Relations of Body Fatness and Cardiovascular Fitness to Lipid Profile in Black and White Adolescents

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ABSTRACT

High body fatness is associated with unfavorable cardiovascular disease risk profiles in juveniles. However, the degree to which the deleterious effects attributed to fatness may actually be due to the low cardiovascular fitness (CVF) that is usually confounded with fatness is not known. This study determined in 14- to 18-y-old ($n = 398$) youths the degree to which percentage body fat (%BF) and CVF explained variability in lipids and lipoproteins. Blood samples were taken after a 12-h fast. %BF was measured with dual-energy x-ray absorptiometry. CVF was determined with a multistage treadmill test. The degree to which %BF and CVF explained variance in outcome variables was determined by regression analyses, controlling for demographic variables before entering %BF or CVF and their interactions with race and sex. Because %BF and CVF were highly correlated ($r = -0.69$, $p < 0.001$), they were first entered separately in the regression models before being considered together. Both higher %BF and lower CVF were associated with unfavorable concentrations of total cholesterol to HDLC ratio and triglycerides. However, the effects of %BF and CVF were not additive; once %BF was in the regression model, CVF did not explain additional variance. For Lp(a), only %BF explained a significant portion of the variance. For triglycerides, there was a %BF by

race interaction, such that the deleterious effects of high %BF were greater in whites than in blacks. These results suggest that interventions to improve lipid profile in youths should be designed primarily to minimize fatness. (*Pediatr Res* 58: 78–82, 2005)

Abbreviations

BMI, body mass index
CVD, cardiovascular disease
CVF, cardiovascular fitness
DXA, dual-energy x-ray absorptiometry
HDLC, high-density lipoprotein cholesterol
HR, heart rate
LDLC, low-density lipoprotein cholesterol
NHANES, National Health and Nutrition Examination Survey
%BF, percentage body fat
TC, total cholesterol
TG, triglycerides
VAT, visceral adipose tissue
 $\dot{V}O_2$, oxygen consumption
WC, waist circumference

Pathophysiologic processes underlying CVD begin in childhood (1,2), suggesting that preventive measures should begin early in life. Observational studies have shown that childhood adiposity is associated with an unfavorable lipid profile (3,4), which continues into adulthood (4). However, less is known about the role of CVF. Because of the strong inverse correlation between CVF and fatness (5), it is possible that deleterious consequences ascribed to adiposity may be partially due to the

influence of low CVF, which is frequently unmeasured. If so, it would imply that interventions to prevent unfavorable lipid profiles should focus on CVF as well as adiposity. In adults, both fatness and fitness predict future mortality (6); in fact, the effects of CVF may even be more robust than the effects of fatness (7). There is some recent evidence that both fatness and fitness are related to unfavorable CVD risk factor status in youths (8).

Another issue concerns the degree to which the relations are similar for different races and sexes. We recently reported that the deleterious consequences on insulin levels of high fatness and low fitness are more clearly seen in boys than in girls (5). With respect to lipid profile, there is some evidence that the deleterious consequences of excess adiposity are clearer in white than in black youths (9), but little is known about the degree to which this is also true for CVF.

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In this article, our primary index of fatness is %BF measured with DXA. To explore the possibility that more clinically available anthropometric measures might provide valuable information, we also conducted analyses using BMI as an index of general fatness and WC as an index of central fatness.

The main purpose of this study was to determine the degree to which fatness and fitness explained variance in several lipids and lipoproteins associated with CVD. We also determined the degree to which the relations were influenced by race and sex.

METHODS

Subjects. High school students 14–18 y of age were recruited *via* flyers sent to schools in the Augusta, Georgia, area. We sought a broad sample that included blacks and whites of both sexes, from both urban and suburban schools. Because we planned to explore the interactions of race and sex with fatness and fitness, we sought to obtain approximately equal numbers in each subcategory. We provided a financial inducement for participation, which may have been more of an inducement for lower socioeconomic status youths.

