



# Prediction of intra-abdominal and subcutaneous abdominal adipose tissue in healthy pre-pubertal children

MI Goran, BA Gower, M Treuth and TR Nagy

*Division of Physiology and Metabolism, Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, AL, USA*

**OBJECTIVE:** To examine the relationship of intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) with body composition and anthropometry in children.

**DESIGN:** Cross-sectional data analysis.

**SUBJECTS:** 113 healthy Caucasian and African-American, pre-pubertal children aged 4–10 y.

**MEASUREMENTS:** IAAT and SAAT by single slice computed tomography at the level of the umbilicus; total fat and trunk fat by dual energy X-ray absorptiometry (DEXA); anthropometric evaluation by skinfolds and circumferences.

**RESULTS:** IAAT was most strongly correlated with abdominal skinfold ( $r = 0.88$ ) and trunk fat by DEXA ( $r = 0.87$ ), and SAAT with trunk fat by DEXA ( $r = 0.96$ ), total fat by DEXA ( $r = 0.93$ ) and waist circumference ( $r = 0.93$ ). In stepwise regression, IAAT was best predicted by trunk fat from DEXA, total fat from DEXA, and abdominal skinfold ( $R^2 = 0.85$ ); SAAT was best predicted by trunk fat from DEXA, body weight, waist circumference and abdominal skinfold ( $R^2 = 0.96$ ). In the absence of DEXA data, IAAT was best predicted by abdominal skinfold, ethnicity and subscapular skinfold ( $R^2 = 0.82$ ) and SAAT was best predicted by waist circumference subscapular skinfold, height and abdominal skinfold ( $R^2 = 0.92$ ). The prediction equations with and without DEXA were successfully cross-validated in an independent sample of 12 additional measures of IAAT and SAAT.

**CONCLUSION:** These data provide useful information that can help in the interpretation of anthropometric data with regard to body fat distribution. IAAT and SAAT can be accurately estimated in Caucasian and African-American prepubertal children from anthropometry with and without the availability of DEXA data.

**Keywords:** fat distribution; obesity; anthropometry; visceral fat; cardiovascular disease risk

## Introduction

Previous studies have demonstrated the existence of visceral fat in children and adolescents.<sup>1–4</sup> We have previously shown a lack of concordance between visceral fat and general adiposity in children.<sup>4</sup> Thus, visceral obesity cannot necessarily be inferred from increased body fatness. Other studies, including epidemiological investigation,<sup>5,6</sup> have shown that body fat distribution and/or visceral fat is significantly related to disease risk factors in children and adolescents.<sup>7–9</sup> Despite a growing emphasis on the study of visceral fat, it remains unclear which aspect of body fat and/or fat distribution is specifically related to increased disease risk. If visceral fat is involved, it is currently not clear whether its relationship with disease risk is due to a specific effect of intra-abdominal adipose tissue (IAAT) or its co-linearity with total fat and/or subcutaneous abdominal adipose tissue (SAAT). Large scale epidemiological studies may be needed to fully address these questions and the design and interpretation of such studies will

be dependent on an understanding of the relationship between anthropometric measures and body fat distribution. Thus, there is a growing need for understanding the relationship between conventional anthropometric measures and visceral fat content, and for screening body fat distribution, as well as total body fat, during childhood development, for long term preventive measures.

Traditionally, body fat distribution has been predicted in children by anthropometric techniques. Recently, *in vivo* imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) have enabled more accurate measures of IAAT and SAAT in children and adolescents.<sup>1–3</sup> However, the use of imaging techniques is limited, due to factors such as cost, availability and radiation exposure (for CT). Thus, there is a need to develop alternative approaches for estimating visceral fat.

A number of investigators, including ourselves, have developed equations for estimating IAAT in adults using anthropometry and dual energy X-ray absorptiometry (DEXA) based measures of body composition.<sup>10–13</sup> The rationale for developing these prediction equations is to enable simple, accurate and inexpensive estimates of IAAT. Although there are now some data in the literature on the relationship between anthropometry and IAAT in adults, there are limited data in children. In adolescent girls, there are

Correspondence: Michael I Goran, PhD, Division of Physiology and Metabolism, Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, Alabama 35294, USA.  
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no significant correlations among waist circumference, waist-to-hip ratio (WHR) or trunk-to-extremity skinfold ratio and IAAT area as measured by MRI.<sup>3</sup> Similarly, in 11-year-old boys and girls, WHR is not significantly correlated with IAAT.<sup>2</sup> In these studies in adolescents, anthropometric indices explain only 25–50% of the variation in IAAT.<sup>2,3</sup> In young, pre-pubertal children,<sup>1</sup> WHR is not significantly correlated with IAAT, whereas individual trunk skinfolds and the ratio of trunk skinfolds to extremity skinfolds explains 62% of the variation in IAAT. These data confirm that circumferences may not be good indices of IAAT in children or adolescents and that anthropometric data are likely to provide prediction equations of limited accuracy.

DEXA provides the ability to measure total abdominal fat but cannot resolve SAAT from IAAT. Thus, the combination of total abdominal fat by DEXA and skinfold data (as an index of SAAT) should offer an alternative measure of IAAT. Svendsen *et al*<sup>12</sup> developed (but did not validate) such a model in a small group of postmenopausal women ( $n = 25$ ) using CT as a criteria method. Total abdominal fat by DEXA, WHR, and the sum of trunk skinfolds explained 91% of the variation in IAAT, as measured by CT scanning. In a larger group of 206 pre- and postmenopausal women, we have previously shown that sagittal diameter, age, waist circumference and percent of fat in the trunk by DEXA explained 81% of the variation in IAAT, as measured by CT scanning.<sup>13</sup> We are unaware of any study that has used a large data set to develop and cross-validate equations for predicting IAAT from anthropometry and/or DEXA in children.

Thus, the objectives of this study were: 1) to examine the relationship of IAAT and SAAT with body composition measures and anthropometric variables in healthy Caucasian and African-American pre-pubertal children; and 2) to derive and cross-validate prediction equations for estimating IAAT and SAAT with and without the availability of DEXA data in healthy Caucasian and African-American pre-pubertal children.

