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Intra-abdominal adipose tissue in young children

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OBJECTIVE: Intra-abdominal adipose tissue (IAAT) is associated with the metabolic complications of obesity. However the time course for the development of IAAT is not clearly defined because it is generally difficult to measure directly. The purposes of this short communication are to present data supporting the existence of IAAT in young children using direct measurement with computed tomography imaging, and to examine the relationship between IAAT and anthropometric indices in 16 healthy children (6.4 ± 1.2 years; 24.8 ± 5.4 kg).
DESIGN: Total body fat (6.4 ± 3.5 kg) and fat free mass (18.4 ± 3.6 kg) were determined by bioelectrical resistance. Fat distribution was estimated from eight individual skinfold measurements, the ratio of three trunk skinfolds to three extremity skinfolds (0.78 ± 0.20), and the waist:hip ratio (0.90 ± 0.08).
RESULTS: Mean abdominal subcutaneous adipose tissue (SCAT) was 65.3 ± 44.8 cm^2, and mean IAAT was 8.3 ± 5.8 cm^2. The ratio of IAAT to SCAT was 0.15 ± 0.08, and the ratio of IAAT to total body fat was 1.44 ± 0.84 cm^2/kg. IAAT was significantly correlated with body weight ($r = 0.54$; $P = 0.03$), all skinfold measures (range $r = 0.60–0.78$; $P = 0.02$ to 0.0003) except at the calf, fat mass ($r = 0.69$; $P = 0.003$), and the trunk to extremity skinfold ratio ($r = 0.78$; $P = 0.0003$). There was no significant correlation between IAAT and the waist:hip ratio ($r = 0.21$).
CONCLUSIONS: These preliminary results establish the existence of IAAT in young children and suggest that individual trunk skinfold measurements and the trunk:extremity skinfold ratio provide a better indication of IAAT compared to the waist:hip ratio. However, as with adults, the relationship between intra-abdominal adipose tissue and anthropometry in children is complex.

Keywords: obesity, fat distribution, computed tomography, body composition, anthropometrics, skinfold

Introduction

There is a scarcity of data on the prevalence of central body obesity in children. This is of particular concern since central body fat in childhood is associated with greater risk of hyperlipidemia,[1] cardiovascular risk factors,[2,3] hyperinsulinemia,[4] and hypertension.[5] It is now well established that increased intra-abdominal adipose tissue in adults is an important metabolic risk factor for the metabolic complications of excess adiposity.[6] Thus, it has become critical to consider the etiology and time course for the accretion of intra-abdominal adipose tissue.

The availability of *in vivo* imaging techniques (e.g., magnetic resonance imaging and computed tomography) has led to significant advances in our understanding of the physiology of intra-abdominal adipose tissue[7–9] and its relation to negative health effects.[10,11] However, the time course for the development of intra-abdominal adipose tissue during growth and development is poorly defined. Two previous studies have detected intra-abdominal adipose tissue in children and adolescents using magnetic resonance imaging abdominal slices at the level of the umbilicus.[12,13] In 11 and 13 year old girls, intra-abdominal adipose tissue was 24.1 ± 4.1 and 25.7 ± 4.1 cm^2, respectively,[13] and in another study in 11 year olds, intra-abdominal adipose tissue was 17.8 ± 10.0 and 24.8 ± 8.8 cm^2 in boys and girls, respectively.[12] In both studies there was wide variation in intra-abdominal adipose tissue area (6–58 cm^2 in 11 year old boys, 15–50 cm^2 in 11 year old girls). These values compare to typical values of 100 to 120 cm^2 in healthy adults.[14] There have been no studies that have attempted to measure intra-abdominal adipose tissue in children under 11 years of age.

Current information on the link between fat distribution in childhood and later health outcome is limited to measurement of fat distribution using crude anthropometric indices (e.g. waist:hip ratio; skinfolds and skinfold ratios). These prior studies are limited by the absence of information on whether young children have intra-abdominal adipose tissue and by lack of understanding of the relationship between intra-abdominal adipose tissue content and anthropometric indices. Therefore, the purposes of this short communication are as follows: (a) To present data supporting the existence of intra-abdominal adipose tissue in young children using direct measurement techniques (computed tomography) and (b) To examine the relationship between intra-abdominal adipose tissue and anthropometric indices in young children.

