Changes in Blood Lipids Consequent to Aerobic Exercise Training Related to Changes in Body Fatness and Aerobic Fitness

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The contribution of changes in body fatness and aerobic fitness to changes in blood lipids after aerobic exercise training was investigated. The sample included 295 men (77 black, 218 white) and 355 women (131 black, 224 white), aged 17 to 65 years, from the HERITAGE Family Study. Participants underwent measurements at baseline and after 20 weeks of supervised exercise training on a cycle ergometer. Body fat mass (FM, in kilograms) was determined by underwater weighing, and aerobic fitness (maximal oxygen uptake, $\dot{V}O_{2max}$, in milliliters per minute) was assessed by cycle ergometry. Blood lipid measurements included fasting plasma levels of high-density lipoprotein cholesterol (HDL-C), HDL_2-C, HDL_3-C, low-density lipoprotein cholesterol (LDL-C), total cholesterol (CHOL), CHOL/HDL, and triglycerides (TG). A composite lipid change index (LCI) was derived by subjecting the Δ scores for the individual blood lipids to principal components analysis. The exercise training was accompanied by a mean increase of 17.5% in $\dot{V}O_{2max}$ and a mean decrease of 3.3% in FM. Partial correlations, controlled for age, between absolute changes in $\dot{V}O_{2max}$ and changes in the blood lipids were consistently low and nonsignificant. On the other hand, absolute changes in FM were significantly ($P < .05$) associated with changes in HDL-C ($r = -.23$), HDL_2-C ($r = -.17$), and CHOL/HDL ($r = .24$) and the LCI ($r = -.27$) in men and with changes in LDL-C ($r = .22$), CHOL ($r = .19$), and CHOL/HDL ($r = .15$) and the LCI ($r = -.19$) in women. Forward stepwise regression confirmed that the change in FM was a better predictor of changes in blood lipids than the change in $\dot{V}O_{2max}$, entering as a predictor in 4 of 8 regressions in both men and women. Change in $\dot{V}O_{2max}$ did not enter as a significant predictor in any regression. Further, there were no differences in LCI between the upper and lower quartiles of $\dot{V}O_{2max}$ change. On the other hand, there were significant differences between the low and high quartiles of FM change. No race effects were observed in any of the relationships, except that race was a significant predictor of changes in TG in both men and women. In conclusion, changes in blood lipids associated with aerobic exercise training do not appear to be related to changes in aerobic fitness per se; rather, they are weakly to moderately associated with changes in body fatness.

THE TRADITIONAL exercise recommendations of the American College of Sports Medicine for the maintenance of aerobic fitness call for 20 to 60 minutes of physical activity at an intensity of 55% to 90% of maximal heart rate 3 to 5 times a week.[1] On the other hand, the current public health recommendations from the Centers for Disease Control and Surgeon General, targeted at the largely sedentary North American population, are for 30 minutes of "moderate" levels of physical activity on most (preferably all) days of the week.[2] Part of the rationale for recommending moderate levels of activity has been the realization that health benefits can accrue at levels of activity below the threshold at which significant improvements in aerobic fitness may occur.

Coronary heart disease (CHD) remains a major health concern in North America. Major risk factors for CHD include smoking, dyslipidemia, hypertension, obesity, and physical inactivity,[3] all of which are potentially modifiable through changes in lifestyle. The focus of the present study is on blood lipids because plasma levels of total cholesterol (CHOL) and the various subfractions are related to risk of CHD,[4] ie, a poor lipid profile promotes and contributes to coronary artery atherosclerosis, the most common cause of cardiac ischemia and infarction.[5]

In general, there is a weak cross-sectional relationship between aerobic fitness and levels of blood lipids in adults.[6] In particular, physically active individuals tend to have higher levels of high-density lipoprotein cholesterol (HDL-C) and lower levels of triglycerides (TG) and low-density lipoprotein cholesterol (LDL-C) than those who are sedentary. On the other hand, the results of training studies on changes in blood lipid levels are equivocal. In general, there is an increase in HDL-C or the HDL/CHOL ratio and a decrease in TG consequent to exercise training. However, few studies have observed changes in LDL-C levels.[6] The changes in blood lipids accompanying 20 weeks of supervised aerobic training in the HERITAGE Family Study have recently been reported.[7] Although there were no significant changes in CHOL, LDL-C, very-low-density lipoprotein (VLDL), or apolipoprotein (apo) B after training, there was a significant increase in HDL-C, particularly HDL_2-C, with an associated increase in apo A-1.[7]

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It has been suggested that the changes in HDL-C observed with training are mostly attributable to the exercise itself rather than to changes in body fatness.[8] On the other hand, a review of several studies concluded that prolonged low-intensity (~50% maximal oxygen uptake [$\dot{V}O_{2max}$]) exercise results in improvements in lipid profiles that are largely independent of changes in cardiorespiratory fitness.[9] Whether weight loss is required for HDL to increase with exercise training is controversial. There is some evidence that exercise-induced weight loss is required,[10-12] and other studies indicate that exercise can have an independent effect on HDL.[13-15] Further work is needed to elucidate the relationship between changes in fitness, fatness, and blood lipid levels that occur with exercise training.