## Methods

### Subjects

The data included observations from 101 pre-pubertal children (16 Caucasian boys, 20 Caucasian girls, 27 African-American boys and 38 African-American girls) used for the purposes of developing the prediction equations and an additional 12 observations used for the purposes of cross-validation. We have previously reported data on the 101 children in the group used to develop the prediction equations in a previous report examining gender and ethnic differences in abdominal fat distribution.<sup>4</sup>

All children were recruited by newspaper and radio advertisements, and by word of mouth. Subjects were screened by a medical history evaluation and were ineligible if they were taking medications known to affect body composition or physical activity (for example, prednisone, ritalin, growth hormone) or had been diagnosed with syndromes known to affect body composition and/or fat distribution (for example, Cushing's Syndrome, Down's Syndrome, Type I diabetes, hypothyroidism) or any major illness since birth. Data from children beyond Tanner stage I were excluded from this analysis. Tanner stage I was defined based on breast stage and pubic hair development in girls and genitalia development in boys, as assessed during a physical examination by a pediatrician. Since the intent was to recruit a heterogeneous group of children, there were no set criteria for other characteristics such as obesity status. This study was approved by the Institutional Review Board at the University of Alabama at Birmingham. The parents of all participants provided informed consent before testing commenced.

### Protocol

Children were admitted to the General Clinical Research Center (GCRC) in the late afternoon for an overnight visit. Upon arrival, anthropometric measurements were obtained and dinner was served at approximately 17.00 h. An evening snack was allowed as long as it was consumed before 20.00 h. After 20.00 h only water and non-caloric, non-caffeine beverages were allowed until after the morning testing. Between 18.50 and 19.50 h a single-slice CT scan was taken at the level of the umbilicus. The following morning, resting energy expenditure (REE) was measured and blood was collected for hormone and lipid analyses, and an oral glucose tolerance test was administered (data not reported in this paper). After the preceding tests were completed, the children were fed breakfast and allowed to leave. Two weeks later, the children arrived at the Energy Metabolism Research Unit at 07.00 h in the fasted state and body composition was determined by DEXA.

### Measurement of abdominal adipose tissue distribution

SAAT and IAAT were measured by CT using a GE Hi Speed scanner (General Electric Medical Systems, Waukesha, WI) running on 120 kVp, variable mA, 1.0 s scan time and 5 mm slice thickness. The radiation dose from this procedure is approximately 0.26 rads. A single slice CT scan of the abdomen was performed at the level of the umbilicus and analysed for cross-sectional area of adipose tissue. Adipose tissue area was measured in cm<sup>2</sup> using the density contour program of the scanner software assuming a density of  $-30$  to  $-190$  Hounsfield Units for adipose tissue. These Hounsfield Units were verified in pilot studies according to the procedures of Kvist *et al*.<sup>14</sup> All scans were analysed by the

same investigator (TRN). The test re-test reliability for IAAT was 1.7% when five scans of children were re-analysed by the same investigator.<sup>1</sup>

#### Measurement of body composition by DEXA

Total body and regional body composition were measured by DEXA using a Lunar DPX-L densitometer (Madison, WI) that we have previously validated in the pediatric body weight range.<sup>15,16</sup> The radiation exposure from this procedure is negligible and is estimated to be 0.06 mR (data from Lunar Corporation). Subjects were scanned in light clothing, while lying flat on their backs with arms by the side. DEXA scans were performed and analysed using pediatric software (version 1.5e). DEXA scan analysis provided estimates of the following parameters: fat mass, bone mineral mass and soft lean tissue mass (that is, body mass minus fat and bone mass). These parameters were recorded for the whole body, arms, legs and trunk. Trunk fat includes the thoracic and abdominal areas. The test re-test reliability for total fat and trunk fat by DEXA was 0% and 1.7% respectively, when 10 scans in children were re-analysed by the same investigator. When 30 girls were scanned by DEXA under identical conditions 6 weeks apart the CV for repeated measures was 6.5% for fat mass and 2.3% for soft lean tissue mass (Figuroa-Colon *et al*, under review).

#### Measurement of height, weight and anthropometry

Height was measured without shoes using a stadiometer and weight was measured in a hospital gown using an electronic scale. In addition, anthropometric variables (axilla, chest, subscapular, superiliac, abdomen, triceps, calf and thigh skinfold, and waist and hip circumferences) were determined by the dietician at the GCRC using the procedure of Lohman *et al*.<sup>17</sup> For skinfolds and circumferences, when five children were reassessed the next day by the same person, the observer reliability was 1–11% depending on the measure (for the key variables in the current study the reliabilities were 1.5% for triceps, 9.6% for subscapular, 11.0% for abdominal skinfold and 1.1% for waist circumference). Weight-for-height percentile was calculated relative to the growth standards of the National Center for Health Statistics (NCHS)<sup>18</sup> using EpiInfo, version 6.

#### Statistics

Pearson correlation coefficients and multiple regression procedures were used to examine the relationship between IAAT and SAAT by CT scanning and total and regional fat mass by DEXA and other anthropometric measures. The procedures of Lohman *et al*<sup>17</sup> were followed for the development and cross-validation of a new equation for estimating abdominal fat compartments. Forward regression analysis was used to derive the predictors of abdominal fat compart-

ments, as measured by CT scanning in the development group ( $n = 101$ ). The independent variables considered in the model were: trunk fat, total fat and total soft lean tissue mass by DEXA; eight skinfolds; body weight and height; body mass index (BMI); waist and hip circumferences; gender; ethnicity; and age. Models were developed with and without DEXA data as predictor variables. Other regression models were examined (for example, stepwise, backward, all possible subsets), but did not yield models with a higher  $R^2$ . The regression equations were then tested for accuracy in the cross-validation group ( $n = 12$ ) by examining the regression between predicted fat area and actual measured fat area. Prediction equations were considered accurate if the regression between measured and predicted fat area was not significantly different from the line of identity (that is, slope = 1, intercept = 0). Bland-Altman plots<sup>19</sup> were used to assess bias by examining the difference between measured and predicted IAAT and SAAT, plotted as a function of the 'real' measured value for the 12 subjects in the cross-validation.

