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Cardiometabolic Risk Factors and Fat Distribution in Children and Adolescents

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Abstract

Objectives—To determine if cardiometabolic risk factors have differential associations with the proportion of fat distributed in the trunk, leg, and arm, in White and African American children and adolescents.

Study design—The sample included 391 White and African American 5–18 year-olds. Total and regional (trunk, leg, and arm) fat were measured by DXA. Resting blood pressure and fasting triglycerides, HDL-C, glucose, insulin, and CRP were measured in a clinical setting. Insulin resistance was determined with HOMA-IR. Multivariable linear and logistic regression models were used to examine associations between each cardiometabolic risk factor and proportion of fat (trunk, leg, or arm fat divided by whole body fat), with whole body fat, age, sex, race, sexual maturity status, and self-reported physical activity as covariates.

Results—Higher odds of low HDL-C, high triglycerides, insulin resistance, and high CRP were associated with % trunk fat. Lower odds of low HDL-C, high triglycerides, and insulin resistance were associated with % leg fat. No cardiometabolic risk factor was associated with % arm fat.

Conclusions—Cardiometabolic risk factors in children and adolescents were attenuated when a larger proportion of fat was distributed in the leg. The clinical assessment of children's fat distribution may be useful in determining cardiometabolic risk factors.

Keywords

cardiovascular risk factors; body fat distribution; obesity; pediatrics

Over 12.5 million children and adolescents in the U.S. are obese.¹ Increased body fat is an important risk factor for chronic disease morbidities. Consequently, 13% of U.S. adolescents have prehypertension or hypertension and 23% have impaired fasting glucose concentrations suggestive of prediabetes or diabetes.² The regional distribution of body fat, however, may portend differential impact on cardiometabolic risk factors.

Since the observation in 1947 of android versus gynoid fat patterns,³ it is well established that fat stored centrally in the body is metabolically more deleterious than the fat stored in

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the periphery (i.e. in the legs or arms). Yet fat regions are highly correlated with each other and with overall adiposity,⁴ so including multiple body fat regions in one model weakens statistical validity. Therefore, examining the relative amount of regional body fat in proportion to whole body fat or to other fat regions is a valid and frequently used statistical method to test for associations with cardiometabolic risk factors. The relative amount of fat stored in the trunk region of the body compared with the gynoid region is indeed associated with clustering of cardiometabolic risk⁵ in children and with insulin resistance in obese children.⁶ The ratio of waist thickness to hip/thigh thickness is associated with elevated triglycerides, low levels of high-density lipoprotein cholesterol (HDL-C), and hypertension.⁷ In contrast, at least in adults, the ratio of leg fat to whole body fat is inversely associated with many cardiometabolic risk factors, resulting in lower risk for metabolic syndrome.⁸ One study found a positive association between leg fat and cardiometabolic risk in children and adolescents,⁷ but the analyses was on the ratio of waist to hip/thigh and not to whole body fat. It is unclear if having a higher proportion of leg fat compared with whole body fat may be inversely associated with cardiometabolic risk factors in children. Finally, upper arm fat (calculated from mid-upper arm circumference and tricep skinfold thickness) was associated with total cholesterol, LDL-cholesterol, and triglycerides in 6–19 year-old children and adolescents,⁹ but this analysis did not consider arm fat as a proportion of whole body fat.

Pediatric studies on the association between cardiometabolic risk factors and extremity versus trunk fat are limited. Fat distribution is typically assessed with anthropometric measures, such as skin-fold thickness and waist and hip circumferences. These are subject to measurement variability or observer bias.⁷ Recent studies on cardiometabolic risk and regional fat distribution in children focus on visceral, ectopic, and subcutaneous fat, with few examining gynoid fat. The inverse association between cardiometabolic risk and leg fat has been predominantly demonstrated in adults, although it is unclear whether or not cardiometabolic risk is associated with fat distribution earlier in life, during childhood and adolescence. Moreover, the evidence for adults is primarily limited to Whites and Asians, with few studies on African Americans (for exceptions, see ^{8, 10}). The purpose of this study was to determine if cardiometabolic risk factors were differentially associated with fat distribution in the trunk, leg, and arm in White and African American children and adolescents.