The purpose of this study was to examine changes in blood lipid levels in relation to changes in both aerobic fitness and body fatness after 20 weeks of standardized, supervised aerobic exercise training. Directly measured $\dot{V}O_{2max}$ and densitometrically measured fat mass (FM) were used as the indicators of aerobic fitness and body fatness, respectively.

SUBJECTS AND METHODS

Sample

The HERITAGE Family Study was designed to investigate the genetics of cardiovascular, metabolic, and hormonal responses to aerobic exercise training and the contribution of regular exercise to changes in risk factors for cardiovascular disease and type 2 diabetes. The aims and design of the HERITAGE Family Study have been described in detail.[16] Briefly, the participating research centers consisted of 4 clinical centers—Arizona State University (now Indiana University), Laval University (now Pennington Biomedical Research Center), University of Minnesota, University of Texas at Austin (now Texas A&M University)—and a data coordinating center at Washington University (St. Louis, MO). Recruitment of participants was based on extensive publicity and advertisements at the clinical centers. The essential criteria for participation in the HERITAGE Family Study included age between 17 and 65 years, being healthy but sedentary (no regular physical activity over the previous 6 months), body mass index (BMI) usually under 40 kg/m^2, and systolic/diastolic blood pressure less than 159/99 mm Hg. Individuals with confirmed or possible CHD, hypertension, chronic or recurrent respiratory problems, and uncontrolled endocrine and metabolic disorders (including diabetes and use of lipid-lowering drugs) were excluded from the study. The sample included here consists of 295 men (77 black, 218 white) and 355 women (131 black, 224 white) for whom measures of aerobic fitness, body fatness, and blood lipids were available before and after the training program. The characteristics of the participants are shown in Table 1.

Table 1. Descriptive Characteristics of Sample at Baseline and Changes After 20 Weeks of Aerobic Exercise Training

Variable	Baseline		Change	
	Mean	SD	Mean	SD
Men				
Age (yr)	35.9	14.4	—	—
Vo_{2max} (L/min)	2.96	0.58	0.44	0.22*
FM (kg)	20.0	10.6	−0.8	1.7*
HDL-C (mmol/L)	0.95	0.20	0.03	0.11*
HDL_2-C (mmol/L)	0.27	0.13	0.02	0.10*
HDL_3-C (mmol/L)	0.68	0.12	0.01	0.09
LDL-C (mmol/L)	3.05	0.86	−0.03	0.39
CHOL (mmol/L)	4.51	1.00	−0.004	0.44
CHOL/HDL	5.03	1.66	−0.16	0.67*
TG (mmol/L)	1.44	0.80	−0.02	0.53
Women				
Age (yr)	34.1	12.9	—	—
Vo_{2max} (L/min)	1.85	0.36	0.34	0.16*
FM (kg)	22.7	11.1	−0.6	2.0*
HDL-C (mmol/L)	1.15	2.26	0.05	0.14*
HDL_2-C (mmol/L)	0.42	0.19	0.05	0.14*
HDL_3-C (mmol/L)	0.72	0.14	−0.001	0.12
LDL-C (mmol/L)	2.87	0.76	−0.03	0.38
CHOL (mmol/L)	4.33	0.87	0.02	0.43
CHOL/HDL	3.93	1.06	−0.13	0.49*
TG (mmol/L)	1.05	0.49	−0.009	0.33

* Change significantly different from 0 at $P < .05$.

Measures

Each participant was examined on a battery of measurements both before and after a 20-week standardized exercise training program. The study personnel were centrally trained on all aspects of recruitment and measurement protocols using a specially prepared manual of procedures. Data quality was assured through an extensive quality control program.[17]

Aerobic fitness. Two progressive maximal exercise tests were conducted on separate days both before and after training on a cycle ergometer (SensorMedics, Yorba Linda, CA) connected to a SensorMedics 2900 metabolic cart. Heart rate was monitored using an electrocardiogram. Gas exchange parameters ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, and respiratory exchange ratio [RER]) were recorded as rolling averages of three 20-second intervals. Two tests were conducted both before and after training. In the first test, participants exercised at a power output of 50 W for 3 minutes, followed by increases of 25 W each 2 minutes until they reached volitional fatigue. For older, smaller, or less fit individuals, the test was started at 40 W, with increases of 10 to 20 W each 2 minutes thereafter. For the second test, participants exercised for 10 to 12 minutes at a power output of 50 W, had a rest period, and then exercised at a relative power output of 60% $\dot{V}O_{2max}$ for 10 to 12 minutes, followed by 3 minutes at a relative power output of 80% $\dot{V}O_{2max}$. Resistance was then increased to the highest power output attained in the first test. If the participant was able to pedal after 2 minutes, power output was increased each 2 minutes thereafter until volitional exhaustion. The criteria for $\dot{V}O_{2max}$ were RER > 1.1, plateau of $\dot{V}O_2$ (change < 100 mL/min in the last three 20-second intervals), and heart rate within 10 beats/min of predicted maximal heart rate. All participants achieved $\dot{V}O_{2max}$ by one of these criteria on at least 1 of the 2 tests both before and after training. The average $\dot{V}O_{2max}$, expressed in milliliters per minute, from the 2 tests before and after training was taken as $\dot{V}O_{2max}$ for each participant if the 2 values were within 5% of one another. If they differed by more than 5%, the higher value was used. Reproducibility of $\dot{V}O_{2max}$ in these participants is quite high, with an intraclass correlation of 0.97 for repeated measures and a coefficient of variation of 5%.[18]

Body fatness. FM was determined from measurements of body density from underwater weighing, with a correction made for residual lung volume by the oxygen dilution technique[19] at 3 of the clinical centers and by the helium dilution technique[20] at the fourth (Laval University Clinical Center). A detailed explanation of the underwater weighing method is found elsewhere.[21] Briefly, relative body fat was estimated from body density using equations for white men,[22] white women,[23] black men,[24] and black women[25] and converted to absolute FM.