Although we have previously shown differences in abdominal fat distribution between Caucasian and African-American children,<sup>4</sup> we did not develop separate regression equations for the following reasons: 1) we do not see any advantage with this approach because when analysed by ethnic or gender subgroups, the predictive power of the regression equations was not as strong as the combined analysis; and 2) the use of one regression equation for both ethnic groups and genders is preferred for ease of practical implementation.

All statistics were computed using SAS for windows version 6.08 (Carey, North Carolina). The level of statistical significance was set at a probability of  $P \leq 0.05$  for all tests. Data are cited as mean  $\pm$  standard deviation, unless otherwise stated.

## Results

#### Group characteristics

The group of 101 children used to develop the prediction equation included 16 Caucasian boys, 20 Caucasian girls, 27 African-American boys and 38 African-American girls, with physical characteristics as summarized in Table 1. The cohort was a mixture of obese and non-obese children. The mean weight-for-height percentile was  $76.1 \pm 28.9$  relative to NCHS growth standards. Four subjects were below the 10th percentile for weight-for-height, 46 children had a 'normal body weight' defined as a weight-for-height between the 10th and 90th percentile, and 51 subjects were obese as defined by a weight-for-height above the 90th percentile. Simple correlations between IAAT and SAAT and other measures of body composition and anthropometry are listed in

Table 2. IAAT was most strongly correlated with abdominal skinfold ( $r = 0.88$ ) and trunk fat by DEXA ( $r = 0.87$ ) as shown in Figure 1. There was no interaction of sex and/or ethnicity for the relationships between IAAT and abdominal skinfold ( $P = 0.12-0.14$ ) or between IAAT and trunk fat ( $P = 0.23-0.31$ ). SAAT was most strongly correlated with trunk fat by DEXA ( $r = 0.96$ ), total fat by DEXA ( $r = 0.93$ ) and waist circumference ( $r = 0.93$ ) as shown in Figure 2, although the correlation with waist was not apparent below a waist measurement of 60 cm. There was no interaction of sex and/or ethnicity for the relationships between SAAT and the waist circumference ( $P = 0.05-0.98$ ); however, for the relationship between SAAT and trunk fat there was a significant interaction with gender ( $P < 0.005$ ) but not ethnicity ( $P = 0.85$ ). As shown in Table 2, frequently used ratios such as the trunk-to-extremity skinfold ratio and the WHR were not highly correlated with IAAT or SAAT ( $r = 0.3-0.5$ ).

#### Development of prediction equations

The results of forward regression analysis for IAAT and SAAT in the presence of DEXA data among potential independent variables are shown in Table 3. For IAAT, 78% of the variance was explained by trunk fat from DEXA, and inclusion of total fat mass and abdominal skinfold thickness explained an additional 4% and 3%, respectively, of the unique variance in IAAT (total model  $R^2 = 0.85$ ; see Table 3). For SAAT, 94% of the variance was explained by trunk fat from DEXA; body weight, waist circumference and abdominal skinfold explained an additional 2% of the variance (total model  $R^2 = 0.96$ ; see Table 3).

We also performed a regression analysis in the absence of DEXA data to derive a simple clinical prediction equation for IAAT and SAAT. The simple Pearson  $r$  correlation coefficients between IAAT and SAAT and anthropometric indices are shown in Table 4. The strongest correlates of IAAT were abdominal skinfold thickness ( $r = 0.88$ ), subscapular skinfold ( $r = 0.85$ ), suprailiac skinfold ( $r = 0.85$ ) and waist circumference ( $r = 0.84$ ); the strongest correlates of SAAT were waist circumference ( $r = 0.93$ ), and skinfolds at the triceps ( $r = 0.92$ ), abdomen ( $r = 0.91$ ), suprailiac ( $r = 0.91$ ) and axilla ( $r = 0.84$ ). There were much lower correlations between IAAT and SAAT and the traditional indices of central fat distribution such as the trunk-to-extremity skinfold ratio ( $r = 0.49$  for IAAT;  $r = 0.5$  for SAAT) and the WHR ( $r = 0.32$  for IAAT;  $r = 0.4$  for SAAT). In forward multiple regression analysis, abdominal skinfold, ethnicity and subscapular skinfold explained 82% of the variance in IAAT (Table 4); waist circumference, subscapular skinfold, height, and abdominal skinfold explained 92% of the variance in SAAT (Table 4).

#### Cross-validation of equations

The prediction equations developed from the initial sample were cross-validated in an independent sample of 12 new children including eight Caucasian boys, one Caucasian girl and three African-American boys. The physical characteristics, body composition and fat distribution of this group were not significantly different to those of the group used to develop the equations, as shown in Table 1. The accuracy and precision of the prediction equations were tested by examining the regression between measured and

**Table 1** Physical characteristics, body composition and body fat distribution for the children in the development ( $n = 101$ ) and cross-validation ( $n = 12$ ) groups. There are no significant differences by  $t$ -test between the development group and the cross-validation group

