Fitness Alters the Associations of BMI and Waist Circumference with Total and Abdominal Fat

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Abstract

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Objective: We tested the following hypotheses in black and white men and women: 1) for a given BMI or waist circumference (WC), individuals with moderate cardiorespiratory fitness (CRF) have lower amounts of total fat mass and abdominal subcutaneous and visceral fat compared with individuals with low CRF; and 2) exercise training is associated with significant reductions in total adiposity and abdominal fat independent of changes in BMI or WC.

Research Methods and Procedures: The sample included 366 sedentary male (111 blacks and 255 whites) and 462 sedentary female (203 blacks and 259 whites) participants in the HERITAGE Family Study. The relationships between BMI and WC with total fat mass (determined by underwater weighing) and abdominal subcutaneous and visceral fat (determined by computed tomography) were compared in subjects with low (lower 50%) and moderate (upper 50%) CRF. The effects of a 20-week aerobic exercise training program on changes in these adiposity variables were examined in 86% of the subjects.

Results: Individuals with moderate CRF had lower levels of total fat mass and abdominal subcutaneous and visceral fat than individuals with low CRF for a given BMI or WC value. The 20-week aerobic exercise program was associated with significant reductions in total adiposity and abdominal fat, even after controlling for reductions in BMI and WC. With few exceptions, these observations were true for both men and women and blacks and whites.

Discussion: These findings suggest that a reduction in total adiposity and abdominal fat may be a means by which CRF attenuates the health risk attributable to obesity as determined by BMI and WC.

Key words: visceral fat, subcutaneous fat, exercise, HERITAGE Family Study

Introduction

Recent estimates indicate that 34% of the adult American population is overweight (preobese) and that 31% are obese, as determined by BMI (1). In Canada, ~35% of the adult population is overweight, and 15% are obese (2). These are alarming figures given the volume of evidence implicating overweight and obesity as leading risk factors for morbidity and mortality (3,4). However, most studies examining the relationships among BMI, disease risk, and mortality have not controlled for physical activity or fitness. This is an important limitation, given that physically inactive individuals are more likely to be obese compared with active individuals (5) and that cardiorespiratory fitness (CRF)[1] substantially attenuates the health risk attributable to an

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[1] Nonstandard abbreviations: CRF, cardiorespiratory fitness; WC, waist circumference; CT, computed tomography; $\dot{V}O_{2max}$, maximal oxygen uptake.

elevated BMI (6–8). In fact, overweight and moderately obese men and women with high CRF have a lower risk of all-cause mortality than lean men and women with low CRF (7,9). These findings suggest that it is important not to make the assumption that all overweight and obese individuals are unhealthy. As well, they underscore the limitations inherent in using BMI alone to interpret obesity-related health risk.

Ross and Katzmarzyk (10) recently explored the issue of why CRF attenuates obesity-related health risk as measured by BMI. They found that men and women with high CRF had lower levels of total fat (as determined by skinfold thickness) and abdominal fat [as determined by waist circumference (WC)] for a given BMI compared with men and women with low CRF. These findings (10) are reinforced by three lines of evidence. First, measures of skinfold thickness (11–13) and WC (14–16) are significant predictors of morbidity and mortality after controlling for the health risk predicted by BMI. Second, physical activity in the absence of weight loss is associated with significant reductions in total fat mass (17,18) and WC (19,20). Third, exercise-induced improvements in cardiovascular disease risk factors are related to the reductions in total adiposity (21,22) and abdominal fat (20,23).

In addition to BMI, findings from one prospective study indicated that CRF attenuates the health risk attributable to an elevated WC (9). In that study, men with a high WC and high CRF had a comparable risk of all-cause mortality as men with a low WC and low CRF (9). This suggests that individuals with a high CRF may have a lower total fat mass and abdominal fat content (higher proportion of lean-to-fat tissue) for a given WC compared with individuals with a low CRF. A lower total fat mass and abdominal fat content for a given WC would attenuate health risk because total fat mass (24–26), abdominal subcutaneous fat (24,25,27,28), and visceral fat (26,29–31) are clear determinants of metabolic risk. The relative contribution of specific fat depots to obesity-related health risk is, however, unclear (32,33).

To date, no studies employing densitometry (e.g., underwater weighting) or imaging methods [e.g., computed tomography (CT)] for measuring total fat mass and abdominal subcutaneous and visceral fat have examined the associations between CRF and adiposity, independent of BMI or WC. Accordingly, there is a need to investigate whether the attenuating effects of CRF on obesity-related health risk, as determined by BMI and WC, are explained by a reduction in total fat mass and/or CT abdominal subcutaneous and visceral fat. Furthermore, current knowledge on the attenuating effects of CRF on obesity-related health risk is primarily based on data from cohorts of white subjects (6–9). Thus, whether CRF provides a protective effect for obesity in other races is largely unknown.