Blood lipids. Fasting (12 hour) blood samples were obtained from an antecubital vein and collected into vacutainer tubes con-

taining ethylenediaminetetraacetic acid twice, at baseline and 72 hours after the last exercise training session. For women, samples were obtained in the early follicular phase of the menstrual cycle. The 2 baseline samples were averaged for the purpose of this study. Plasma was ultracentrifuged, and the top fraction containing VLDL was quantitatively recovered. The LDL in the ultracentrifuged bottom fraction was precipitated with heparin and $MgCl_2$,[26,27] and HDL was obtained in the supernatant. Selective precipitation was used to isolate HDL_2 and HDL_3 subfractions using dextran sulfate.[28] The concentrations of cholesterol[29] in the lipoprotein fractions were measured using a Technicon RA-500 analyzer (Bayer, Tarrytown, NY).

To adjust for potential plasma volume changes accompanying the exercise training, plasma total proteins were analyzed using the Biuret method (Roche Molecular Biochemicals, Dallas, TX) on the baseline and posttraining specimens. Posttraining values were corrected based on the correlation of pretraining to posttraining plasma total protein levels.

Training Program

Each participant completed a 20-week standardized aerobic training program. The exercise training involved 3 sessions per week of supervised exercise on a cycle ergometer (Universal Aerocycle, Cedar Rapids, MI). Participants started at 55% of their baseline $\dot{V}O_{2max}$ for 30 minutes per session and progressed in intensity or duration every 2 weeks following a standardized protocol until they were working at 75% $\dot{V}O_{2max}$ for 50 minutes per session for the final 6 weeks of the program. Participants were counseled at baseline and midway through the training program not to alter their health habits and to continue their usual eating pattern, physical activity outside of the study, alcohol and tobacco use, and oral contraceptive or hormone replacement therapy. More details about the exercise training program have been provided elsewhere.[30]

Statistical Analyses

Absolute changes in $\dot{V}O_{2max}$, FM, and blood lipids after training were calculated by subtracting posttraining from baseline values (Δ scores). To study the changes in the blood lipid "profile" in addition to changes in the individual lipids, principal components analysis was used. Briefly, the Δ scores for the individual blood lipids were subjected to principal components analysis, and the first principal component scores were saved and used as a composite lipid change index (LCI). Partial correlations, controlled for age, between changes in individual risk factors, LCI, and changes in aerobic fitness and FM were calculated. Forward stepwise regression was then used to predict the changes in blood lipid levels based on changes in FM, aerobic fitness ($\dot{V}O_{2max}$, mL/min), and the potentially confounding effects of age, baseline level of the blood lipid, smoking status (0, no; 1, yes), and race (0, black; 1, white). Differences in LCI between the upper and lower quartiles of changes in $\dot{V}O_{2max}$ and FM were examined using analysis of covariance, with age, race, and smoking status included as covariates. All analyses were conducted using SAS procedures (SAS Institute, Cary, NC).[31]

RESULTS

Table 1 presents the baseline levels and mean changes in fitness, fatness, and blood lipid levels after 20 weeks of aerobic training. Overall, the training was accompanied by a mean increase of 17.5 % in $\dot{V}O_{2max}$ and a mean decrease of 3.3% in FM (both $P < .05$). Results of the principal components analysis of the Δ scores is presented in Fig 1. The first principal component explained 34.4% and 35.5% of the variance in lipid Δ scores in men and women, respectively. The factor loading

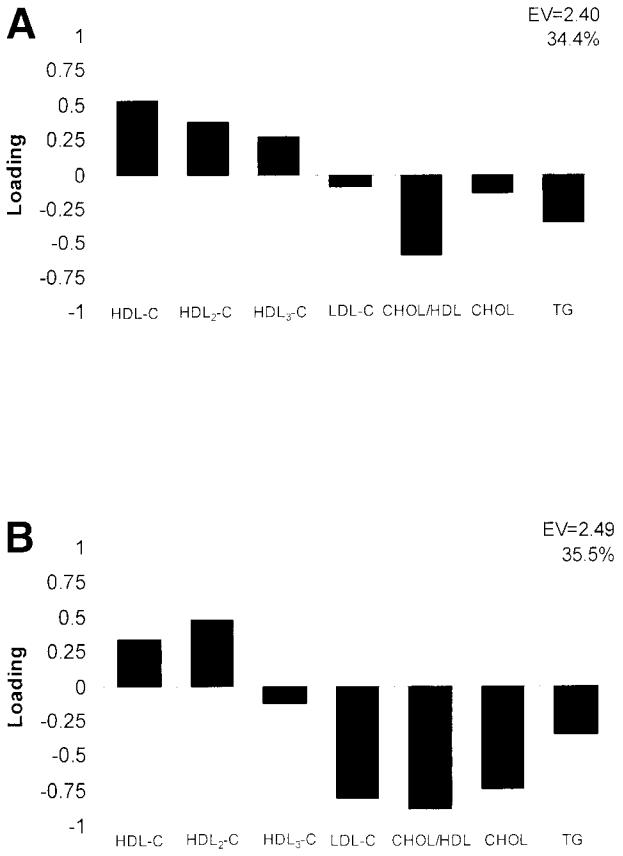

Fig 1. Risk factor loadings on LCI, derived from principal components analysis of the risk factor change scores in (A) men and (B) women. The eigenvalue (EV) and percentage of the variance accounted for by the LCI (first principal component) are provided in the inset.