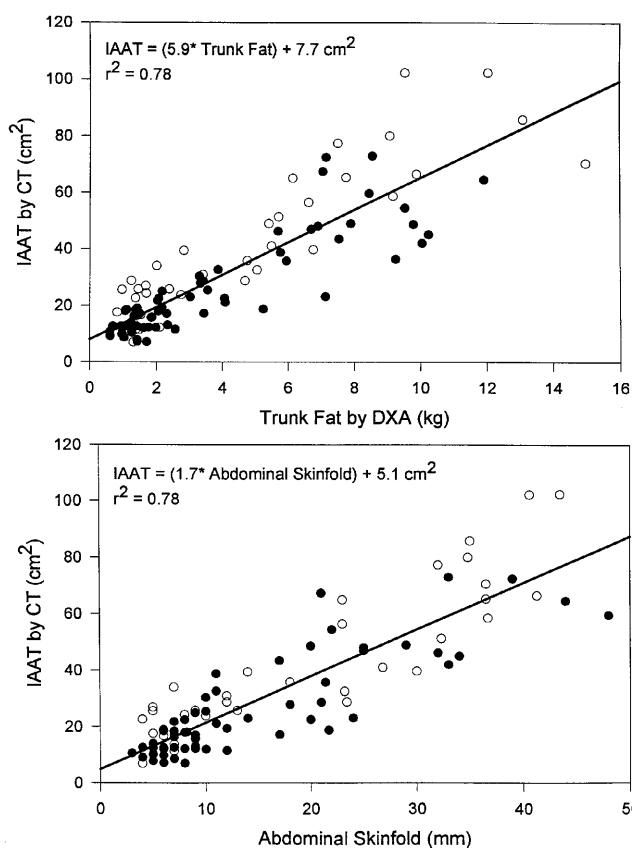
	Development group Mean $\pm$ s.d. (range)	Cross-Validation Group Mean $\pm$ s.d. (range)
Age (y)	7.7 $\pm$ 1.6 (4.2 - 10.0)	8.1 $\pm$ 1.4 (5.6 - 10.4)
Weight (kg)	33.3 $\pm$ 12.6 (14.1 - 70.8)	38.4 $\pm$ 15.4 (25.0 - 68.4)
Height (m)	1.29 $\pm$ 12 (1.02 - 1.58)	1.31 $\pm$ 0.1 (1.15 - 1.53)
BMI (kg/m <sup>2</sup> )	19.6 $\pm$ 5.2 (11.8 - 39.2)	21.7 $\pm$ 6.0 (16.0 - 35.7)
Waist (cm)	64 $\pm$ 12 (44 - 95)	70 $\pm$ 16 (55 - 102)
Abdominal skinfold	16 $\pm$ 12 (3 - 48)	23 $\pm$ 19 (5 - 62)
Subscapular skinfold	12 $\pm$ 10 (4 - 40)	17 $\pm$ 15 (5 - 45)
Fat Mass (kg)	10.8 $\pm$ 7.6 (2.1 - 32.6)	13.3 $\pm$ 9.7 (3.1 - 31.7)
Trunk fat mass (kg)	4.1 $\pm$ 3.3 (0.6 - 15.0)	5.4 $\pm$ 4.6 (10.9 - 14.9)
SAAT (cm <sup>2</sup> )	100 $\pm$ 93 (8 - 372)	150 $\pm$ 139 (31 - 463)
IAAT (cm <sup>2</sup> )	31 $\pm$ 22 (7 - 102)	45 $\pm$ 33 (11 - 114)

BMI = body mass index; SAAT = subcutaneous abdominal adipose tissue; IAAT = intra-abdominal adipose tissue.

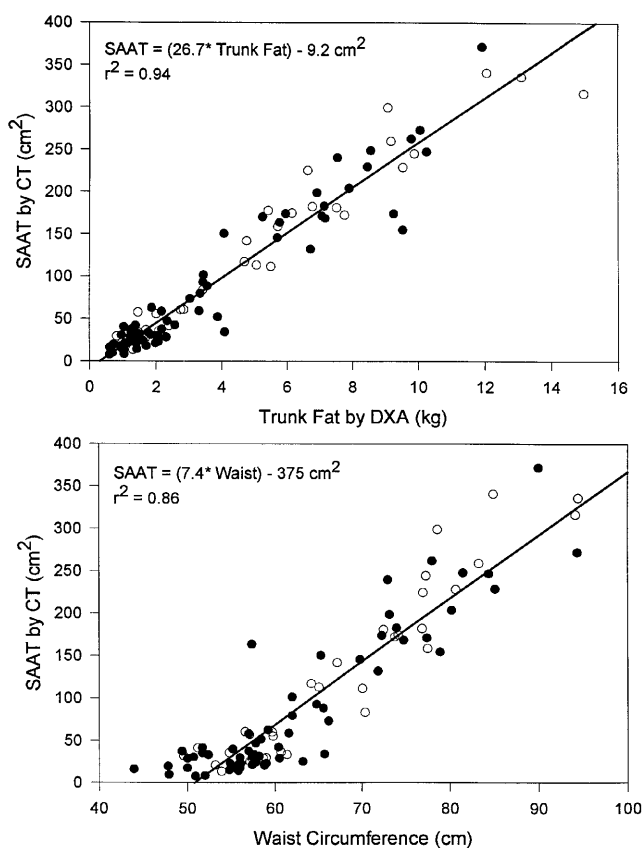
**Table 2** Correlations of intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) with body composition by dual energy X-ray absorptiometry (DEXA) and simple anthropometric variables

	Correlation with IAAT	Correlation with SAAT
Abdominal skinfold	0.88	0.91
Trunk fat by DEXA	0.87	0.96
Subscapular skinfold	0.85	0.89
Suprailiac skinfold	0.85	0.91
Total fat by DEXA	0.84	0.93
Waist circumference	0.84	0.93
Hip circumference	0.81	0.88
Body mass index	0.81	0.88
Triceps skinfold	0.8	0.92
Calf skinfold	0.79	0.88
Axilla skinfold	0.77	0.91
Weight	0.77	0.86
Thigh skinfold	0.76	0.86
Sagittal diameter	0.74	0.86
Chest skinfold	0.66	0.69
Trunk-to-extremity skinfold ratio	0.49	0.5
Height	0.4	0.45
Age	0.34	0.32
Waist-to-hip ratio	0.32	0.4

All correlations significant at the  $P < 0.05$  level.



**Figure 1** Correlations between intra-abdominal adipose tissue (IAAT) and trunk fat by dual energy X-ray absorptiometry (DEXA) and abdominal skinfold. IAAT is intra-abdominal adipose tissue measured with computed tomography (CT) scanning, plotted as a function of trunk fat mass by DEXA (top panel) or abdominal skinfold thickness (lower panel). Lines shown are the regression lines. Open circles are Caucasian children, filled circles are African-American children.



**Figure 2** Correlations between subcutaneous abdominal adipose tissue (SAAT) and trunk fat by dual energy X-ray absorptiometry (DEXA) and waist circumference. SAAT is subcutaneous abdominal adipose tissue measured with computed tomography (CT) scanning, plotted as a function of trunk fat mass by DEXA (top panel) or waist circumference (lower panel). Lines shown are the regression lines. Open circles are Caucasian children, filled circles are African-American children.