Methods

A sample of 423 children and adolescents were recruited from Baton Rouge, LA, for a study of the anthropometric markers of abdominal adiposity. Recruitment aimed to attain a balance across age, sex, race, and body mass index category (normal weight, overweight, and obese). For the present analysis, participants were included if they were White or African American and excluded if they were missing data on primary analysis variables. The final sample was 391 5–18 year-olds (mean age = 12.2 ± 3.5 years), including 101 White boys, 84 African American boys, 88 White girls, and 118 African American girls. Participants provided written assent, and parents or guardians provided informed consent. All study procedures were approved by the Pennington Biomedical Research Center institutional review board.

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and weight was measured to the nearest 0.1 kg using a digital scale with outer clothing and shoes removed. The SAS program for the 2000 CDC Growth Charts for the U.S. was used to compute BMI percentile, with overweight defined as 85th to 95th percentile and obese defined as 95th percentile.

Whole body fat was measured using a whole-body Hologic QDR 4500 dual energy x-ray absorptiometry (DXA) scanner (Bedford, MA, USA). The participant lay supine and motionless on a table wearing no metal containing objects, while a detector and scanner passed over the body for a total of 4 to 6 minutes. The radiation dose equaled approximately 12 h of background radiation. QDR software for Windows V11.2 was used to compute whole body fat as the sum of the fat content of the tissue at each pixel, based on variations of the attenuation ratio determined from known tissue content. Regional fat mass, including leg (femoral neck to toes), arm (head of the humerus to the fingertips), and trunk (humerus head and jaw to the femoral head), was automatically demarcated by the Hologic software.

Resting blood pressure was measured with a standard mercury manometer, and the average of two systolic and two diastolic measurements were used for analysis (or closest two of three if difference exceeded 10 mm Hg). A blood sample was drawn using venipuncture following an overnight fast. HDL-C was assayed using Trinity DXC600; serum triglyceride and glucose were obtained on a Beckman Coulter DXC600; insulin levels were assayed on a Siemens Immulite 2000; and high sensitivity C-reactive protein (CRP) levels were measured with high-sensitivity Siemens Immulite 2000, with a lower limit detection of 0.20 mg/L (36.3% of the sample).

Age was self-reported by participants and verified by birth certificate and observation date. Race was self-reported. Sexual maturity status was based on pubic hair development using the criteria developed by Tanner^{11, 12} and was physician-assessed for participants < 9 years old and self-assessed for participants ≥ 9 years old. The self-assessment tool used methods employed in the FELS Longitudinal Study.¹³ The participant self-assessed sexual maturity stage while alone in a private room equipped with a full-length mirror. Moderate-to-vigorous physical activity was self-reported using the Godin-Shephard Leisure-Time Physical Activity Questionnaire,¹⁴ which has been validated against accelerometry.¹⁵ The number of 15 minute bouts of strenuous, moderate, or mild exercise in a 7-day period was estimated, then multiplied by estimated metabolic equivalents (METs) (9 for strenuous, 5 for moderate, and 3 for mild)¹⁴ to derive total estimated METs per week.

Statistical Analyses

Each region of fat was divided by total body fat to create percentage fat (e.g. % trunk fat = trunk fat divided by whole body fat). Elevation in cardiometabolic risk factors was determined based on the 2011 National Institutes of Health Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents.^{16, 3} High triglyceride level was defined as triglycerides ≥ 75 mg/dL for those aged 5–9 years and ≥ 90 mg/dL for those aged 10–18 years. Low HDL-C level was defined as HDL-C < 45 mg/dL. High glucose level was defined as fasting glucose ≥ 100 mg/dL. High blood pressure was defined as ≥ 90th percentile for age, sex, and height.¹⁷ The Homeostatic Model Assessment was calculated to determine insulin resistance (HOMA-IR),¹⁸ with a conservative value of 4.39 selected as the criteria for insulin resistance. The high sensitivity C-reactive protein (CRP) was assessed to measure systemic inflammation. High CRP was defined as > 3 mg/L, which is the definition of high risk in adults^{19, 20} that has been used in other pediatric cohort studies.^{21, 22} Thirteen participants with a CRP value > 10 mg/L, which indicates current or recent acute infection, were excluded from the CRP analysis.