pattern indicates that the response to training was similar in men and women because there are positive loadings for HDL-C and HDL_2-C and negative loadings for CHOL/HDL and TG. The loading for HDL_3-C was low and positive in men and low and negative in women. Additionally, the loadings were stronger for LDL-C and CHOL in women, suggesting some sex differences in the response to exercise for blood lipids. The second and third principal components explained successively less variance in the response, and the loading patterns could not be interpreted meaningfully. Thus, only the first principal component was retained for further analysis (LCI).

Figures 2 and 3 show the partial correlations between changes in aerobic fitness, body fatness, and blood lipid levels in men and women, controlling for age. The correlations between changes in $\dot{V}O_{2max}$ and changes in the risk factors were consistently low and nonsignificant. On the other hand, changes in FM were significantly ($P < .05$) associated with changes in HDL-C ($r = -.23$), HDL_2-C ($r = -.17$), and CHOL/HDL ($r = .24$) and the LCI ($r = -.27$) in men and with changes in LDL-C ($r = .22$), CHOL ($r = .19$), and CHOL/HDL ($r = .15$) and the LCI ($r = -.19$) in women.

Forward stepwise regression analysis confirmed that FM was a better predictor of changes in risk factors than $\dot{V}O_{2max}$ be-

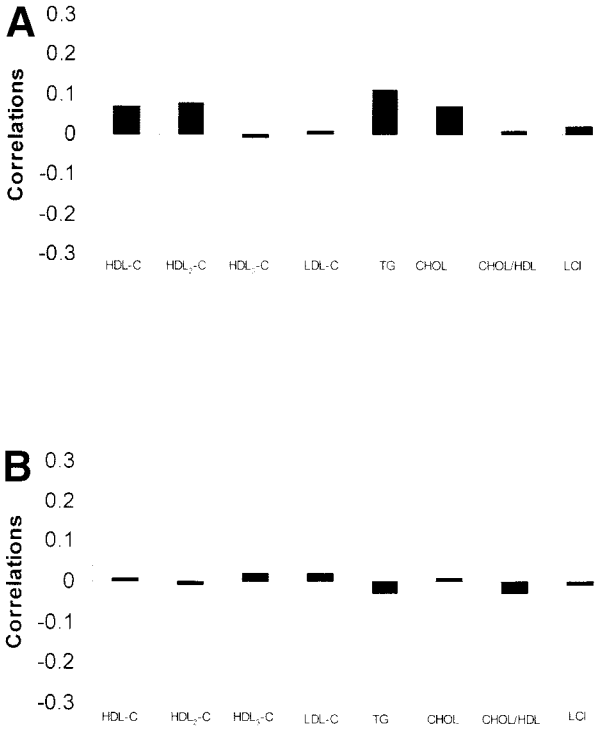

Fig 2. Correlations between changes in $\dot{V}O_{2max}$ and changes in risk factors after 20 weeks of aerobic exercise training in (A) men and (B) women. None of the correlations are significant at $P < .05$.

cause changes in FM entered as a predictor in 4 of 8 regressions in both men and women, whereas change in $\dot{V}O_{2max}$ did not enter as a significant predictor in any regression (Table 2). Figure 4 outlines the results of the analyses of covariance between the upper and lower quartiles of response in $\dot{V}O_{2max}$ and FM for differences in LCI. There were no differences in LCI between the upper and lower quartiles of change in $\dot{V}O_{2max}$; however, participants in the lower quartile of change in FM (lost more FM) had a higher LCI than those in the upper quartile of change in FM (lost less or gained FM).

Race effects were observed for changes in HDL$_3$-C in women and for changes in TG in both men and women (Table 2). However, the amount of variance accounted for by race in these regressions was small, ranging from 1.3% to 4%. Race did not enter as a significant predictor in any of the other regressions in Table 2. Correlations between changes in $\dot{V}O_{2max}$, FM, and blood lipid levels followed a similar pattern when stratified by race, as in the combined sample. Correlations between changes in $\dot{V}O_{2max}$ and LCI were uniformly low and nonsignificant in all 4 sex-by-race groups, and correlations between changes in FM and LCI were moderate and significant in all groups (Table 3).

DISCUSSION

On average, the exercise training program in the HERITAGE Family Study resulted in significant mean increases in HDL-C but had no effect on LDL-C or CHOL.[7] The protocol of the HERITAGE Family Study was designed to elicit increases in aerobic fitness, and the study was successful in this endeavor because there was a significant mean increase in $\dot{V}O_{2max}$ of 17.5%. However, the increases observed in aerobic fitness were not uniform. Some individuals' fitness levels increased considerably, and others had no increase in fitness (range from approximately 0% to 51%). Similarly, although the mean change in body fatness was quite small (but significant),[32] the response to training for several indicators of adiposity showed considerable interindividual variability.[33] Thus, it is difficult to resolve whether the changes in blood lipid levels observed in this study are primarily associated with changes in fitness or fatness based on the mean changes that occurred because of the great heterogeneity in response. One must consider individual responses to the exercise protocol across the entire range of variation. Thus, in this study we used correlation and regression analyses on the individual scores in addition to examining overall mean changes in the variables.