The youths were apparently healthy, had no contraindications to any of the study procedures, including the treadmill test, and were taking no medications that might influence the results. Analyses were conducted on 398 subjects for whom complete data were available for %BF, CVF, and at least one lipid measure. Based on self-assessment of sexual characteristics using Tanner stages, approximately 95% of the youths were in stages 4 or 5. Interested youths and parents signed consent forms in accordance with the procedures of the Human Assurance Committee at the Medical College of Georgia.

Laboratory measurement. To reduce the discomfort of the blood draw, parents and youths were instructed to apply Emla cream (5 g tube) 1 h before reporting to the Georgia Prevention Institute at 0800 h. Each youth was to have nothing to eat or drink besides water from 2000 h the night before. Blood samples were sent to the Emory University Lipid Research Laboratory to be assayed. Plasma lipids were performed using enzymatic methods on the Beckman CX7 chemistry autoanalyzer (Beckman Coulter Diagnostics, Fullerton, CA). LDLC and HDLC were determined using homogeneous assay kits (Equal Diagnostics, Exton, PA). LDL particle diameter was determined by nondenaturing gradient gel electrophoresis as previously reported (10).

Weight was assessed with a balance scale and height with a stadiometer; and BMI was calculated (kg/m^2). Total body composition was measured with DXA using the Hologic QDR-4500W or QDR-1000W (Waltham, MA). DXA provides reliable measurement of %BF. In the first 219 youths from the current project, we performed repeat measurements and found the intraclass correlation to be 0.99 (11). For some subjects, DXA values were not available from the Hologic QDR-4500W model, but were available only from the Hologic QDR-1000W model. For these individuals, %BF values were derived from the prediction equations that were derived on 284 youths who were assessed on both instruments, using linear regression; race, sex, and QDR-1000W measurement were the predictor variables. The multiple R^2 value for %BF was 0.99. We used %BF rather than BMI as the primary index of fatness because BMI can misclassify people as obese who are really overweight due to having large amounts of fat-free mass (FFM), such as athletes (12), and it is fatness rather than weight that is associated with poor cardiovascular health (13). WC was measured with a tape measure at the level of the umbilicus.

CVF was measured with a multistage treadmill test. HR was monitored during the test using a Polar Accurex Plus HR monitor (Port Washington, NY). $\dot{V}\text{O}_2$ was measured using a Sensormedics $\dot{V}_{\text{max}}$ 229 cardiopulmonary system (Yorba Linda, CA). The treadmill protocol began with a 3-min warm-up at 0% grade and 2.0 mph. The speed was then increased by 0.5 mph every 2 min until reaching 3.5 mph, at which time the grade was increased by 2% every minute until reaching 16% grade, after which the treadmill speed was increased by 0.5 mph every minute until voluntary exhaustion. Verbal cues were given to encourage a maximal effort. To designate the peak value attained as a true $\dot{V}\text{O}_{2\text{max}}$, the youth had to meet two of the following three criteria: 1) an increase in HR <5 bpm between the final two workloads; 2) an increase in $\dot{V}\text{O}_2 <100$ mL between the final two workloads; and 3) a respiratory exchange ratio >1.00 .

Because a substantial proportion of children, especially those with higher fat and lower CVF levels, typically fail to meet objective criteria for $\dot{V}\text{O}_{2\text{max}}$, our primary index of CVF was submaximal in nature: the $\dot{V}\text{O}_2$ at a HR of 170 bpm, per kilogram of body weight ($\dot{V}\text{O}_{2-170}$). In this sample, 183 (45% of the subjects) did not attain $\dot{V}\text{O}_{2\text{max}}$. The HR response to a given workload or level of energy expenditure is an accepted index of CVF (14). Using all the treadmill workloads completed by each youth, we computed individual regression

equations of $\dot{V}\text{O}_2$ on HR for each youth. The $\dot{V}\text{O}_2$ corresponding to a HR of 170 bpm was calculated and per unit of body weight ($\text{mL}/\text{kg}/\text{min}$). Youths who are more fit exhibit a higher $\dot{V}\text{O}_2$ (*i.e.* a higher treadmill work rate) before their HR reach 170 bpm. For the 215 youths who achieved $\dot{V}\text{O}_{2\text{max}}$, the correlation between $\dot{V}\text{O}_{2\text{max}}$ and $\dot{V}\text{O}_{2-170}$ was 0.83 ($p < 0.0001$).

