

Growth of Visceral Fat, Subcutaneous Abdominal Fat, and Total Body Fat in Children

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Abstract

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Objective: To examine the patterns of growth of visceral fat, subcutaneous abdominal fat, and total body fat over a 3- to 5-year period in white and African American children.

Research Methods and Procedures: Children (mean age: 8.1 ± 1.6 years at baseline) were recruited from Birmingham, Alabama, and those with three or more repeated annual measurements were included in the analysis ($N = 138$ children and 601 observations). Abdominal adipose tissue (visceral and subcutaneous) was measured using computed tomography. Total body fat and lean tissue mass were measured by DXA. Random growth curve modeling was performed to estimate growth rates of the different body fat compartments.

Results: Visceral fat and total body fat both exhibited significant growth effects before and after adjusting for subcutaneous abdominal fat and lean tissue mass, respectively, and for gender, race, and baseline age (5.2 ± 2.2 cm^2/yr and 1.9 ± 0.8 kg/yr , respectively). After adjusting for total body fat, the growth of subcutaneous abdominal fat was not significant. Whites showed a higher visceral fat growth than did African Americans (difference: 1.9 ± 0.8 cm^2/yr), but there was no ethnic difference for growth of

subcutaneous abdominal fat or total body fat. There were no gender differences found for any of the growth rates.

Discussion: Growth of visceral fat remained significant after adjusting for growth of subcutaneous abdominal fat, implying that the acquisition of the two abdominal fat compartments may involve different physiologic mechanisms. In contrast, growth of subcutaneous abdominal fat was explained by growth in total body fat, suggesting that subcutaneous fat may not be preferentially deposited in the abdominal area during this phase of growth. Finally, significantly higher growth of visceral fat in white compared with African American children is consistent with cross-sectional findings.

Key words: fat, children, growth, central adiposity

Introduction

Growth during childhood is known to be a time of rapid change in body composition; however, there have been few longitudinal studies that examined changes in specific fat compartments during the growth process. The study of change of various compartments of fat is important because it helps to elucidate the dynamics of growth in children and how changes in body composition may be related to health outcomes. This is especially important for the growth of visceral fat, which may contribute to metabolic disease risk.

Visceral fat (i.e., intra-abdominal adipose tissue) and subcutaneous abdominal fat are two discrete compartments of fat that have been studied in association with health outcomes. Previous studies suggest that different types of adipose tissue may relate to different risk factors of type 2 diabetes and cardiovascular diseases and that these relationships emerge early in life (1–9).

In children, visceral fat has been shown to be positively related to a wide range of health indicators, including total cholesterol, low-density lipoprotein cholesterol, triacylglycerol, insulin areas after an oral glucose test, basal insulin

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secretion, and stimulated insulin secretion (3–5). In addition, visceral fat seems to have a negative relationship with insulin sensitivity and high-density lipoprotein cholesterol (4–6). Moreover, subcutaneous abdominal fat has been associated with increased basal and 2-hour insulin concentrations in African American girls (8) and greater insulin area-under-the-curve in African Americans in general (9).

Different associations between body fat and health risk may exist in different segments of the population. For instance, African American children have been shown to have less visceral fat than whites (7,8), yet African American adults are at an increased risk for type 2 diabetes and cardiovascular diseases. Gender differences, in contrast, have not been consistently reported. Fox et al. (10) reported that 11-year-old girls had more visceral fat than age-matched boys. In one recent study, however, no gender differences were found (7).

Although some associations between different adipose tissues and risk factors have been identified, how visceral fat or subcutaneous abdominal fat is acquired in children and the mechanisms through which visceral fat or subcutaneous abdominal fat affect disease risks are still unclear. Furthermore, whether cross-sectional differences found previously remain true for growth-related changes also needs to be investigated. There have been few previous reports from longitudinal studies that examined the growth trajectory of visceral fat or subcutaneous abdominal fat in children (11–13). Information is particularly limited in young children with precise measures of body composition. However, given the relationship between childhood obesity and later disease risks, it is important to obtain a better understanding of the growth patterns of these different adipose tissues. This study, therefore, aimed to explore the pattern of change in visceral fat, subcutaneous abdominal fat, and total body fat during a 5-year longitudinal study in white and African American children. We hypothesized that total body fat, subcutaneous abdominal fat, and visceral fat would exhibit significant growth rates over time.