The analyses in this paper are based on absolute changes in $\dot{V}O_{2max}$ (mL/min) and FM (kg) rather than on relative changes (%). However, when the data were analyzed using relative changes in these variables, the results were virtually identical (results not shown). The correlations between relative changes in $\dot{V}O_{2max}$ and the changes in blood lipid levels were uniformly low and nonsignificant, whereas the relative changes in FM where related to changes in the same blood lipid fractions as were absolute changes in FM. Thus, for conciseness, only the relationships with absolute changes in $\dot{V}O_{2max}$ and FM are presented here.

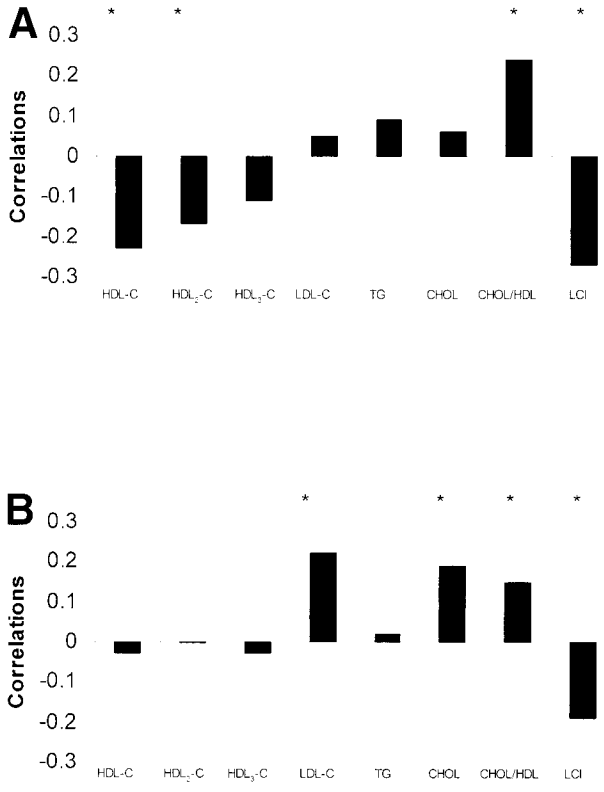

Fig 3. Correlations between changes in FM and changes in risk factors after 20 weeks of aerobic exercise training in (A) men and (B) women. *$P < .05$.

Table 2. Results of Forward Stepwise Multiple Regression Analyses to Predict Changes in Blood Lipid Levels After 20 Weeks of Aerobic Exercise Training From Age, Race, Smoking Status, Baseline Levels, Changes in $\dot{V}O_{2max}$, and Changes in FM

Variable	Model R^2	Predictors		
		R^2	β	Variable
Men				
Δ HDL-C	5.5	5.5	0.02	Δ FM
Δ HDL_2-C	7.3	5.7	−0.16	Baseline HDL_2-C
		1.6	−0.01	Δ FM
Δ HDL_3-C	5.9	5.9	−0.19	Baseline HDL_3-C
Δ LDL-C	3.5	3.5	−0.09	Baseline LDL-C
Δ CHOL	2.3	2.3	−0.09	Baseline CHOL
Δ CHOL/HDL	16.1	12.5	−0.14	Baseline CHOL/HDL
		3.6	0.08	Δ FM
Δ TG	14.0	12.7	−0.39	Baseline TG
		1.3	0.13	Race
LCI	7.1	7.1	0.16	Δ FM
Women				
Δ HDL-C	—	—	—	No variables entered
Δ HDL_2-C	4.1	4.1	−0.14	Baseline HDL_2-C
Δ HDL_3-C	17.9	16.5	−0.37	Baseline HDL_3-C
		1.4	0.03	Race
Δ LDL-C	13.4	7.2	0.16	Baseline LDL-C
		4.3	0.04	Δ FM
		1.9	0.005	Age
Δ CHOL	10.3	4.6	−0.14	Baseline CHOL
		3.3	0.04	Δ FM
		2.4	0.006	Age
Δ CHOL/HDL	9.1	5.2	−0.12	Baseline CHOL/HDL
		2.0	0.006	Age
		1.9	0.04	Δ FM
Δ TG	7.1	3.1	−0.18	Baseline TG
		4.0	0.14	Race
LCI	3.3	3.3	0.09	Δ FM

NOTE. R^2 values are expressed as percentages (ie, × 100).

