 13 cm² in white children; IAAT = 0.17 x SAAT + 11 cm² in African American children). The rate of increase in IAAT relative to SAAT was significantly lower in African American than in white children.
TABLE 3
Regression of intraabdominal adipose tissue versus subcutaneous abdominal adipose tissue by ethnic and sex groups

<table>
<thead>
<tr>
<th></th>
<th>Combined</th>
<th>White</th>
<th>African American</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 101)</td>
<td>(n = 27)</td>
<td>(n = 38)</td>
</tr>
<tr>
<td>Intercept (cm²)</td>
<td>11 ± 1.6</td>
<td>12 ± 2</td>
<td>10 ± 3</td>
</tr>
<tr>
<td>Slope (cm²/cm²)</td>
<td>0.21 ± 0.01</td>
<td>0.17 ± 0.02</td>
<td>0.18 ± 0.02</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.75</td>
<td>0.71</td>
<td>0.68</td>
</tr>
</tbody>
</table>

\(^1\) All regressions in the subgroups were significant at \(P < 0.05\).

Although our data are cross-sectional, they imply that the rate of accumulation of IAAT relative to SAAT is 26% lower in African American than in white children. Dowling and Pinsky (17) originally hypothesized that a lower visceral fat accumulation might explain why African American women appears to be protected from obesity-related diseases. Further studies are warranted to examine whether ethnicity influences the strength or magnitude of the relation between IAAT and disease risk factors.

There are many factors other than ethnicity that could explain differences in visceral fat accumulation between African American and white children. The lower IAAT in African American children could be explained by the 1-y age difference between groups. However, this is unlikely because when IAAT was adjusted for SAAT, there was no significant relation with age. In adults, physical inactivity is associated with elevated IAAT (1, 18, 19), and IAAT can be selectively reduced after exercise (20, 21). Thus, it could be hypothesized that an increased level of physical activity in African American children might explain their lower IAAT. However, this seems unlikely given that the African American children also had a lower peak oxygen consumption (22), which may indicate reduced fitness, habitual aerobic physical activity, or both. Thus, differences in physical activity are not likely to explain the lower IAAT in African American children. Several sex hormones are known to affect regional fat deposition (23) and this could explain the ethnic differences. It is also possible that the single-slice CT scan at the umbilicus did not equally represent abdominal fat distribution in both ethnic groups. As discussed previously by Conway et al (11), the umbilicus is traditionally used as a physical landmark for assessment of abdominal fat distribution, although it is not always coincident with that in the L4-L5 region, and ethnic differences in visceral fat were actually more pronounced at the L2-L3 region. Thus, multiple-slice scanning may be necessary to fully examine differences in fat distribution within the abdomen. Finally, the extent of visceral fat accumulation is also likely to be explained by genetic factors. A recent study on twins estimated that genetic influences explained 70% of the population variance in total central abdominal fat as measured by regional DXA (24).

It is important to note that well-validated and accurate measurement techniques and appropriate data normalization are essential to show ethnic differences in visceral fat accumulation. On the basis of the waist-to-hip ratio, there was no significant effect of sex or ethnicity on IAAT in this sample of children (0.88 ± 0.05 and 0.87 ± 0.05 in white and African American boys, respectively; 0.87 ± 0.04 and 0.87 ± 0.05 in white and African American girls, respectively). In a previous study we showed that the waist-to-hip ratio was not correlated with IAAT in children (6).

In summary, prepubertal children exhibit extreme variation in the accumulation of IAAT and the degree of visceral obesity. IAAT, SAAT, and total body fat were strongly interrelated, making it necessary to develop an index of IAAT that was independent of other obesity indexes. When IAAT was controlled for SAAT, there was no significant partial correlation of IAAT with total body fat. Thus, the excess accumulation of abdominal fat in the intraabdominal relative to the subcutaneous region was independent of total body fatness. Therefore, we propose that the residual from a regression between IAAT and SAAT could be viewed as an index of visceral fat that is independent of total body fatness. Our data also suggest that ethnicity influences differential partitioning of adipose tissue within the abdominal region, with African Americans depositing less IAAT per unit SAAT than whites. Thus, African American children could be protected from the relative deposition of fat in the intraabdominal region.

We thank Tena Hilario and Betty Darnell for their enthusiastic work on this project. We are also grateful to the children and families who committed their time to this study.
REFERENCES