Research Methods and Procedures

Subjects

Children were recruited by newspaper and radio advertisements and by word of mouth. Subjects were screened by medical history and were ineligible if they were: 1) <4 years of age; 2) taking medications known to affect body composition or physical activity (e.g., prednisone, ritalin, or growth hormone); 3) previously diagnosed with syndromes known to affect body composition or fat distribution (e.g., Cushing's syndrome, Down's syndrome, insulin-dependent diabetes, or hypothyroidism); or 4) 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 ap-

proved by the institutional review board at the University of Alabama at Birmingham. Parents provided informed consent before testing began.

Protocol

Children were admitted to the General Clinical Research Center in the late afternoon for an overnight visit. On arrival, anthropometric measurements were obtained and dinner was served at ~5:00 PM. An evening snack was allowed but only water and energy-free, noncaffeinated beverages were permitted after 8:00 PM until after the morning testing. Between 7:00 PM and 8:00 PM, a single-slice computerized tomography scan was taken at the level of the umbilicus for the measurement of visceral fat and subcutaneous abdominal fat, using the density contour program of the scanner software as described previously (14). Sexual maturity was assessed by a physician using Tanner's criteria. Two weeks later, the children arrived at the Energy Metabolism Research Unit at 7:00 AM while in a fasted state, and total body fat and lean tissue mass were determined by DXA with a Lunar DPX-L densitometer (Lunar Corp., Madison, WI) that was validated previously in the pediatric body weight range (15,16). Using an identical protocol, the current study was carried out for 5 consecutive years with a follow-up examination conducted each year.

Statistical Analysis

Children with at least three annual data points were included in the analyses ($N = 138$ children and 601 total observations). Mean values of age and body compositions at baseline and across repeated observations were compared between the two genders and two ethnicities using Student's t tests. General linear models and post hoc Tukey tests were then used to examine the two-way factorial mean differences.

In addition, growth curve modeling was performed using the mixed procedure in SAS (SAS Institute Inc., Cary, NC), nesting repeated measures within subjects while controlling for within-subject covariation. Visceral fat, subcutaneous abdominal fat, and total body fat were the primary dependent variables of interest.

Visit number (0 to 5) was entered as a class (categorical) variable; this variable was also used in the repeated statement to take missing data into account (i.e., repeated observations were arranged systematically according to the visit number). The time variable used to estimate growth rates was the precise time in years of each visit since baseline. The intercept was defined at baseline. Both the time variable and intercept were treated as random effects. Age at the first visit was entered into the hierarchical models as a fixed covariate to account for the range of ages when children first enrolled in the study. Race and gender, coded dichotomously, were also entered as fixed covariates. Tanner Stage was not entered into the models because the majority of our subjects remained at Tanner Stages 1 or 2 throughout

the study. The effect of baseline age, race, and gender on the growth rate of the dependent outcome was tested using the respective interaction terms with the time variable.

The relevant covariates in the models (i.e., subcutaneous abdominal fat, total body fat, and total lean tissue mass) were centered at their respective sample mean value. When visceral fat was the dependent outcome, subcutaneous abdominal fat was used as a covariate to examine the unique change of visceral fat in the abdomen relative to that of subcutaneous fat within the same region. When subcutaneous abdominal fat was the dependent outcome, a model adjusting for total body fat was performed, because the majority of total body fat is subcutaneous in nature. Total lean tissue mass was used as a covariate when estimating the growth of total body fat to ascertain the degree of total fat growth beyond that which is expected as a result of normal maturation.