The results of the forward stepwise multiple regression analyses indicate that overall, changes in blood lipid levels associated with the standardized exercise training program are only moderately predicted from the variables used in this study (Table 2). Only up to 18% of the variance in changes in blood lipid levels was explained by the regression models. The best predictors were generally the baseline levels of the lipid fraction itself, and the negative beta weights suggest an inverse relationship between baseline levels and the direction of change observed with the exercise training. In general, changes in body fatness were better predictors of changes in blood lipid levels than were changes in fitness. Indeed, these results are confirmed in Fig 4, which shows no differences in LCI between the upper and lower quartiles of $\dot{V}O_{2max}$ change but significant differences between the upper and lower quartiles of FM change. The familial aggregation in the blood lipid response to training in HERITAGE has been investigated, and the estimated heritabilities for changes in HDL, HDL_2-C, HDL_3-C, and TG range from 25% to 32% in black families and from 24% to 64% in white families.[34] These results indicate that familial factors explain a significant proportion of the variance in blood lipid levels in response to training. The role of genes has not been fully investigated; however, genetic factors appear more important than changes in fitness or fatness in the lipid and lipoprotein responses to regular exercise.

There is still no consensus on the independent effects of weight (fat) loss versus increases in fitness in determining the lipid response to exercise training. This is by far the largest study to investigate this issue, and the results support the idea that changes in lipid levels are more closely associated with fat loss than with increases in fitness. Two randomized, controlled trials in which men were assigned to diet, exercise, or control groups for 1 year also support the contention that improvements in blood lipid levels are independent of increases in fitness. In both studies, the diet and exercise groups lost weight and had improved blood lipid profiles.[11,12] In the first study, there were no differences between exercisers or dieters in the mean plasma lipid changes, and there were significant correlations between changes in HDL-C, HDL_2-C, and HDL_3-C and changes in FM.[11] Correlations between changes in FM and LDL, TG, and CHOL were in the expected direction, although not statistically significant. In the second study, changes in BMI were significantly correlated with changes in HDL_2-C, small LDL, and LDL peak flotation rate in both dieters and exercisers.[12] There were also significant associations between changes in lipoproteins and changes in fitness levels, but these differences disappeared when adjusted for the changes in BMI.

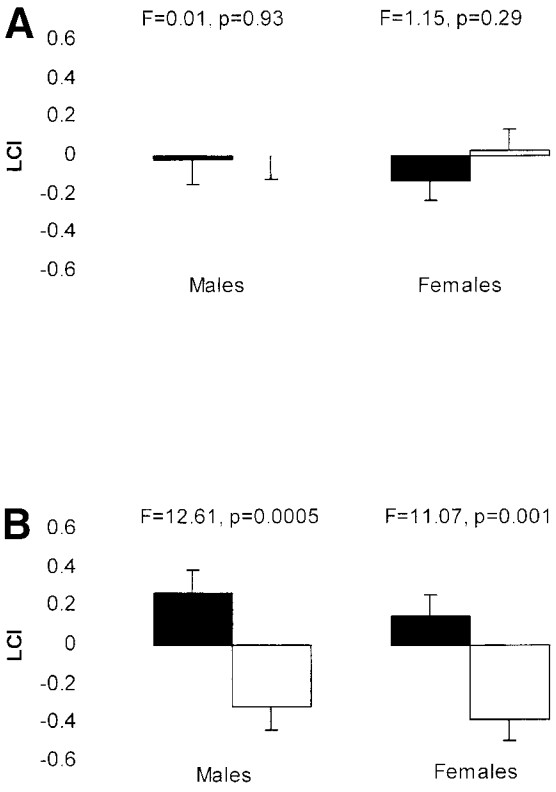

Fig 4. Comparison of LCI among participants in the lower quartile of change (■) and the upper quartile of change (□) for (A) $\dot{V}O_{2max}$ and (B) FM after 20 weeks of aerobic exercise training.

The results of an earlier study from the laboratory of one of the investigators (A.S.L.) indicated that both weight loss and exercise training over 12 weeks result in increases in HDL-C and that the effects are additive.[14] Schwartz[15] also reported that HDL-C increased after both diet and exercise in men, but the changes in aerobic capacity and body composition were not significantly related to the changes in plasma lipid concentrations. However, the small sample size in this study may not have provided sufficient power to detect meaningful differences.

Intervention studies involving exercise training and diet-induced weight loss in obese men suggest that changes in blood lipid levels are more closely associated with changes in FM than changes in $\dot{V}O_{2max}^{35}$ and that an exercise intervention (resulting in a significant increase in $\dot{V}O_{2max}$) did not improve blood lipid levels after diet-induced weight loss.[36] Further, comparison of a hypocaloric diet versus a hypocaloric diet plus aerobic exercise in obese men showed no significant effect on blood lipid levels with the addition of exercise to the intervention, despite a significant increase in $\dot{V}O_{2max}$.[37] Taken together, these studies highlight the importance of weight loss for the improvement of blood lipid levels and the lipoprotein profile.

Some studies have shown mean increases in $\dot{V}O_{2max}$ in concert with improvements in blood lipid levels[38,39]; however, it is difficult to determine associations when only mean changes are considered. For example, Kiens et al.[39] reported significant mean changes in HDL-C, TG, and CHOL after exercise training in middle-aged men. There was also a mean 12% increase in $\dot{V}O_{2max}$ but no significant mean change in body weight. However, the changes in $\dot{V}O_{2max}$ ranged from 0% to 27%, and correlations between changes in $\dot{V}O_{2max}$ and variations in body weight with changes in lipids were not presented. Similarly, Thompson et al.[38] demonstrated elevations in HDL-C (13%) after an exercise program in previously sedentary men. There was an average increase in $\dot{V}O_{2max}$ of 26%; however, the correlation between variations in $\dot{V}O_{2max}$ and changes in HDL-C was not significant. On the other hand, in a study that incorporated long-term (100 days) low-intensity (~55% $\dot{V}O_{2max}$) exercise that resulted in no increase in $\dot{V}O_{2max}$ but a significant decrease in FM, there were significant improvements in HDL-C, LDL-C, and the HDL-C/CHOL ratio in a small sample of young men.[40] Based on mean changes, it is thus difficult to determine whether the changes in blood lipid levels were related to the changes in $\dot{V}O_{2max}$ or to changes in body fatness in these studies.