Group differences in body composition and cardiometabolic risk factors across sex and race groups were tested using independent samples *t* tests and chi squared tests. Associations between adiposity variables were assessed using bivariate correlations. Multivariable linear regression models were used to examine the associations between cardiometabolic risk factors and % fat (trunk, leg, or arm). Models were tested for each fat region individually. Whole body fat, age, sex, race, sexual maturation, and physical activity were included as

covariates. Next, each model was tested for interactions among % fat by race, sex, or sexual maturation; race by sex or sexual maturation; sex by sexual maturation; and the three-way interaction of race by sex by sexual maturation. The analysis was further stratified by sex or by race when the interaction term was significant. Finally, logistic regression models were used to examine the association of elevated cardiometabolic risk factors with each fat distribution proportion (% trunk, leg, or arm fat). Odds ratios (ORs) are expressed per standard deviation unit and reported with 95% confidence intervals. The Bonferroni correction for multiple comparisons was used to determine the significance level (0.05 divided by 7 risk factors). Statistical significance was accepted at $p < 0.007$.

Results

The mean BMI percentile was 73.2 ± 27.8 , with a median of 83.9 and an interquartile range of 54.5 to 97.3. The skewness of BMI percentile (-0.93) was due to the sampling method to attain a balance across BMI status. Table I presents descriptive characteristics of the sample stratified by sex and race, with significant differences noted. Table II presents the bivariate correlations between adiposity measurements.

Linear regression models were used to examine the associations between cardiometabolic risk factors with % trunk, leg, and arm fat, in separate models. DBP percentile and triglycerides were positively associated with % trunk fat, and HDL-C was inversely associated with % trunk fat. Triglycerides were inversely associated with % leg fat. No cardiometabolic risk factor was associated with % arm fat. Each model had a variance inflation factor of less than 5, indicating low levels of multicollinearity. Stratified analyses were conducted for the one model that had a significant interaction term and a significant main effect for % fat (Table III). Triglycerides were significantly associated with % trunk fat for whites ($p < 0.01$) but not for black ($p = 0.06$).

Logistic regression models were used to examine the odds of cardiometabolic risk factor elevation based on % trunk, leg, or arm fat, in separate models. Higher odds of low HDL-C, high triglycerides, insulin resistance, and high CRP were associated with % trunk fat (Figure). Lower odds of low HDL-C, high triglycerides, and insulin resistance were associated with % leg fat. No cardiometabolic risk elevation was associated with % arm fat.

Discussion

This study indicates that a larger proportion of leg fat is inversely associated with elevated cardiometabolic risk factors in children and adolescents. When a greater percentage of fat was distributed in the leg, the odds of high triglycerides, insulin resistance, and low HDL-C were actually lower. In other words, a child or adolescent with more fat deposited in the leg, even with the same whole body fat, was less likely to have elevated cardiometabolic risk factors than a child or adolescent with less proportionate fat deposited in the leg.

Higher odds of low HDL-C, high triglycerides, insulin resistance, and high CRP were each significantly associated with % trunk fat. Elevated cardiometabolic risk factors were associated with the distribution of fat in the trunk region in this pediatric sample. The lack of association between fasting glucose and trunk fat may be due to the low prevalence of elevated glucose in the overall sample (4%). However, the present findings do agree with a prior study of 66 obese children and adolescents, for whom fasting glucose levels did not relate to android or gynoid fat.⁶ Insulin resistance, which was more prevalent in the present sample (8%), was associated with % trunk fat but inversely associated with % leg fat. In contrast to leg or trunk fat, % arm fat was not significantly associated with cardiometabolic

risk factors. These results contradict prior findings of a positive correlation between children's dyslipidemia and high fat content in the upper arm.⁹

There were few sex or race interactions with any region of fat, indicating that the associations between cardiometabolic risk factors and regional fat mass did not vary between girls and boys or between African Americans and Whites. However, one key difference warrants further study. Triglyceride level was significantly related to % trunk fat in whites but not in blacks.

There are several potential biological mechanisms that may explain the adverse association between leg fat and cardiometabolic risk factors. Fat tissue in the leg is primarily stored subcutaneously.²³ In contrast with ectopic depots, subcutaneous fat in the leg secretes lower levels of adipokines including free fatty acids,²² tumor necrosis factor alpha,²⁴ and plasminogen activator inhibitor-1.²⁵ Peripheral fat also secretes adiponectin, which improves insulin sensitivity and lowers risk for atherosclerosis.²⁶ Furthermore, subcutaneous fat stored in the periphery may express gene coding for adipocytes differently than ectopic fat, favoring a more metabolically healthy phenotype.²⁷

An important limitation of this study was its cross-sectional design, so causal relationships cannot be inferred. It is not clear, for instance, if weight reduction may result in a preferential deposition or maintenance of leg fat and reduction in trunk fat, thereby improving the cardiometabolic profile.²² Strengths of this study include the large sample size of African American and White boys and girls with laboratory measures of cardiometabolic risk factors, the wide range of trunk and extremity fat, and the use of DXA to assess fat mass and fat percentage.