Statistical analysis. All variables were checked for normality of distribution, and appropriate transformations applied when necessary. Group comparisons were made on unweighted means using 2×2 analyses of covariance (sex by race), adjusting for age.

Multiple regression was performed to assess the correlates of each of the lipid factors. We tested these relationships in separate regression models that always retained age, sex, race, and the sex $\times$ race interaction as the base model. Because %BF and CVF are so highly (and inversely) correlated ($r = -0.69$, $p < 0.0001$), they are difficult to disentangle in an observational study. Thus, we first investigated the degree to which each alone explained variance in the lipid factor, before examining their joint influence in a single model. Regression Model 1 addressed the question of whether CVF and its interactions with sex and race were significant predictors of the lipid factor. Model 2 examined the influence of %BF and its interactions. In Model 3, we included only significant variables from Models 1 and 2 to evaluate the contributions of both CVF and %BF in explaining variance in the risk factor. In Model 4, we added a CVF by %BF interaction term to Model 3 to test whether such an interaction term could make a unique contribution in explaining variation in the lipid factor. We excluded all nonsignificant variables in the final models. With respect to the anthropometric measurements, BMI and WC were so highly correlated ($r = 0.88$, $p < 0.0001$) that we did not include both in a single model. To see how much variance can be explained by BMI and WC, each was regressed on the lipid factor using the same regression model described previously.

Statistical significance was set at $\alpha < 0.05$. The statistical analyses were conducted with SPSS 11.5 (SPSS Inc., Chicago, IL).

RESULTS

Table 1 shows the descriptive characteristics of the subjects. The distribution of the subjects' BMI categories was similar to those reported in current NHANES data. Fourteen percent were overweight (BMI-for-age ≥ 95 th percentile), 13% were at risk of overweight (BMI-for-age 85th percentile to <95 th percentile), and 4% were underweight (BMI-for-age <5 th percentile). BMI was higher in the blacks than in the whites. The girls were higher than the boys in %BF and lower in CVF and WC. The whites were higher than the blacks in CVF.

Although intensive analyses of race-sex differences in the lipid variables are beyond the scope of this article, they are described here to indicate the nature of the adjustments made in the regression analyses that determined the influence of fatness and fitness. For some of the lipid variables (*i.e.* TC and LDLC), there were race-sex interactions, such that the black males had especially unfavorable levels compared with the white males, whereas the race difference was not so clear in the females. There was also a race-sex interaction for HDLC, such that white males had the most unfavorable levels, whereas the black females had the most favorable levels. The blacks had less favorable values of Lp(a) than the whites, whereas the whites were higher than the blacks in TG.

Table 2 shows the results of the regression analyses, in which the demographic variables were included as covariates, but are not shown. Only significant variables were retained in the models and are reported in Table 2. The substantive results were similar for TC, HDLC, LDLC, and the TC/HDLC ratio. Therefore, we reduced redundancy among these variables by reporting the results for only the TC/HDLC ratio.

Both CVF in Model 1 and %BF in Model 2 explained significant proportions of the variance TC/HDLC ratio [squared semi-partial correlation coefficient (sr^2) = 0.029 and