**Table 3** Forward regression analysis for the determinants of intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) as measured by computed tomography (CT) scanning

Step	Variable selected	Regression equation	R <sup>2</sup> ; SEE, cm <sup>2</sup>
Dependent variable = IAAT by CT			
1	Trunk fat by DEXA	For IAAT (cm <sup>2</sup> ) (5.9*TRKFAT) + 7.7	0.78; 10.9
2	Total fat by DEXA	(12.9*TRKFAT) - (3.3*TOTFAT) + 13.8	0.82; 9.6
3	Abdominal skinfold	(10.0*TRKFAT) - (3.1*TOTFAT) + (0.77*ABDOMSF) + 11.2	0.85; 8.9
Dependent variable = SAAT by CT			
1	Trunk fat by DEXA	For SAAT (cm <sup>2</sup> ) (26.7*TRKFAT) - 9.2	0.94; 24.9
2	Total weight	(31.9*TRKFAT) - (1.6*WEIGHT) + 22.0	0.94; 23.5
3	Waist circumference	(26.4*TRKFAT) - (2.9*WEIGHT) + (3.0*WAIST) - 105	0.95; 22.5
4	Abdominal skinfold	(23.3*TRKFAT) - (2.9*WEIGHT) + (2.6*WAIST) + 1.4*ABDOMSF - 88	0.96; 22.2

DEXA = dual energy X-ray absorptiometry; TRKFAT = trunk fat mass (kg) by DEXA; TOTFAT = total fat mass by DEXA (kg); ABDOMSF = abdominal skinfold thickness (mm); WEIGHT = body weight (kg); WAIST = waist circumference (cm); other variables included but not selected by the regression model were: gender, age, height, body mass index, soft lean tissue mass by DEXA, and other skinfold and anthropometric data listed in Table 2.

**Table 4** Forward regression analysis for the determinants of intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) as measured by computed tomography (CT) scanning in the absence of dual energy X-ray absorptiometry (DEXA) data

Step	Variable selected	Regression equation	R <sup>2</sup> ; SEE, cm <sup>2</sup>
Dependent variable = IAAT by CT scanning			
1	Abdominal skinfold	(1.7*ABDOMSF) + 5.1	0.78; 10.8
2	Ethnicity	(1.6*ABDOMSF) - (7.5*Ethnicity) + 18.4	0.8; 10.2
3	Subscapular skinfold	(1.1*ABDOMSF) - (7.2*Ethnicity) + (0.7*SUBSCASF) + 17.5	0.82; 9.8
Dependent variable = SAAT by CT scanning			
1	Waist circumference	For SAAT (cm <sup>2</sup> ) (7.4*WAIST) - 375	0.86; 35.3
2	Subscapular skinfold	(4.8*WAIST) + (3.6*SUBSCASF) - 254	0.91; 30.1
3	Height	(6.1*WAIST) + (2.9*SUBSCASF) - (1.1*HEIGHT) - 177	0.92; 29.4
4	Abdominal skinfold	(5.1*WAIST) + (1.9*SUBSCASF) - (1.1*HEIGHT) + 1.8*ABDOMSF - 135	0.92; 28.8

ABDOMSF = abdominal skinfold thickness (mm); SUBSCASF = subscapular skinfold thickness (mm); Ethnicity = 1 for Caucasian and 2 for African-American; WAIST = waist circumference (cm); HEIGHT = height in cm; other variables included but not selected by the regression model were: gender, age, height, body mass index, soft lean tissue mass by DEXA, and other skinfold and anthropometric data listed in Table 3.

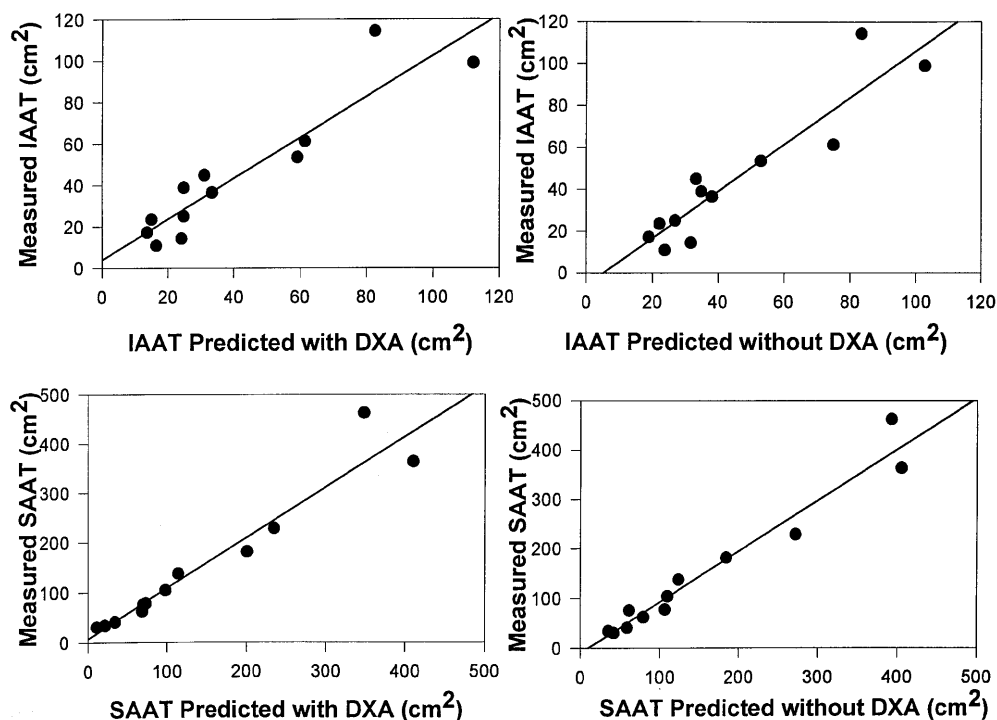
predicted IAAT and SAAT using the equations developed in Table 3 and Table 4. In all cases, there was no significant difference by paired *t*-test between measured and predicted IAAT and SAAT, as shown in Figure 3 and summarized in Table 5. In addition, none of the regression equations between measured and predicted fat area were significantly different from the line of identity (that is, measured = predicted), as summarized in Table 5 and Figure 3. The difference between measured and predicted IAAT and SAAT plotted as a function of the measured value for the 12 subjects in the cross-validation is shown in Figure 4 (Bland-Altman plots). These plots show that the accuracy of the prediction equations is randomly scattered, and there is a loss in prediction accuracy at extremely high levels of IAAT and SAAT.