Between/within-subjects degree of freedom was selected and the covariance structure in the random statement was left as unconstrained. In the repeated statement, a default variance component covariance structure was used.

All procedures were conducted using SAS, version 6.12 (SAS Institute Inc.) and all statistical tests had a type I error set at 0.05.

Results

Baseline Characteristics

Baseline characteristics (Table 1) for the 138 children are outlined in Table 1. The mean baseline age for the total sample was 8.1 ± 1.6 years, with a range from 4.6 to 12.1 years. In addition, the overall sample had a mean baseline value of 9.6 ± 6.1 kg for total body fat, 90.0 ± 84.9 cm² for subcutaneous abdominal fat, 29.1 ± 19.9 cm² for visceral fat, and 20.8 ± 0.4 kg for lean tissue mass. Student's *t* tests revealed that boys had higher visceral fat (34.4 ± 26.7 cm² vs. 26.3 ± 14.7 cm²; $p < 0.05$) and total lean tissue mass (22.7 ± 5.5 kg vs. 19.9 ± 4.7 kg; $p < 0.01$) than girls at baseline. Furthermore, compared with whites, African Americans had higher baseline total body fat (11.1 ± 7.6 kg vs. 8.7 ± 4.8 g; $p < 0.05$) and lean tissue mass (22.1 ± 5.6 kg vs. 20.1 ± 4.6 kg; $p < 0.05$). In stratifying the data by gender and ethnicity interaction, general linear models suggested that African American boys had significantly higher levels of lean tissue mass than did white girls (mean difference: 4.1 kg; $p < 0.01$). No other differences were found between groups. All results regarding baseline characteristics were unadjusted.

Sample across Repeated Observations

In this analysis, 32 individuals had 3 repeated observations, 39 individuals had 4 repeated observations, 53 individuals had 5 repeated observations, and 14 individuals had 6 repeated observations, for a total of 601 study observa-

tions in 138 children (Table 2). Table 2 shows the breakdown of sample size across observations by gender and ethnicity.

Growth Rates before Adjusting for Appropriate Adipose or Lean Tissue

Random growth curve models were constructed to estimate the growth rates of total body fat, subcutaneous abdominal fat, and visceral fat. Models without adjusting for relevant adipose or lean tissue were conducted first. As shown in Model 1 of Table 3, growth rates were statistically significant at the 0.05 level for total body fat (2.0 ± 0.9 kg/yr), for subcutaneous abdominal fat (32.6 ± 10.7 cm²/yr), and for visceral fat (11.6 ± 2.9 cm²/yr).

Growth Rates Adjusting for Relevant Adipose and Lean Tissue

In the final random growth curve models, total body fat was adjusted for lean tissue mass, subcutaneous abdominal fat was adjusted for total body fat, and visceral fat was adjusted for subcutaneous abdominal fat (Tables 3 and 4). Results from Model 2 in Table 3 show that the growth of total body fat remained significant after adjusting for lean tissue mass (1.9 ± 0.8 kg/yr; $p < 0.05$). The growth of subcutaneous abdominal fat, adjusting for total body fat, was only marginally significant (8.8 ± 5.0 cm²/yr; $p < 0.10$; Table 3), but visceral fat continued to exhibit a significant growth over time (5.2 ± 2.2 cm²/yr; $p < 0.05$; Table 3), even after adjusting for growth of subcutaneous abdominal fat.

With regard to total body fat, several significant main effects were found in the final model (Table 4). African Americans seemed to have a higher level of total body fat than did whites at baseline ($p < 0.05$). In addition, those who were older at the first visit seemed to have a higher level of total body fat than those who were younger ($p < 0.001$). Change in lean tissue mass was also related to change in total body fat ($p < 0.01$).

In terms of subcutaneous abdominal fat (Table 4), change in total body fat was the only significant predictor of subcutaneous abdominal fat ($p < 0.001$).