Methods

Subjects

The volunteers in this study were 16 children (12

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Caucasian, four Mohawk Indian; four boys and 12 girls) aged 4.4–8.8 years. The children were recruited either by newspaper advertisement, notices posted at pre-schools or word of mouth, from Burlington, VT and Hogansburg, NY. Informed consent was obtained from the parents of each child prior to participation. The study was approved by the Committee on Human Research for the Medical Sciences at the University of Vermont.

Measurement of regional adipose tissue by computed tomography

Regional adipose tissue area was measured directly by computed tomography imaging using a General Electric High Speed Advantage scanner at the Medical Center Hospital of Vermont, Burlington, VT. Scan criteria included 120kVp, variable mA, 1 second scan time, 5 mm slice thickness, and calibration with the manufacturer's phantom. The reduced scan time (1 second *vs* 10 seconds) and slice thickness (5 mm *vs* 1 cm) greatly reduce the radiation dose to acceptable levels for studying children (the radiation exposure of a single slice scan is less than a standard chest X-ray). When scanning children using high efficiency solid state detectors, there is no visually perceptible increase in noise when reducing the scan thickness or scan time. The scans were performed by certified radiology technicians. Subjects were scanned at the abdomen at the level of the umbilicus. The density contour computer program from the scanner was used to compute the cross-sectional area of adipose tissue within the abdominal regional as previously described assuming an adipose tissue density of –250 to –50 Hounsfield Units, as defined by Borkan.[15] Adipose tissue in the abdominal region was measured in the subcutaneous and intra-abdominal compartments. The reliability of analyzing abdominal scans in children for intra-abdominal adiopse tissue was established by repeated analysis of the same scans in each of the children. The repeat analysis was performed by the same research assistant who was unaware of the results of the original analysis at the time of the repeat analysis which was performed 3 months later. Thus, the reported reliability is a measure of the precision of the investigator to highlight areas of intra-abdominal adipose tissue for the same scan. Sagittal diameter was measured on the computer image of the abdominal slice using the measure option in the scanner's computer software. All analyses were completed by the same researcher (MK).

Total body composition measurements

Total body fat and fat free mass were measured by bioelectrical resistance which we have previously cross-validated against total body water in young children.[16] Height was measured to the nearest 0.5 cm using a wall mounted metric stadiometer and weight was measured to the nearest 0.1 kg on an electronic load cell scale (Scale-tronix, Whiteplains, NY). Total body water was estimated from height^2/resistance using the equation of Kushner *et al.*[17] Fat free mass was calculated by dividing total body water by the hydration constant of fat free mass using age-specific constants for children,[18] modified as previously described.[16] Fat mass was obtained by subtracting fat free mass from total body weight.

Anthropometry

Skinfold measurements were obtained using Lange skinfold calipers (Cambridge Instruments, Baltimore, Maryland) at the triceps, subscapular, axilla, suprailiac, abdominal (horizontal), mid-thigh and lateral calf according to the standardized procedures of Lohman *et al.*[19] Waist and hip circumferences were measured while the children stood upright using a metric plastic tape. Waist circumference was measured at the minimal circumference of the abdomen and hip circumference was recorded at the maximum gluteal protuberance of the buttocks. All anthropometric measures were performed by the same researcher (MK) and reflect the average of three measurements. Body fat distribution was estimated from the waist:hip ratio and from the ratio of trunk skinfolds (sum of chest, axilla and abdomen) to extremity skinfolds (triceps, thigh, and calf).

Statistics

Variables are presented as mean values ± standard deviations. Gender related differences between variables were tested by one-way ANOVA. Pearson correlation coefficients were used to assess the relationship between intra-abdominal adipose tissue and various anthropometric indices (e.g. total body fat, waist:hip ratio; skinfolds).