The purpose of this study was to test the following hypotheses in black and white men and women: 1) for a given BMI or WC, individuals with moderate CRF have lower amounts of total fat mass, CT abdominal subcutaneous fat, and CT visceral fat compared with individuals with low CRF; and 2) exercise training is associated with significant reductions in total adiposity and CT abdominal fat independent of changes in BMI or WC. If consistent, the observations from the exercise intervention will provide strong support for the cross-sectional observations from this and prior studies. These hypotheses were tested using data from the HERITAGE Family Study.

Research Methods and Procedures

Subjects

The HERITAGE Family Study was designed to investigate the genetics of cardiovascular, metabolic, hormonal, and body composition 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 elsewhere (34). Briefly, the participating research centers consisted of four clinical centers—Arizona State University (now Indiana University), Laval University (now Pennington Biomedical Research Center), University of Minnesota, and University of Texas at Austin (now Texas A&M University)—and a data coordinating center at Washington University. 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), systolic/diastolic blood pressure $<$160/100 mm Hg, and BMI under 40.0 kg/m^2. Several participants with BMI values slightly in excess of this criterion value were included in the study if they were considered by the supervising physician to be relatively healthy and able to exercise at the intensities and for the duration required in the study. Individuals with confirmed or possible coronary heart disease, hypertension, chronic or recurrent respiratory problems, or diabetes, or those using blood pressure or lipid-lowering drugs were excluded from the study. The sample for the cross-sectional analyses consisted of 366 men (111 blacks and 255 whites) and 462 women (203 blacks and 259 whites), for whom measures of CRF, total body fat, and abdominal subcutaneous and visceral fat were available before the training program. The sample for the intervention analyses consisted of 311 men (84 blacks and 227 whites) and 403 women (160 blacks and 243 whites), for whom the aforementioned measures were available before and after the training program.

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 (35).

Cardiorespiratory Fitness. Maximal oxygen uptake (VO_{2max}) tests were conducted on a cycle ergometer connected to a SensorMedics 2900 metabolic cart (SensorMedics, Yorba Linda, CA). A detailed explanation of the VO_{2max} tests is provided elsewhere (36). Briefly, two graded tests to exhaustion were conducted on separate days pre- and post-training. The criteria for VO_{2max} were respiratory exchange ratio >1.1, plateau of VO_2 (change <100 mL/min in the last three 20-second intervals), and a heart rate within 10 beats/min of predicted maximal heart rate. All participants achieved VO_{2max} by one of the criteria on at least one of the two tests before and after training. The average VO_{2max} from the two tests before and after training was taken as the VO_{2max} for each participant if the values were within 5% of one another. If they differed by more than 5%, the higher value was used. Reproducibility of VO_{2max} in these participants is quite high, with an intraclass correlation of 0.97 for repeated measures and a coefficient of variation of 5% (36).

VO_{2max} was used to split participants into low CRF (lower 50%) and moderate CRF (upper 50%) groups. We chose to label the upper 50% "moderate CRF" rather than "high CRF," because the subjects had to be sedentary to participate in the study. Independent of race and sex, the mean VO_{2max} values for the low and moderate CRF groups were within the ranges used to classify low (least 20% fit) and moderate (21–60th percentiles for fitness) CRF, respectively, in the Aerobics Center Longitudinal Study (37). Previous studies from the Aerobics Center Longitudinal Study have shown that low CRF is associated with an ~2-fold increased risk of cardiovascular disease and all-cause mortality compared with moderate or high CRF in both men and women (7).

The cut-offs for low CRF in black and white men were <32.0 and <36.0 mL/kg/min, respectively. The corresponding cut-offs in black and white women were <23.5 and <29.5 mL/kg/min, respectively.

Anthropometry. Height and body mass were measured to the nearest 0.1 cm and 0.1 kg, respectively, using a stadiometer and balance-beam scale. BMI was calculated as body mass/height^2 (kilograms per meter squared). WC was measured to the nearest 0.1 cm at the level of noticeable waist narrowing using an anthropometric fiberglass tape (Grafco Fiberglass Tape; Grahams-Fields Inc., Hauppague, NY) in accordance with the procedures recommended by Lohman et al. (38). In these participants, there was an intraclass correlation of 0.99 for repeated measures of WC, with a coefficient of variation of 1% (39).