## Discussion

This study is the first attempt to develop research and clinical based prediction equations for IAAT and SAAT in children. We used a database of 113 obser-

vations of body fat and body fat distribution to examine the relationship between anthropometry, trunk fat by DEXA and IAAT and SAAT by CT scanning. IAAT was best predicted by trunk fat and total body fat by DEXA, and abdominal skinfold (explaining 82% of the variance); SAAT was best predicted by waist circumference, subscapular skinfold and height (explaining 92% of the variance). In the absence of DEXA data, abdominal skinfold, subscapular skinfold and ethnicity (Caucasian vs African-American) explains 80% of the variance in IAAT.

The prediction equations incorporating DEXA measures of total and trunk fat, did not improve the accuracy of the prediction equations. The regression statistics for measured vs predicted IAAT and SAAT were similar for the prediction equations with and without DEXA data (Table 5). In fact for SAAT, the prediction equation without DEXA had slightly improved regression parameters [intercept closer to zero, slope closer to 1.0, higher R<sup>2</sup> and lower standard error of the estimate (SEE)]. Thus, we suggest that when DEXA data is available, IAAT should be predicted from trunk fat by DEXA, total fat by DEXA and abdominal skinfold, and SAAT predicted from waist circumference, subscapular skinfold and height.



**Figure 3** Cross-validation of measured vs predicted intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) with and without dual energy X-ray absorptiometry (DEXA) data as predictor variables. IAAT is intra-abdominal adipose tissue, and SAAT is subcutaneous abdominal adipose tissue either measured with computed tomography (CT) scanning or predicted with or without DEXA data. IAAT predicted with DEXA data using trunk fat by DEXA, total fat by DEXA, and abdominal skinfold (see equation in Table 3). SAAT predicted with DEXA data using trunk fat data by DEXA, body weight, waist circumference and abdominal skinfold (see equation in Table 3). IAAT predicted without DEXA data using abdominal skinfold and ethnicity (see equation in Table 4). SAAT predicted without DEXA data using waist circumference, subscapular skinfold and height (see equation in Table 4). Lines shown are the regression lines between measured and predicted, none of which are significantly different from the line of identity as summarized in Table 5.

**Table 5** Summary of the cross-validation of prediction equations developed in Table 2 and Table 4

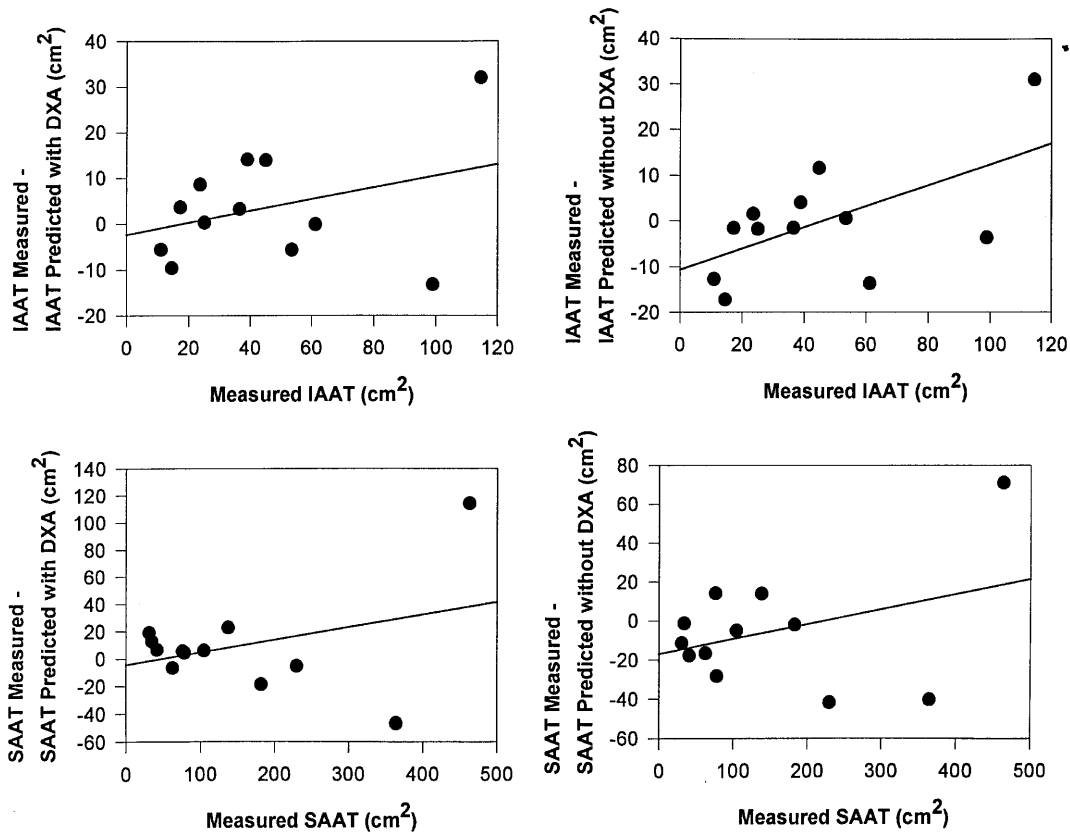
Dependent variable (Mean ± s.d.)	Independent variable (Mean ± s.d.)	Intercept (cm <sup>2</sup> )	Slope	R <sup>2</sup>	SEE (cm <sup>2</sup> )
IAAT by CT (45.0 ± 32.9 cm <sup>2</sup> )	IAAT predicted from trunk fat by DEXA, total fat by DEXA and abdominal skinfolds (41.5 ± 30.8 cm <sup>2</sup> )	4.1 ± 6.5	0.99 ± 0.13	0.86	13.0
IAAT by CT (45.0 ± 32.9 cm <sup>2</sup> )	IAAT predicted from abdominal skinfold and ethnicity (45.3 ± 27.3 cm <sup>2</sup> )	-5.5 ± 7.5	1.11 ± 0.14	0.86	13.0
SAAT by CT (150.4 ± 138.5 cm <sup>2</sup> )	SAAT predicted from trunk fat by DEXA, body weight, waist circumference and abdominal skinfold (140.7 ± 130.7 cm <sup>2</sup> )	7.0 ± 17.2	1.02 ± 0.09	0.93	39.5
SAAT by CT (150.4 ± 138.5 cm <sup>2</sup> )	SAAT predicted from waist circumference subscapular skinfold and height (155.8 ± 131.0 cm <sup>2</sup> )	-10.4 ± 14.4	1.03 ± 0.07	0.95	31.3