Results

Physical characteristics, body composition and fat distribution data are provided in Table 1. There were no significant differences between boys and girls for any of the variables listed in Table 1, although the power to test for gender differences was limited. In a single slice at the level of the umbilicus, mean abdominal subcutaneous adipose tissue area was 65.3 ± 44.8 cm^2, and mean intra-abdominal adipose tissue area was 8.3 ± 5.8 cm^2. Repeat analysis of the same scans demonstrated excellent reliability for the detection of intra-abdominal adipose tissue by computed tomography in children. There was no significant difference for intra-abdominal adipose tissue when the same scans were re-analyzed (7.9 ± 5.5 cm^2 of intra-abdominal adipose tissue when the same scans were re-analyzed), although cross-sectional area tended to be lower in the repeat analysis ($P = 0.09$ by paired *t*-test). For intra-abdominal adipose tissue, the mean coefficient of variation for the two dupli-

Table 1 Physical characteristics, body composition, and fat distribution for all children in the study (boys and girls combined)

	Mean ± s.d.	*Range*
Age (years)	6.4 ± 1.2	4.4–8.8
Weight (kg)	24.8 ± 5.4	16.2–33.7
Height (cm)	119 ± 9	102–130
Fat free mass (kg)	18.4 ± 3.6	11.6–23.3
Fat mass (kg)	6.4 ± 3.5	1.1–14.2
Trunk:extremity skinfold ratio	0.78 ± 0.2	0.51–1.34
Waist:hip ratio	0.90 ± 0.08	0.80–1.12
Intra-abdominal adipose tissue (cm^2)	8.3 ± 5.8	2.4–20.8
Subcutaneous abdominal adipose tissue (cm^2)	65.3 ± 44.8	10.4–141.1

Table 2 Relationship of simple anthropometric indices and body composition with intra-abdominal adipose tissue by computed tomography in all children

Independent variable	*Correlation coefficient (P value)*	*Standard error of the estimate (cm^2)*
Suprailiac skinfold	0.78 (0.0003)	3.64
Trunk: extremity skinfold ratio	0.78 (0.0003)	3.65
Abdominal skinfold	0.74 (0.001)	3.96
Axilla skinfold	0.72 (0.002)	4.10
Fat mass (kg)	0.69 (0.003)	4.28
Chest skinfold	0.67 (0.005)	4.37
Subscapular skinfold	0.67 (0.005)	4.38
Thigh skinfold	0.60 (0.02)	4.72
Body weight	0.54 (0.03)	4.93
Triceps skinfold	0.54 (0.03)	4.96
Calf skinfold; waist Circumference: hip Circumference: waist:hip Ratio; fat free mass	All not significant	>5.0

Dependent variable = intra-abdominal adipose tissue in a single slice at the level of the umbilicus measured by computed tomography.

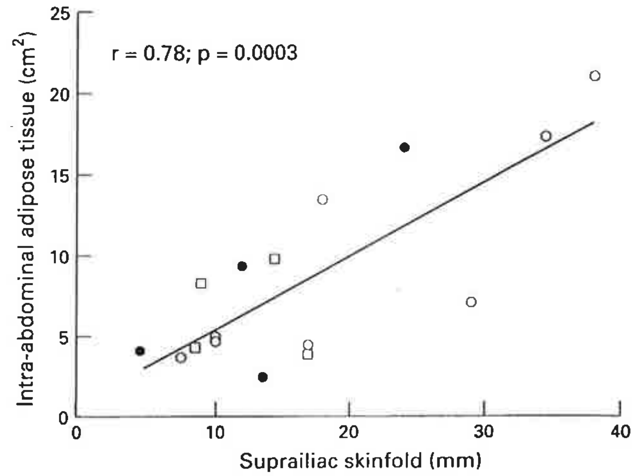

Figure 1 Correlation between intra-abdominal adipose tissue and suprailiac skinfold thickness. Correlation between intra-abdominal adipose tissue at the level of the umbilicus measured by CT scanning and suprailiac skinfold thickness. Open circles are Caucasian girls, filled circles are Caucasian boys, and open boxes are Mohawk girls.

cate scan analysis was 6.2% and the intraclass correlation coefficient was 0.99[20] where the intraclass reliability was estimated using equation ICC (3,1) from Shrout and Fleiss.[21] Intra-abdominal adipose tissue from the initial scan analysis was used in the main data analysis.

Intra-abdominal adipose tissue comprised 11% of the total abdominal adipose tissue area and 3 ± 2% of the total cross-sectional abdominal area. The ratio of intra-abdominal adipose tissue to subcutaneous abdominal adipose tissue was 0.15 ± 0.08, and the ratio of intra-abdominal adipose tissue to total body adipose tissue was 1.44 ± 0.84 cm^2kg. The correlations between intra-abdominal adipose tissue area and anthropometric indices and body composition are summarized in Table 2. The relationships between intra-abdominal adipose tissue and suprailiac skinfold thickness and the ratio of trunk skinfolds:extremity skinfolds are shown in Figures 1 and 2.