Total Fat Mass. Total fat mass was determined by measures of body density from underwater weighing, with a correction for residual lung volume measured using the oxygen dilution technique (40) at three of the clinical centers and the helium dilution technique (41) at the fourth (Laval University). A detailed explanation of the underwater weighing method is found elsewhere (39). Briefly, 10 measurements were obtained, and the 3 highest values were averaged. Total fat mass was estimated from body density using equations for white men (42), white women (43), black men (44), and black women (45). In these participants, there was an intraclass correlation of 0.98 for repeated measures of fat mass, with a coefficient of variation of 4% (39).

CT Abdominal Subcutaneous and Visceral Fat. CT was used to provide estimates of abdominal subcutaneous and visceral fat using either a Siemens Somatom DRH scanner (Erlangen, Germany) or a General Electric model CT 9800 scanner (Waukesha, WI). Pre- and post-training measurements were conducted at the same time of day by the same technician to minimize technical error. To ensure the reliability and consistency of the CT method among the four clinical centers, a standardized calibration unit (lard sealed within a plexiglas cylinder) was scanned every 6 to 12 months at each center. Participants were examined in the supine position, with their arms stretched above their heads. One scan was performed using a lateral radiographic view of the skeleton to establish the position of the space between the fourth and fifth lumbar vertebrae (L_4–L_5). A second scan was performed at the L_4–L_5 space (125 kV with a slice thickness of 8 mm). CT total abdominal and CT visceral fat areas were calculated by delineating the total abdominal and intra-abdominal areas, respectively, with an electronic graph pen and by computing the adipose tissue surfaces using an attenuation range of -10 to -190 Hounsfield units (46). CT abdominal subcutaneous fat area was calculated as the difference between CT total abdominal and CT visceral fat areas.

Training Program

Each participant completed a 20-week standardized aerobic exercise training program. The training involved three weekly sessions of supervised exercise on a cycle ergometer (Universal Aerocycle, Cedar Rapids, IA). Participants started at 55% of their baseline VO_{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% of baseline VO_{2max} for 50 minutes per session for the final 6 weeks. Participants were counseled at baseline and midway through the exercise training program not to alter their usual health and lifestyle habits outside of the study. More details about the exercise training program have been provided elsewhere (47).

Statistical Analysis

Differences in the subject characteristics between the low and moderate CRF groups were tested using unpaired Student's t tests and analysis of covariance. Differences in the relationships of BMI and WC with total fat mass, CT total abdominal, CT abdominal subcutaneous, and CT visceral fat between low CRF and moderate CRF groups were tested using general linear models, including age as a covariate. Age, BMI, WC, total fat mass, CT total abdominal, CT abdominal subcutaneous, and CT visceral fat were included in the models in their original continuous scales of measurements, whereas CRF group was entered as a dichotomous variable. Models for BMI and WC were run separately for total fat mass, CT total abdominal, CT abdominal subcutaneous, and CT visceral fat. Both the main effects for CRF group and interaction effects (e.g., BMI $\times$ CRF group) were included in each of the models to test for equality of slopes. If no interaction effects were detected (e.g., the slopes were not different), the analysis for the main effects was repeated excluding the interaction term. Each of the effects reported in the results was adjusted for the other variables in the model (e.g., total fat mass effects were adjusted for the main effects of age and BMI). To facilitate comparisons, all figures were standardized to a 40-year-old individual. Paired Student's t tests and repeated measures analysis of covariance were used to determine significant differences between pre- and post-training data. Given the mean race and sex differences in body composition and CRF scores, all analyses were stratified by race and sex. All analyses were conducted with SAS software and procedures (SAS version 8; SAS Institute, Cary, NC).

Results

Comparisons of Low and Moderate CRF Groups

Table 1 provides the descriptive characteristics of the subjects divided into low and moderate CRF groups at baseline according to race and sex. The mean age and all of the indicators of total and regional adiposity were higher in the low CRF groups compared with the moderate CRF groups ($p < 0.001$). Given the mean age differences, all subsequent analyses were adjusted for the effects of age.

Relationships for BMI

Total Fat Mass. The results of the general linear models indicate that, in both races and sexes, being in the moderate CRF group resulted in a lower total fat mass for a given BMI (main effect, $p < 0.001$; Figure 1). These relationships were significantly influenced by age (main effect, $p < 0.05$) but not BMI level (interaction effect, $p > 0.1$).

CT Total Abdominal Fat. Individuals with moderate CRF had lower CT total abdominal fat for a given BMI than individuals with low CRF (main effect, $p \leq 0.01$), independent of race and sex (Figure 2). These relationships were significantly influenced by age (main effect, $p < 0.001$) but not BMI level (interaction effect, $p > 0.1$).