The assessment of fat distribution may have clinical utility in discriminating cardiometabolic risk in children and adolescents.

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Abbreviations

CRP	C-reactive protein
DBP	diastolic blood pressure
DXA	dual energy x-ray absorptiometry
FM	fat mass
HDL-C	high density lipoprotein cholesterol
HOMA-IR	homeostatic model of insulin resistance
OR	odds ratio
SBP	systolic blood pressure
SD	standard deviation

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Figure.

Logistic regression results for elevated cardiometabolic risk factors per 1 standard deviation unit higher % trunk fat, % leg fat, or % arm fat, controlling for whole body fat, age, sex, race, sexual maturation, and physical activity.

Note. * indicates that the 95% confidence interval is significantly different from 1.

Table 1

Descriptive characteristics of the sample stratified by sex and race.

	White Boys	African American	White Girls	African American Girls	All	p-value
n	101	84	88	118	391	
Age, years	12.2 (3.5)	11.7 (3.5)	12.3 (3.4)	12.3 (3.7)	12.2 (3.5)	0.61
Pubertal Stage, %						
I	35.6	35.7	26.1	19.5	28.6	0.04
II	16.8	13.1	15.9	8.5	13.3	
III	5.9	13.1	5.7	11.0	9.0	
IV	9.9	8.3	13.6	16.1	12.3	
V	31.7	29.8	38.6	44.9	36.8	
BMI Percentile	69.5 (28.6)	72.7 (28.0)	69.8 (25.9)	79.2 (27.6)	73.2 (27.8)	0.03
BMI Status, %						
Underweight	2.0	3.6	1.1	1.7	2.1	0.004
Normal Weight	58.4	47.6	61.4	34.8	49.6	
Overweight	11.9	15.5	15.9	14.4	14.3	
Obese	27.7	33.3	21.6	49.2	34.0	
Total Fat Mass, kg	14.0 (10.4)	13.8 (10.3)	16.9 (9.5)	21.5 (14.1) ^{a, b}	16.9 (11.9)	<0.0001
Trunk Fat Mass, kg	5.5 (5.0)	5.1 (4.5)	7.0 (4.8) ^b	8.7 (6.8) ^{a, b}	6.7 (5.6)	<0.0001
% Trunk Fat	36.3 (5.8) ^a	34.2 (5.6)	38.5 (6.2) ^b	37.5 (6.1) ^b	36.7 (6.1)	<0.0001
Leg Fat Mass, kg	5.9 (4.2)	6.1 (4.5)	7.0 (3.6)	9.4 (5.7) ^{a, b}	7.2 (4.9)	<0.0001
% Leg Fat	42.3 (4.7)	43.9 (5.0) ^a	42.5 (4.5)	44.6 (4.8) ^a	43.4 (4.8)	0.001
Arm Fat Mass, kg	1.7 (1.3)	1.6 (1.3)	2.1 (1.2) ^b	2.5 (1.7) ^{a, b}	2.0 (1.4)	<0.0001
% Arm Fat	12.0 (1.3) ^a	11.6 (1.4)	12.2 (1.2) ^a	11.5 (1.4)	11.8 (1.4)	0.0001
SBP percentile	37.2 (25.3)	35.5 (23.0)	42.9 (27.9)	45.8 (26.1)	40.6 (25.9)	0.06
DBP percentile	51.2 (21.8)	54.9 (22.5)	52.6 (24.7)	58.0 (26.1)	54.4 (24.0)	0.03
High BP, %	7.9	8.3	3.4	10.2	7.7	0.34
HDL-C, mg/dL	50.2 (12.1) ^a	56.9 (14.6)	51.1 (9.7) ^a	54.6 (10.7)	53.2 (12.0)	0.0003
Low HDL-C, %	35.6	22.6	25.0	17.0	24.8	0.01