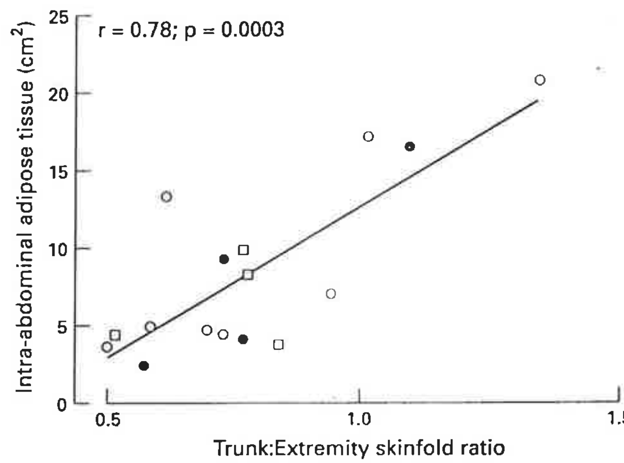

Figure 2 Correlation between intra-abdominal adipose tissue and the trunk: extremity skinfold ratio. Correlation between intra-abdominal adipose tissue at the level of the umbilicus measured by CT scanning and ratio of three trunk skinfolds (chest, axilla and abdomen) to three extremity skinfolds (triceps, thigh and calf). Open circles are Caucasian girls, filled circles are Caucasian boys, and open boxes are Mohawk girls.

Discussion

Our preliminary data in children make two important contributions to the existing literature. First, we have established that intra-abdominal adipose tissue can be measured *in vivo* in young children using computed tomography. Furthermore, our data provide the first experimental evidence demonstrating that individual trunk skinfolds or the trunk:extremity skinfold ratio provide a better index of intra-abdominal adipose tissue in children compared to the waist:hip ratio.

Changes in absolute intra-abdominal adipose tissue area and the aforementioned ratios, from childhood through adulthood, are summarized in Table 3 using data from several studies, although cross-laboratory comparisons may be confounded by methodological differences (e.g. computed tomography versus magnetic resonance imaging, differences in Hounsfield Units). As noted in Table 3, there is a two- to three-fold increase in intra-abdominal adipose tissue between childhood and early adolescence on an absolute scale and when expressed relative to subcutaneous abdominal adipose tissue. On an absolute scale, intra-abdominal adipose tissue in children is approximately 7–8% of that seen in adults. However, when expressed relative to subcutaneous abdominal adipose tissue or total body fat, the level of intra-abdominal adipose tissue in children is 25–50% of that seen in adults (see Table 3). Interestingly, the ratio of subcutaneous abdominal adipose tissue to total body fat is 11 cm^2/kg in adult men and women,[14] compared to a value of 12 cm^2/kg in children in the present study,

Table 3 Intra-abdominal adipose tissue across the life-span

Sample	*Mean IAAT (cm^2) (range)*	*IAAT/SAAT*	*IAAT/TBF, (cm^2/kg)*
6 year old children (current study)	8.3 (2-24)	0.15	1.44
11–13 year old boys[12]	17.8 (6-58)	0.31	1.1
11–13 year old girls[13]	24.8 (15-50)	0.37	NR
11 year old girls[13]	24.1 (range NR)	0.55	NR
13 year old girls[13]	25.7 (range NR)	0.41	NR
Adult males[14]	122 (28-253)	0.48	5.4
Adult females[14]	104 (24-234)	0.24	3.2

IAAT is intra-abdominal adipose tissue area at the level of the umbilicus (cm^2), and SAAT is subcutaneous abdominal adipose tissue at the level of the umbilicus by computed tomography (present study and adults) or magnetic resonance imaging (adolescents); TBF is total body fat (kg); NR, not reported.

suggesting that the amount of subcutaneous adipose tissue in the abdominal region in children is similar to adults after taking into account differences in total body fat content. Collectively, these comparisons suggest that pre-adolescent growth is associated with an expansion of the intra-abdominal adipose tissue depot and that the partitioning of adipose tissue into the intra-abdominal region is reduced in children.