In addition to the training studies discussed above, the results of the present study are in agreement with a 4-year observational study of men, in which changes in adiposity were correlated with changes in CHOL/HDL-C ratio, HDL-C, and TG.[41] Changes in $\dot{V}O_{2max}$ were correlated with changes in TG, but the use of multiple regression demonstrated that the effects of fitness on TG were moderated by the changes in body fatness. It appears as though both experimentally induced weight loss and natural changes in body fatness over time are related to changes in blood lipid levels more than are changes in fitness per se.

Current public health recommendations for physical activity call for moderate levels of physical activity. It has been suggested that heath benefits can accrue from physical activity that does not result in increases in aerobic fitness.[42] Support for this statement can be found in the results of a 24-week randomized controlled trial in which there was a dose-response relationship for $\dot{V}O_{2max}$ across 4 groups of women randomized into different walking speed programs.[43] In contrast, there was no dose-response relationship for HDL-C because both aerobic walkers and strollers had similar increases. More recently, Spate-Douglas and Keyser[44] reported that HDL-C and HDL_2-C both increased significantly in women after exercise training and that high-intensity exercise provided no additional benefit over moderate-intensity exercise in terms of improving HDL levels.

Although the results from the present study certainly support the contention that changes in aerobic fitness are not necessary to obtain health benefits, these findings must be interpreted with caution. All participants exercised at the same relative intensity throughout the exercise training program, beginning at 55% $\dot{V}O_{2max}$ and progressing to 75% $\dot{V}O_{2max}$ for the final 6 weeks. Thus, this study did not test for a dose-response relationship

Table 3. Correlations Among Changes in Fitness and Fatness and LCI, Stratified by Race and Sex

	Black Men	White Men	Black Women	White Women
Δ $\dot{V}O_{2max}$	−0.09	0.01	0.01	0.01
Δ FM	0.23*	0.28*	0.29*	0.13*

* $P < .05$.

between physical activity and blood lipid levels because all participants received the same relative dose of activity. However, using a standardized protocol, some individuals' fitness increased more than others', and the changes in blood lipid levels were unrelated to the changes in fitness in both black and white participants.

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REFERENCES

1. American College of Sports Medicine: American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 30:975-991, 1998

2. US Department of Health and Human Services: Physical Activity and Health: A Report of the Surgeon General. Atlanta, GA, Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996

3. Grundy SM, Balady GJ, Criqui MH, et al: Primary prevention of coronary heart disease: Guidance from Framingham. Circulation 97: 1876-1887, 1998

4. The Expert Panel: National Cholesterol Education Program Second Report. The expert panel on detection, evaluation, and treatment high blood cholesterol in adults (Adult Treatment Panel II). Circulation 89:1333-1445, 1994

5. Ross R: The pathogenesis of atherosclerosis—An update. N Engl J Med 314:488-500, 1986

6. Stefanick ML, Wood PD: Physical activity, lipid and lipoprotein metabolism, and lipid transport, in Bouchard C, Shephard RJ, Stephens T (eds): Physical Activity, Fitness and Health. Champaign, IL, Human Kinetics, 1994, pp 417-431

7. Leon AS, Rice T, Mandel S, et al: Blood lipid response to 20 weeks of supervised exercise in a large biracial population: The HERITAGE Family Study. Metabolism 49:513-520, 2000

8. Thompson PD: What do muscles have to do with lipoproteins? Circulation 81:1428-1430, 1990

9. Després JP, Lamarche B: Low-intensity endurance exercise training, plasma lipoproteins and the risk of coronary heart disease. J Intern Med 236:7-22, 1994

10. Williams PT, Wood PD, Krauss RM, et al: Does weight loss cause the exercise-induced increase in plasma high density lipoproteins? Atherosclerosis 47:173-185, 1983

11. Wood PD, Stefanick ML, Dreon DM, et al: Changes in plasma lipids and lipoproteins in overweight men during weight loss through dieting as compared with exercise. N Engl J Med 319:1173-1179, 1988

12. Williams PT, Krauss RM, Vranizan KM, et al: Changes in lipoprotein subfractions during diet-induced and exercise-induced weight loss in moderately overweight men. Circulation 81:1293-1304, 1990

13. Thompson PD, Yurgalevitch SM, Flynn MM, et al: Effect of prolonged exercise training without weight loss on high-density lipoprotein metabolism in overweight men. Metabolism 46:217-223, 1997

14. Sopko G, Leon AS, Jacobs DR Jr, et al: The effects of exercise and weight loss on plasma lipids in young obese men. Metabolism 34:227-236, 1985

15. Schwartz RS: The independent effects of dietary weight loss and aerobic training on high density lipoproteins and apolipoprotein A-I concentrations in obese men. Metabolism 36:165-171, 1987