Table 1. Descriptive data for all subjects and by race and sex subgroup

	All subjects		Males				Females				ANCOVA group comparison*
			Whites		Blacks		Whites		Blacks		
	<i>n</i> = 398		<i>n</i> = 103		<i>n</i> = 84		<i>n</i> = 99		<i>n</i> = 112		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Age (y)	16.13	1.19	16.17	1.21	15.91	1.09	16.13	1.18	16.26	1.25	NS
%BF	24.09	9.73	18.76	7.62	16.80	8.85	29.51	7.23	29.67	7.49	F > M
Fat mass (kg)	16.12	9.79	13.11	8.14	12.48	9.86	17.85	8.40	20.09	10.48	F > M
Fat free mass (kg)	47.98	9.72	52.87	8.48	56.10	8.75	40.23	5.23	44.23	7.10	M > F
BMI (kg/m ²)	22.96	4.93	22.03	4.21	23.00	4.80	22.09	4.35	24.56	5.71	B > W‡
Waist circumference (cm)	74.00	10.48	76.02	9.37	75.31	11.08	70.87	9.33	73.92	11.40	M > F
CVF (mL/kg/min)	27.56	7.76	33.23	6.73	31.22	7.38	24.66	5.75	22.16	5.20	W > B, M > F
TC (mmol/L)	3.77	0.70	3.49	0.63	3.92	0.74	3.85	0.63	3.86	0.71	Interaction
TG (mmol/L)	0.71	0.38	0.83	0.53	0.64	0.29	0.77	0.34	0.58	0.22	W > B†
HDL (mmol/L)	1.19	0.27	1.05	0.21	1.21	0.24	1.21	0.22	1.27	0.32	Interaction‡
TC/HDL	3.29	0.80	3.41	0.81	3.34	0.84	3.29	0.77	3.16	0.77	NS
LDL (mmol/L)	2.38	0.69	2.21	0.59	2.52	0.75	2.42	0.70	2.40	0.70	Interaction‡
Lp(a) (mg/dL)	46.12	48.27	29.09	33.22	60.91	53.36	30.45	35.02	64.66	55.79	B > W‡
LDL-S (nm)	25.84	0.81	25.89	0.74	25.80	0.75	25.86	0.91	25.81	0.82	NS

Analyses were performed on † inversely and ‡ log-transformed data. Lp(a), lipoprotein (a); LDL-S, LDL particle size.

* Significance set at $p < 0.05$

Table 2. Significant predictors for lipid variables from multiple regression models

Dependent variable	Predictors	B	SE	$p <$	sr^2	Adjusted model R^2
TC/HDL†	Model 1	CVF	−0.002	0.001	0.001	0.029
	Model 2	%BF	0.004	0.000	0.0000	0.128
	Model 3	Model 2				
TG*	Model 1	CVF	−0.002	0.001	0.011	0.015
	Model 2	%BF	0.010	0.002	0.0001	0.046
		Race*%BF	−0.004	0.001	0.002	0.021
	Model 3	Model 2				
Lp(a)†	Model 1	None				
	Model 2	%BF	0.009	0.003	0.002	0.020
	Model 3	Model 2				0.156

Analyses were performed on * inversely and † log-transformed data. TC/HDL, total cholesterol to high-density lipoprotein cholesterol ratio; Lp(a), lipoprotein (a); B, unstandardized coefficients; SE, standardized error for B; sr^2 , squared semi-partial correlation coefficient.

0.128, respectively]. Model 3 was the same as Model 2; *i.e.* CVF did not contribute significantly once %BF was in the model.

When inversely transformed TG was the outcome variable, CVF explained a significant proportion of the variance in Model 1 ($sr^2 = 0.015$). Model 2 revealed a significant contribution of %BF ($sr^2 = 0.046$) and the race by %BF interaction ($sr^2 = 0.021$), such that the deleterious impact of %BF on TG was greater in the whites than in the blacks (Fig. 1). Model 3 was the same as Model 2.

For Lp(a), Model 1 showed that CVF did not contribute significantly and Model 2 showed that %BF explained a significant proportion of the variance ($sr^2 = 0.02$); higher %BF was associated with higher Lp(a).

For LDL particle size, neither CVF nor %BF contributed significantly (data not shown).

Table 3 shows the results of the regression analyses using the anthropometric indices as predictor variables. Both BMI and WC explained significant and similar proportions of the variance in TC/HDL ($sr^2 = 0.12$ and 0.13 , respectively), TG ($sr^2 = 0.08$ and 0.08 , respectively), and Lp(a) ($sr^2 = 0.02$ and 0.01 , respectively).

Figure 1. Interaction of %BF and race on triglycerides. The regression analyses were performed on %BF as a continuous variable; however, in the figure it is broken into three groups to illustrate the nature of the interaction.