There is little information on the factors accounting for differences in fat distribution in children, and the normal developmental changes in internal body fat stores are unknown. One factor that is known to influence fat distribution is ethnic background. There is insubstantial data from this preliminary report to evaluate ethnic differences in body fat distribution based on computed tomography measurements. However, several studies have compared ethnic differences in body fat distribution during childhood based on anthropometry. Greaves *et al.* showed that Black American and Mexican Americans had greater fat in the central region, and that this held true for parents and children.[22] In addition, we have previously shown that Mohawk Indian children[23] have similar whole body fat to Caucasian children (using bioelectrical impedance), but that subcutaneous fat (by skinfolds) is more centrally distributed in the Mohawk children. Thus, ethnic groups with higher risk for cardiovascular disease have greater fat in the central region. However, since prior studies have been limited to use of skinfold data, it is unknown whether the aforementioned groups have alterations in intra-abdominal adipose tissue. More importantly, further studies using computed tomography to measure intra-abdominal adipose tissue are required to determine the mechanism for altered fat distribution in the aforementioned ethnic groups.

Our data confirm that individual skinfold measurements in the trunk region, or the trunk:extremity skinfold ratio are stronger indicators of intra-abdominal adipose tissue in children as compared to the waist to hip ratio. Our data in children are similar to those in adolescents. One previous study in adolescents showed no significant correlation between waist circumference, waist:hip ratio or trunk:extremity skinfold ratio and intra-abdominal adipose tissue area as measured by magnetic resonance imaging.[13] In another study in 11 year old adolescents, waist-to-hip ratio was not significantly correlated with intra-abdominal adipose tissue as measured by magnetic resonance imaging.[12] Subscapular skinfold in girls and the ratio of subscapular:triceps skinfold in boys were the strongest anthropometric correlates with intra-abdominal adipose tissue[12] but the *r* values were modest (0.64–0.80). Collectively the data in children and adolescents support the notion that trunk individual skinfold measures or the trunk:extremity skinfold ratio are more reliable estimates of intra-abdominal adipose tissue than the waist:hip ratio. However, as in adults,[24–27] the utility of anthropometric data for estimating intra-abdominal adipose tissue remains limited.

From a clinical perspective it is becoming more important to identify good diagnostic tools for estimating intra-abdominal adipose tissue that do not rely primarily on the expensive and heavily used clinical equipment with radiation exposure. The preliminary data currently reported suggest limited accuracy of simple anthropometry for predicting intra-abdominal adipose tissue (Table 2) which may be related to the limited sample size reported. More accurate estimates of intra-abdominal adipose tissue may be obtained by including regional measures of body fat by dual energy X-ray absorptiometry in addition to anthropometric indices as potential predictor variables (although this option may not be practical for routine evaluations by pediatricians). Although dual energy X-ray absorptiometry can measure total abdominal fat, this technique cannot resolve subcutaneous fat from the abdominal compartments. Thus, the combination of dual energy X-ray absorptiometry (as an index of total abdominal fat) and skinfolds (as an index of subcutaneous fat) should in theory offer an alternative means to estimate intra-abdominal adipose tissue as measured by computed tomography. In post-menopausal women, total abdominal fat by dual energy X-ray absorptiometry, waist-hip ratio, and the sum of trunk skinfolds explained 91% of the variation in intra-abdominal adipose tissue measured by computed tomography.[28] Further studies across all ages and ethnic backgrounds are required to develop population-specific equations for quick, simple and reliable estimates of intra-abdominal adipose tissue.

In summary, we have identified that intra-abdominal adipose tissue can be quantified in young children using computed tomography. When expressed relative to subcutaneous abdominal adipose tissue or total body fat mass, the amount of intra-abdominal adipose tissue in children is about 25–50% of that seen in adults. In addition, our data provide the first experimental evidence supporting the use of individual trunk skinfolds or the trunk:extremity skinfold ratio, rather than the waist:hip ratio as a suitable indicator of intra-abdominal adipose tissue in children. These preliminary data provide the framework for further studies examining the determinants of biological variability in intra-abdominal adipose tissue during growth and development and the relationship between intra-abdominal adipose tissue early in life and health outcome later in life.

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