16. Bouchard C, Leon AS, Rao DC, et al: The Heritage Family Study: Aims, design, and measurement protocol. Med Sci Sports Exerc 27:721-729, 1995

17. Gagnon J, Province MA, Bouchard C, et al: The HERITAGE Family Study: Quality assurance and quality control. Ann Epidemiol 6:520-529, 1996

18. Skinner JS, Wilmore KM, Jaskólska A, et al: Reproducibility of maximal exercise test data in the HERITAGE family study. Med Sci Sports Exerc 31:1623-1628, 1999

19. Wilmore JH: A simplified method for determination of residual lung volume. J Appl Physiol 27:96-100, 1969

20. Meneely GR, Kaltreider NL: The volume of the lung determined by helium dilution: Description of the method and comparison with other procedures. J Clin Invest 28:129-139, 1949

21. Wilmore JH, Stanforth PR, Domenick MA, et al: Reproducibility of anthropometric and body composition measurements: The HERITAGE Family Study. Int J Obes 21:297-303, 1997

22. Siri WE: Body composition from fluid spaces and density: Analysis of methods, in Brozek J, Henschel A (eds): Techniques for Measuring Body Composition. Washington, DC, National Academy of Sciences National Research Council, 1961, pp 223-244

23. Lohman TG: Applicability of body composition techniques and constants for children and youths. Exerc Sport Sci Rev 14:325-357, 1986

24. Schutte JE, Townsend EJ, Hugg J, et al: Density of lean body mass is greater in blacks than in whites. J Appl Physiol 56:1647-1649, 1984

25. Ortiz O, Russell M, Daley TL, et al: Differences in skeletal muscle and bone mineral mass between black and white females and their relevance to estimates of body composition. Am J Clin Nutr 55:8-13, 1992

26. Burstein M, Scholnick HR, Morfin R: Rapid method for the isolation of lipoproteins from human serum by precipitation with polyanions. J Lipid Res 11:583-595, 1970

27. Lopes-Virella MF, Stone P, Ellis S, et al: Cholesterol determination in high-density lipoproteins separated by three different methods. Clin Chem 23:882-884, 1977

28. Gidez LI, Miller GJ, Burstein M, et al: Separation and quantitation of subclasses of human plasma high density lipoproteins by a simple precipitaion procedure. J Lipid Res 23:1206-1223, 1982

29. Allain CC, Poon LS, Chan CSG, et al: Enzymatic determination of total serum cholesterol. Clin Chem 20:470-475, 1974

30. Skinner JS, Wilmore KM, Krasnoff JB, et al: Adaptation to a standardized training program and changes in fitness in a large, heterogeneous population: The HERITAGE Family Study. Med Sci Sports Exerc 32:157-61, 2000

31. SAS Institute: SAS/STAT Users Guide. Cary, NC: SAS Institute, 1988

32. Wilmore JH, Després JP, Stanforth PR, et al: Alterations in body weight and composition consequent to 20 weeks of endurance training: The HERITAGE Family Study. Am J Clin Nutr 70:346-352, 1999

33. Pérusse L, Rice T, Province MA, et al: Familial aggregation of amount and distribution of subcutaneous fat and their responses to exercise training in the HERITAGE family study. Obes Res 8:140-150, 2000

34. Rice T, Després J-P, Pérusse L, et al: Familial aggregation of lipids, lipoproteins and apolipoproteins in response to 20 weeks of exercise training: The HERITAGE Family Study. (submitted)

35. Katzel LI, Bleecker ER, Colman EG, et al: Effects of weight loss vs aerobic exercise training on risk factors for coronary disease in

healthy, obese, middle-aged and older men. A randomized controlled trial. JAMA 274:1915-1921, 1995

36. Katzel LI, Bleecker ER, Rogus EM, et al: Sequential effects of aerobic exercise training and weight loss on risk factors for coronary disease in healthy, obese middle-aged and older men. Metabolism 46:1441-1447, 1997

37. Dengel DR, Hagberg JM, Coon PJ, et al: Comparable effects of diet and exercise on body composition and lipoproteins in older men. Med Sci Sports Exerc 26:1307-1315, 1994

38. Thompson PD, Cullinane EM, Sady SP, et al: Modest changes in high-density lipoprotein concentration and metabolism with prolonged exercise training. Circulation 78:25-34, 1988

39. Kiens B, Jorgensen I, Lewis S, et al: Increased plasma HDL-cholesterol and apo A-1 in sedentary middle-aged men after physical conditioning. Eur J Clin Invest 10:203-209, 1980

40. Després JP, Tremblay A, Moorjani S, et al: Long-term exercise training with constant energy intake. 3: Effects on plasma lipoprotein levels. Int J Obes 14:85-94, 1990

41. Leaf DA, Parker DL, Schaad D: Changes in $\dot{V}O_2$max, physical activity, and body fat with chronic exercise: Effects on plasma lipids. Med Sci Sports Exerc 29:1152-1159, 1997

42. Pate RR, Pratt M, Blair SN, et al: Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA 273:402-407, 1995

43. Duncan JJ, Gordon NF, Scott CB: Women walking for health and fitness. How much is enough? JAMA 266:3295-3299, 1991

44. Spate-Douglas T, Keyser RE: Exercise intensity: Its effect on the high-density lipoprotein profile. Arch Phys Med Rehabil 80:691-695, 1999