In Table 4, results from the final models also showed that for visceral fat, boys had a higher level at baseline than girls ($p < -0.05$) and whites exhibited a steeper growth than African Americans over time ($p < 0.05$). On average, the rate of growth of visceral fat was ~ 1.9 cm²/yr greater in white children than in African American children. A significant interaction between baseline age and the time variable indicated that the growth of visceral fat might not be linear ($p < 0.01$), suggesting that as age increased, the growth of visceral fat decelerated. Change in subcutaneous abdominal fat was also significantly positively related to change in visceral fat ($p < 0.001$).

Table 1. Subject characteristics at baseline

Characteristics	Total sample (n = 138)	African American girls (n = 31)	African American boys (n = 24)	White girls (n = 60)	White boys (n = 23)	Significant effects (p < 0.05)
Age (years)	8.1 ± 1.6	8.1 ± 2.0	7.9 ± 1.5	8.1 ± 1.4	8.6 ± 1.9	None
Total body fat (kg)	9.6 ± 6.2	10.8 ± 7.2	11.4 ± 8.3	8.4 ± 4.2	9.5 ± 6.3	Ethnicity
Subcutaneous abdominal fat (cm ²)	90.3 ± 84.9	94.4 ± 83.0	104.3 ± 124.8	77.9 ± 61.2	103.2 ± 91.6	None
Visceral fat (cm ²)	29.1 ± 19.9	24.7 ± 14.1	36.2 ± 32.2	27.3 ± 15.2	32.6 ± 20.4	Gender
Lean tissue mass (kg)	20.8 ± 5.1	21.2 ± 5.8	23.3 ± 5.1	19.2 ± 3.8	22.2 ± 5.9	Gender, ethnicity
Weight (kg)	32.1 ± 11.2	33.8 ± 12.6	36.3 ± 13.4	29.3 ± 8.0	33.3 ± 12.1	Gender, ethnicity

Note: values shown are unadjusted means ± SD.

Discussion

To our knowledge, this is one of the first studies that has examined the growth of different adipose tissue compartments in a cohort of white and African American children over time, using precise measurements of body composition. The results for total body fat and visceral fat support our hypotheses, which state that after adjusting for the effect of lean tissue mass, the growth rate of total body fat remained significant and after adjusting for the effect of subcutaneous abdominal fat, visceral fat continued to exhibit a significant growth. However, there was no significant growth of subcutaneous abdominal fat over and above that explained by total body fat. In addition, whites had a higher growth rate of visceral fat, compared with African Americans. No gender differences were found in any of the growth rates.

Total body fat showed significant growth even after adjusting for lean tissue mass, implying that children in our

sample gained body fat in excess of the level to be expected due to normal maturation. One of our most important findings is that we have quantified the rate of growth at ~2 kg/yr during this age and time period. This is fairly consistent with reported findings in the literature, where the unadjusted gain of total body fat in children and adolescents usually falls between 0.7 and 3.0 kg/yr (11,17). However,

Table 3. Growth rate of total body fat, subcutaneous abdominal fat, and visceral fat before and after adjusting for relevant adipose or lean tissue

Dependent variable	Model 1: before adjusting for relevant adipose or lean tissue mass	Model 2: after adjusting for relevant adipose or lean tissue mass
Total body fat (kg/yr)	2.0 (0.9)†	1.9 (0.8)†
Subcutaneous abdominal fat (cm ² /yr)	32.6 (10.7)†	8.8 (5.0)*
Visceral fat (cm ² /yr)	11.6 (2.9)†	5.2 (2.2)†

Note: figures shown are regression coefficients (SE). All models adjusted for race, gender, and baseline age. In Model 2, the rate of visceral fat growth was adjusted for subcutaneous abdominal fat; the rate of subcutaneous abdominal fat growth was adjusted for total body fat; the rate of total body fat growth was adjusted for total lean tissue mass.

* p < 0.10.

† p < 0.05.