Table 3. Multiple regression with anthropometric measures as predictor variables

Dependent variable	Predictor variable	B	SE	<i>p</i> <	sr ²	Adjusted model R ²
TC/HDL [†]	BMI [†]	0.33	0.04	0.0000	0.12	0.13
TG*	BMI [†]	−0.36	0.06	0.0000	0.08	0.14
Lp(a) [†]	BMI [†]	0.83	0.29	0.0047	0.02	0.15
TC/HDL [†]	Waistcircumference [†]	0.50	0.06	0.0000	0.13	0.14
TG*	Waistcircumference [†]	−0.54	0.09	0.0000	0.08	0.14
Lp(a) [†]	Waistcircumference [†]	0.75	0.43	0.0780	0.01	0.14

Analyses were performed on * inversely and [†] log transformed data. TC/HDL[†], total cholesterol to high-density lipoprotein cholesterol ratio; Lp(a), lipoprotein (a); B, unstandardized coefficients; SE, standardized error for B; sr², squared semi-partial correlation coefficient.

DISCUSSION

The primary finding of this study was that more favorable lipid profiles were associated with higher CVF and lower %BF. For most variables, %BF was slightly more predictive; thus, when both were included in the regressions (Model 3), only %BF and its interactions with demographic factors explained a significant proportion of the variance. It is important to note that the collinearity of CVF and %BF makes it difficult to disentangle their separate influences in an observational study. Thus, we examined the influence of each variable and its interaction with age, race, and sex before including both variables in one model. This allowed us to see that each explained a significant proportion of the variance in most variables, but when entered together only %BF remained in the models. It is possible that the greater precision of the %BF measurements permitted it to explain slightly more of the variance than did CVF. The most parsimonious conclusion is that both are important, but that %BF explains somewhat more of the variance in the lipid variables when considered by itself.

The finding that higher %BF and lower CVF were associated with a poorer lipid profile is consistent with those of other studies of youths (3,8). Our finding that the association between higher fatness levels with unfavorable levels of TG was greater in whites than in blacks is consistent with data from the Bogalusa study (9). However, such interactions with race were not seen for CVF, despite the fact that %BF and CVF were highly and inversely correlated. There appears to be some race-linked factor that influences the impact of body fatness on TG metabolism.

Our finding that both BMI and WC explained similar proportions of the variance in lipid factors as the DXA-derived measurement of %BF indicates that clinicians can feel confident in using these easily-derived indices of fatness in their screening and counseling efforts. It is also noteworthy that BMI and WC explained similar amounts of the variance; thus, no evidence was provided that central fatness is especially highly correlated to lipid profile compared with general fatness.

A limitation of this study is the cross-sectional design, which precludes firm conclusions about whether the variations in fatness and fitness cause the variation in lipid profile. However, the results are consistent with the results of experimental studies in which exercise and diet interventions that improved CVF and body composition also improved the lipid profiles of obese youths (15). Thus, to some extent, CVF and %BF probably play a causal role in the development of atherogenic lipid profiles.

We found that %BF, but not CVF, was associated with higher concentrations of Lp(a), a molecule which has both atherogenic and thrombogenic components (16). This suggests another pathway through which obesity adversely affects cardiovascular health.

We found that LDL particle size was not associated with %BF or CVF, which was a surprise in light of our previous finding that physical training that resulted in reduced %BF and improved CVF also led to an increase in LDL size in obese youths (15). However, this physical training study also found a decrease in VAT, which we found to be related to the small, dense LDL phenotype even when %BF was not (17). Taken together, these results suggest that VAT may be the key fat depot that adversely influences LDL size.

In conclusion, this cross-sectional study of black and white adolescents found that unfavorable lipid profiles were associated with higher fatness and lower fitness. For most variables, the influence of fatness was slightly greater than the influence of fitness. Taken together with findings from other studies, our results support the concept that weight control interventions during juvenile years may improve lipid metabolism, thus helping to prevent the progression of pathophysiologic processes that contribute to the development of cardiovascular disease later in life.

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