IAAT=intra-abdominal adipose tissue; CT=computed tomography; SAAT=subcutaneous abdominal adipose tissue; DEXA=dual energy X-ray absorptiometry.

This approach generates independent predictions since it avoids using the same predictor variables in the equations for IAAT and SAAT. In the absence of DEXA data we suggest using the same equation for SAAT and using abdominal skinfold and ethnicity to predict IAAT.

In studies of adults that have used DEXA to predict IAAT,<sup>12,13</sup> specific locations within the trunk region have been analysed for fat content and used as predictor variables. One of the limitations of the Lunar DPX-L pediatric software is that manual analysis of specific anatomical regions is not possible,

and trunk fat by DEXA includes the entire thoracic and abdominal areas. This may have compromised the accuracy of DEXA prediction equations since more specific analysis of anatomic locations within the DEXA scan (for example, fat at the umbilicus to match the CT scan) may improve the accuracy of prediction. However, in a previous study in adult women,<sup>13</sup> we did not see any advantage of additional analysis of specific locations within the trunk and the prediction of IAAT was not improved. In addition, another potential limitation is a previous report which suggests that DEXA may not accurately reflect trunk



**Figure 4** Bland-Altman plots examining bias in the prediction equations. Intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) either measured with computed tomography (CT) scanning or predicted with or without dual energy X-ray absorptiometry (DEXA) data using equations in Table 3 and Table 4 as described for Figure 1. These graphs show the increased error in predicting IAAT and SAAT at extreme levels.

fat. Snead *et al*<sup>21</sup> showed that DEXA regional measures of trunk fat failed to accurately detect endogenous fat (in the form of lard) placed on the abdomen.

As has been previously reported,<sup>1</sup> this study confirms that traditionally used indices of IAAT are not useful in children. The correlations between IAAT and the trunk-to-extremity skinfold ratio ( $r = 0.49$ ), sagittal diameter ( $r = 0.74$ ) and the WHR ( $r = 0.32$ ) were not as strong as those between IAAT and other measures such as abdominal skinfold ( $r = 0.88$ ), subscapular skinfold ( $r = 0.85$ ), suprailiac skinfold ( $r = 0.85$ ), and waist circumference ( $r = 0.84$ ).

In a previous report, we suggested that the residual from the regression between IAAT and SAAT could be the most appropriate index of visceral obesity for several reasons.<sup>4</sup> Firstly, this approach explains the relative distribution (intra-abdominal vs subcutaneous) of adipose tissue in the abdominal region. Secondly, this approach is a more mathematically correct procedure<sup>21,22</sup> than using the IAAT-to-SAAT ratio. Finally, the residual is useful because it is independent of total body adiposity,<sup>4</sup> thus allowing distinct and independent indices of obesity, (that is, whole body fat vs visceral fat). We performed similar regression analysis with the residual as the dependent variable. However, the residual from IAAT vs SAAT was not related to any body composition variable (including DEXA data) or anthropometric variable

in the data set other than ethnicity (partial  $r^2 = 0.12$ ; parameter estimate for ethnicity =  $-7.8 \text{ cm}^2$ ). Thus, separate measures/predictions of IAAT, SAAT and total body fat are required for thorough obesity classification.

We have previously discussed gender and ethnic differences (Caucasian vs African-American) in IAAT and SAAT.<sup>4</sup> We showed that the relative distribution of IAAT and SAAT were similar across genders in pre-pubertal children, but that African-American children distributed less adipose tissue in intra-abdominal vs subcutaneous abdominal regions. We are unaware of studies that have looked at IAAT and SAAT in other ethnic groups, and thus our new equations are currently limited to Caucasian and African-American children. Although there are differences in abdominal fat distribution between Caucasian and African-American children, we have not developed separate regression equations. We do not see any advantage with this approach because when analysed by ethnic group, the predictive power of the regression equations were not as strong as the combined analysis. Also, the use of one regression equation for both ethnic groups is preferred for practical implementation purposes. Another important consideration is that the relationships between IAAT and SAAT, and body fat and anthropometric variables are likely to change during the maturation process. Our study was limited to pre-pubertal children

and the prediction equations are therefore limited in application to this group. Additional studies throughout the maturation process are warranted.

A number of limitations of this study warrant discussion. First, the predictive equations cannot be used for visceral adipose volume, as our major dependent variable was cross-sectional visceral fat from a single slice. Total visceral adipose tissue volume can be estimated by multiple slice CT, but this would involve a much higher radiation dose. The alternative use of MRI, which does not require ionizing radiation, may be useful for this purpose, although the cost becomes excessive for multiple slices. Second, despite successful cross-validation in a small independent sample, the individual accuracy of the prediction equations appears to be low to moderate. This is likely a reflection of the heterogeneous nature of abdominal fat distribution as well as the relatively low quantities of IAAT and SAAT. In addition, the estimate of error is inflated by the lack of accuracy of the prediction equations at extremely high levels of IAAT and SAAT. This bias is most likely explained by the inability to accurately measure skinfolds and circumferences in very obese subjects. Thus, further cross-validation studies are needed, particularly in obese subjects, and as mentioned above, in other ethnic and maturation groups. Also, other anthropometric measures not included in this study should be explored for their potential in improving the accuracy of IAAT prediction (for example, ultrasound measures of tissue thickness).