Table 2. Sample size across repeated measures by gender and ethnicity

Group	Number of repeated measures			
	3	4	5	6
White boys (n = 23)	8	14	1	0
African American boys (n = 24)	5	6	13	0
White girls (n = 60)	10	18	20	12
African American girls (n = 31)	9	1	19	2
Total sample (n = 138)	32	39	53	14

Table 4. Growth rates and significant predictors of total body fat, subcutaneous abdominal fat, and visceral fat

Outcome	Predictor	Parameter estimate	<i>p</i> <
Visceral fat	Time	5.2 ± 2.2 cm ² /yr	0.05
	Sex	4.2 ± 1.8 cm ²	0.05
	Time * race	1.9 ± 0.8 cm ² /yr	0.05
	Time * age at baseline	-0.8 ± 0.3 cm ² /yr	0.01
	Subcutaneous abdominal fat	0.2 ± 0.01 cm ²	0.001
Subcutaneous abdominal fat	Time	8.8 ± 4.9 cm ² /yr	0.1
	Sex	8.2 ± 4.5 cm ²	0.1
	Total body fat	0.01 ± 0.0 cm ²	0.001
Total body fat	Time	1.9 ± 0.8 kg/yr	0.05
	Race	-2.2 ± 0.9 kg	0.05
	Age at baseline	1.4 ± 0.2 kg	0.001
	Lean tissue	0.2 ± 0.1 kg	0.01

Note: parameter estimates are regression coefficients ± SE. Sex coded as 1 = boys and 0 = girls. Race coded as 1 = whites and 0 = African Americans. Visceral fat was adjusted for subcutaneous abdominal fat. Subcutaneous abdominal fat was adjusted for total body fat. Total body fat was adjusted for lean tissue mass.

Guo et al. (17) had suggested a quadratic growth of total body fat in subjects 8 to 20 years of age ($\beta = -0.003$), but the rate was reported as crude and unadjusted. In addition, data from that study included older subjects compared with our sample and were obtained between 1976 and 1988; therefore, they may not reflect changes in body composition in contemporary children. Furthermore, in adolescent white females, it has been shown that there is a crude gain of total body fat up until ~14 years of age, although the rate of change decelerates over time (11). However, because that study did not include subjects <11.5 years of age, it is unclear from the results what the pattern of change in total body fat would be in younger ages. Our data did not suggest any curvilinear changes of total body fat in childhood.

Our results with regard to subcutaneous abdominal fat are consistent with the fact that the accumulation of total fat is most often accompanied by the accumulation of subcutaneous fat. They also suggest that subcutaneous fat is not preferentially deposited in the abdominal region in children. This is why change in total body fat was positively related to change in subcutaneous abdominal fat, yet subcutaneous abdominal fat was only marginally significant after adjusting for total body fat. The gain in subcutaneous abdominal fat, without adjusting for total body fat, was similar to that reported by Owens et al. (12), where it was shown that among 7- to 11-year-old control children in a physical training program, the rate of change was ~30 cm²/yr. In a smaller sample of adolescents, Brambilla et al. (13) showed similar crude results.

In comparison with previous reports in the literature, the rate of change of visceral fat, without adjusting for subcu-

taneous abdominal fat, was consistent with that reported by Owens et al. (12). In contrast, Brambilla et al. (13) did not show any significant change of visceral fat in adolescents from 13 to 17 years old. In the latter study, however, all 16 adolescents were pubertal or postpubertal and had stable weight as adjusted for height during the 4-year study. In the current study, the fact that the growth of visceral fat, after adjusting for subcutaneous abdominal fat, remained statistically significant (5.2 cm²/yr) supports the hypothesis that the accumulation of visceral fat may not necessarily be accompanied by the accumulation of subcutaneous fat (7). This indicates that although the two compartments of intra-abdominal fat are positively correlated, change in subcutaneous abdominal fat does not fully explain the growth of visceral fat. Different regulatory mechanisms must exist for the acquisition of visceral fat versus subcutaneous fat. Several sex hormones have been shown to affect regional fat deposition (18), and this may explain the differential deposition of visceral versus subcutaneous abdominal fat during this phase of growth. However, the current study was not able to examine this due to the large proportion of subjects in prepubescence and early pubescence. Future studies are needed to examine how the growth of fat is influenced by and related to changes in various metabolic markers, and whether these relationships differ between the two genders beyond childhood. Nevertheless, significant gain in visceral fat after adjusting for subcutaneous abdominal fat suggests that the acquisition of visceral fat in childhood may have important implication for the development of disease later on in life.