	White Boys	African American	White Girls	African American Girls	All	p-value
Triglycerides, mg/dL	76.1 (39.8) ^a	52.8 (24.6)	83.0 (47.8) ^a	61.4 (26.4) ^b	68.2 (37.2)	<0.0001
High Triglycerides, %	33.7 ^a	10.7	40.9 ^a	15.3	24.8	<0.0001
Glucose, mg/dL	89.9 (5.4)	88.4 (6.1)	88.7 (6.0)	87.6 (7.8)	88.6 (6.5)	0.06
High Glucose, %	3.0	3.6	3.4	5.1	3.8	0.86
HOMA-IR	1.6 (1.4)	1.6 (2.1)	2.0 (2.0)	2.3 (2.7) ^b	1.9 (2.2)	0.04
Insulin Resistant, %	5.0	4.8	9.1	13.6 ^b	8.4	0.07
C-reactive Protein, mg/L ^c	0.9 (1.4)	0.9 (1.5)	1.1 (1.6)	1.5 (2.1) ^b	1.1 (1.7)	<0.0001
High CRP, %	8.9	9.5	12.5	17.8	12.5	0.14

Parentheses indicate standard deviation.

^a $p < 0.05$ between Whites and African Americans, within sex group.

^b $p < 0.05$ between boys and girls, within race group.

^c $n = 378$ due to exclusion of participants with recent or acute infection.

Table 2

Bivariate correlations between adiposity measures.

	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.
A. Trunk Fat (kg)	--	--	--	--	--	--	--	--	--	--	--	--	--
B. Trunk Fat %	0.80	--	--	--	--	--	--	--	--	--	--	--	--
C. Leg Fat (kg)	0.94	0.63	--	--	--	--	--	--	--	--	--	--	--
D. Leg Fat %	-0.29	-0.63	-0.01	--	--	--	--	--	--	--	--	--	--
E. Arm Fat (kg)	0.97	0.73	0.96	-0.19	--	--	--	--	--	--	--	--	--
F. Arm Fat %	0.14	0.20	0.14	-0.21	0.31	--	--	--	--	--	--	--	--
G. Total Fat (kg)	0.99	0.74	0.98	-0.16	0.98	0.16	--	--	--	--	--	--	--
H. % Fat	0.81	0.69	0.81	-0.11	0.84	0.36	0.82	--	--	--	--	--	--
I. BMI	0.94	0.72	0.94	-0.17	0.95	0.18	0.96	0.76	--	--	--	--	--
J. BMI Z-score	0.73	0.62	0.75	-0.12	0.77	0.37	0.75	0.80	0.82	--	--	--	--
K. WC	0.93	0.77	0.92	-0.20	0.93	0.18	0.94	0.74	0.96	0.78	--	--	--
L. WHR	0.47	0.53	0.36	-0.42	0.46	0.29	0.43	0.56	0.45	0.57	0.54	--	--
M. WHTR	0.84	0.73	0.79	-0.30	0.85	0.30	0.83	0.86	0.87	0.87	0.86	0.77	--

Note. WC indicates waist circumference, WHR indicates waist-to-hip ratio, and WHTR indicates waist-to-height-ratio.

Table 3

Linear regression results reporting beta coefficients for elevated cardiometabolic risk factors per increase in percentage trunk, leg, or arm fat.

	% Trunk Fat	% Leg Fat	% Arm Fat
SBP, mm Hg	48.8 (31.6)	11.9 (27.6)	39.0 (98.3)
DBP, mm Hg	87.5 (30.0)	−14.6 (26.4)	81.5 (93.9)
HDL-C, mg/dL	−40.9 (13.9)	16.3 (12.2)	34.8 (43.6)
Triglycerides, mg/dL	158.3 (42.3)	−96.4 (37.2)	58.8 (133.7)
Glucose, mg/dL	−8.2 (8.1)	13.7 (7.0)	13.0 (25.1)
HOMA-IR	2.6 (2.3)	−1.4 (2.0)	4.1 (7.2)
CRP, mg/L ^a	2.6 (1.8)	−2.7 (1.5)	0.4 (5.4)

Note. Each value represents beta coefficient (standard error) derived from a separate regression model. Bold indicates significance at $p < 0.007$. Models controlled for whole body fat, sex, race, age, sexual maturation, and physical activity.

^a n = 378 due to exclusion of participants with recent or acute infection.