In summary, we have examined the relationships between body composition and anthropometry and IAAT and SAAT in a heterogeneous group of African-American and Caucasian pre-pubertal children. IAAT and SAAT can be accurately predicted from a series of regression equations that are provided, with and without the availability of DEXA data. The optimal approach is to estimate IAAT by trunk fat and total body fat by DEXA, and abdominal skinfold (explaining 82% of the variance), and SAAT from waist circumference, subscapular skinfold and height (explaining 92% of the variance). This approach yields predictions of IAAT and SAAT using independent predictor variables. In the absence of DEXA data, abdominal skinfold, subscapular skinfold and ethnicity (Caucasian vs African-American) explain 80% of the variance in IAAT. The new prediction equations were successfully cross-validated in an additional group of children. The new equations are specific to Caucasian and African-American pre-pubertal children.

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#### References

- 1 Goran MI, Kaskoun MC, Shuman WP. Intra-abdominal adipose tissue in young children. *Int J Obes* 1995; **19**: 279–283.
- 2 Fox K, Peters D, Armstrong N, Sharpe P, Bell M. Abdominal fat deposition in 11-year-old children. *Int J Obes* 1993; **17**: 11–16.
- 3 de Ridder CM, de Boer RW, Seidell JC, Nieuwenhoff CM, Jeneson JAL, Bakker CJG, Zonderland ML, Erich WBM. Body fat distribution in pubertal girls quantified by magnetic resonance imaging. *Int J Obes* 1992; **16**: 443–449.
- 4 Goran MI, Nagy TR, Treuth MT, Trowbridge C, Dezenberg C, McGloin A, Gower BA. Visceral fat in Caucasian and African-American pre-pubertal children. *Am J Clin Nutr* 1997; **65**: 1703–1708.
- 5 Freedman DS, Srinivasan SR, Burke GL, Shear CL, Smoak CG, Harsha DW, Webber LS, Berenson GS. Relation of body fat distribution to hyperinsulinemia in children and adolescents: the Bogalusa Heart Study. *Am J Clin Nutr* 1987; **46**: 403–410.
- 6 Freedman DS, Srinivasan SR, Harsha DW, Webber LS, Berenson GS. Relation of body fat patterning to lipid and lipoprotein concentrations in children and adolescents: the Bogalusa Heart Study. *Am J Clin Nutr* 1989; **50**: 930–939.
- 7 Brambilla P, Manzoni P, Sironi S, Simone P, Del Maschio A, Di Natale B, Chiumello G. Peripheral and abdominal adiposity in childhood obesity. *Int J Obes* 1994; **18**: 795–800.
- 8 Caprio S, Hyman LD, Limb C, McCarthy S, Lange R, Sherwin RS, Shulman G, Tamborlane WV. Central adiposity and its metabolic correlates in obese adolescent girls. *Am J Physiol Endocrinol Metab* 1995; **269**: E118–E126.
- 9 Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: Importance of the intra-abdominal fat depot. *Am J Clin Nutr* 1996; **64**: 12–17.
- 10 Kekes-Szabo T, Hunter G, Nyikos I, Nicholas C, Snyder S, Berland L. Development and validation of computed tomography derived anthropometric regression equations for estimating abdominal adipose tissue distribution. *Obes Res* 1994; **2**: 450–457.
- 11 Després J-P, Prud'homme D, Pouliot M-C, Tremblay A, Bouchard C. Estimation of deep abdominal adipose-tissue accumulation from simple anthropometric measurements in men. *Am J Clin Nutr* 1991; **54**: 471–477.
- 12 Svendsen OL, Hassager C, Bergmann I, Christiansen C. Measurement of Abdominal and Intra-abdominal fat in Postmenopausal Women by Dual Energy X-ray Absorptiometry and Anthropometry: comparison with computerized tomography. *Int J Obes* 1993; **17**: 45–51.
- 13 Treuth MS, Hunter GR, Kekes-Szabo T. Estimating intra-abdominal adipose tissue by dual energy X-ray absorptiometry. *Am J Clin Nutr* 1995; **62**: 527–531.
- 14 Kvist H, Sjostrom L, Tylen U. Adipose tissue volume determinations in women by computed tomography: technical considerations. *Int J Obes* 1986; **10**: 53–67.
- 15 Pintauro S, Nagy TR, Duthie C, Goran MI. Cross-calibration of fat and lean measurements by dual energy X-ray absorptiometry to pig carcass analysis in the pediatric body weight range. *Am J Clin Nutr* 1996; **63**: 293–299.
- 16 Goran MI, Driscoll P, Johnson R, Nagy TR, Hunter GR. Cross-calibration of body composition techniques against dual-energy X-ray absorptiometry in young children. *Am J Clin Nutr* 1996; **63**: 299–305.
- 17 Lohman TG, Roche AF, Martorell R. Anthropometric Standardization Reference Manual. Human Kinetics: Champagne, IL, 1988.



- 18 Dibley MJ, Goldsby JB, Staehling NW, Trowbridge FL. Development of normalised curves for the international growth reference: historical and technical considerations. *Am J Clin Nutr* 1987; **46**: 736–748.
- 19 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **Feb 8**: 307–310.
- 20 Snead DB, Birge SJ, Kohrt WM. Age-related differences in body composition by hydrodensitometry and dual-energy X-ray absorptiometry. *J Appl Physiol* 1993; **74**: 770–775.
- 21 Allison DB, Paultre F, Goran MI, Poehlman ET, Heymsfield SB. Statistical considerations regarding the use of ratios to adjust data. *Int J Obes* 1995; **19**: 644–652.
- 22 Goran MI, Allison DB, Poehlman ET. Issues relating to normalization of body fat content in men and women. *Int J Obes* 1995; **19**: 638–643.