In addition, our results suggest that whites had a greater

visceral fat growth than African Americans (1.9 cm²/yr). The longitudinal finding of an ethnic difference is congruent with cross-sectional findings in the literature, where African Americans were shown to have less visceral fat and more subcutaneous abdominal fat. Genetic factors may play a role in the ethnic difference. The lack of ethnic difference in subcutaneous abdominal fat growth may be the fact that the covarying total body fat explained much of the variance in the growth of subcutaneous abdominal fat. In addition, it is also possible that the single-slice computerized tomography scan at the umbilicus did not equally represent abdominal fat distribution in both ethnic groups (7). Multiple-slice scanning may be necessary to fully examine ethnic differences in fat distribution within the abdomen. Gender differences in the relative accumulation of visceral fat vs. subcutaneous abdominal fat have not been consistently reported in the literature. We did not find any significant differences between the two genders in terms of growth of the various compartments of body fat.

The current study uses a complex random coefficients modeling technique to estimate the growth of body compositions over time. Much of the strength of the current article lies in its methodology in treating longitudinal population-based metabolic data. Our approach not only took intraclass correlation into account by building random effects into the models, it also accounted for the disturbances derived from missing measurements, different ages at enrollment, and varying intervals of measurements. Such disturbances are almost inevitable in large-scale studies such as ours. Therefore, appropriate statistical adjustments are necessary to provide accurate estimations.

The use of advanced techniques to measure body composition is also a great strength of the current study. As mentioned previously, few studies have examined longitudinal changes in body composition in children using precise measures. In addition, our study sample was relatively large compared with previous studies in children and included both white and African American children. Annual measurements across 5 years also make the current study a relatively more powerful design.

Although the effect of sexual maturation may be an important confounder to consider, the current study was unable to address this question due to the small number of cases that were in sexually advanced stages. Sixty percent of our sample remained at Tanner Stages 1 and 2, which, by definition, would imply a transition period from prepubescence to pubescence without having fully moved through the changes that occur in pubescent development. To fully examine the effect of sexual maturation, repeated measures of individuals who move across the spectrum of sexual maturation would be necessary. Therefore, our findings may be limited to early puberty.

Because the current study used a procedure of convenient sampling, it is limited in its generalization to individuals

who do not share characteristics (e.g., ethnicity, age, baseline adiposity, etc.) similar to those of our subjects. Specifically, a longer-term study is required to investigate whether the pattern of growth estimated continues in a similar manner in late childhood and adolescence, particularly with regard to the linearity and direction of change. Pubertal and postpubertal changes may possibly alter these patterns. Larger samples with repeated measures would also afford the opportunity to better examine differences between subgroups of children.

Despite the limitations discussed above, the current study is the first of such to estimate the growth pattern of total body fat, subcutaneous abdominal fat, and visceral fat in a relatively large cohort of prepubertal African American and white children, using advanced measures of body composition. Visceral fat and total body fat were found to exhibit significant growth even after adjusting for relevant adipose or lean tissue compartments, implying that their growth cannot simply be explained by growth associated with normal maturation. Subcutaneous abdominal fat showed only a marginally significant growth effect after adjusting for total body fat, implying that subcutaneous fat is not preferentially deposited in the abdominal region. Because the growth of different compartments of fat may result from different regulatory mechanisms, it is also possible that these mechanisms may have different effects in different populations.

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