CT Abdominal Subcutaneous Fat. Individuals with moderate CRF had lower CT abdominal subcutaneous fat for a given BMI than individuals with low CRF (main effect, $p \leq 0.05$), independent of race and sex. The differences between the moderate and low CRF groups tended to decrease with increasing BMI in women (interaction effect, $p \leq 0.06$), such that abdominal subcutaneous fat was not lower in the moderate CRF group once the BMI values were in the obese range. Age was not a significant covariate in any of the models (main effect, $p > 0.2$).

CT Visceral Fat. Men and women with moderate CRF had lower CT visceral fat for a given BMI than men and women with low CRF, respectively (main effect, $p < 0.001$). These relationships were influenced by age (main effect, $p < 0.001$) but not by BMI level (interaction effect, $p > 0.1$).

WC. Although not an explicit hypothesis in this study, the influence of CRF on the relationship between BMI and WC was examined for comparison with earlier studies. The results of the general linear models indicate that individuals with moderate CRF had a lower WC for a given BMI than individuals with low CRF (main effect, $p < 0.001$), independent of race and sex. This difference decreased with increasing BMI in black women (interaction effect, $p = 0.02$), such that WC was not lower in the moderate CRF group after a BMI of $\sim$35 kg/m^2. All general linear models included age as a covariate ($p < 0.001$).

Relationships for WC

Total Fat Mass. In both races and sexes, being in the moderate CRF group resulted in a lower total fat mass for a given WC (main effect, $p < 0.001$; Figure 3). The relationship between WC and total fat mass was influenced by age in all groups (main effect, $p < 0.05$) except white women and by WC level in white men and white women (interaction effect, $P \leq 0.05$).

CT Total Abdominal Fat. Individuals with moderate CRF had lower CT total abdominal fat for a given WC than individuals with low CRF (main effect, $p < 0.001$), independent of race and sex (Figure 4). The relationship between WC and total abdominal fat was influenced by age in black men and white women (main effect, $p < 0.01$) and by BMI level in white men (interaction effect, $p < 0.01$).

CT Abdominal Subcutaneous Fat. In both races and sexes, being in the moderate CRF group was associated with a lower CT abdominal subcutaneous fat for a given WC (main effect, $p < 0.001$). The difference between the low and moderate CRF groups was not influenced by BMI level (interaction effect, $p > 0.05$). With the exception of white women ($p = 0.3$), the general linear models included age as a covariate (main effect, $p < 0.01$).

CT Visceral Fat. In black men, white men, and white women, the relationship between WC and CT visceral fat was not different in the low and moderate CRF groups (main effect, $p > 0.2$). However, for a given WC, black

Table 1. Descriptive characteristics of the subjects divided into low and moderate CRF groups

	Men		Women	
	Low CRF	Moderate CRF	Low CRF	Moderate CRF
Black				
Number of subjects (n)	55	56	101	102
Age (years)	39.5 ± 12.1	26.6 ± 8.7*	38.2 ± 10.6	27.6 ± 8.8*
Height (cm)	175.6 ± 6.0	175.7 ± 7.0	162.8 ± 6.6	162.0 ± 6.8
Body mass (kg)	93.0 ± 16.7	75.0 ± 13.0†	84.9 ± 16.8	64.7 ± 12.2†
BMI (kg/m^2)	30.1 ± 5.1	24.2 ± 3.6†	32.1 ± 6.4	24.6 ± 4.2†
WC (cm)	101.4 ± 13.3	81.7 ± 10.2†	99.9 ± 13.0	80.5 ± 11.0†
Total fat (% body mass)	28.5 ± 5.5	17.0 ± 5.9†	42.4 ± 6.8	30.8 ± 6.9†
Total fat mass (kg)	27.0 ± 9.5	13.3 ± 6.4†	36.7 ± 12.1	20.7 ± 8.1†
CT total abdominal fat (cm^2)	433.6 ± 185.7	170.9 ± 121.7†	550.0 ± 184.1	292.6 ± 146.5†
CT visceral fat (cm^2)	110.9 ± 59.1	42.4 ± 27.7†	95.4 ± 39.5	44.1 ± 23.4†
CT abdominal subcutaneous fat (cm^2)	322.8 ± 153.2	128.4 ± 99.8†	459.6 ± 164.9	248.6 ± 130.5†
$V\text{O}_{2max}$ (L/min)	2.55 ± 0.48	2.94 ± 0.44†	1.67 ± 0.37	1.83 ± 0.36†
$V\text{O}_{2max}$ (mL/kg/min)	27.6 ± 3.5	39.5 ± 4.5†	19.8 ± 2.6	28.5 ± 4.3†
White				
Number of subjects (n)	127	128	129	130
Age (years)	44.9 ± 13.5	27.6 ± 10.7*	43.3 ± 12.9	25.9 ± 8.3*
Height (cm)	177.3 ± 6.6	178.4 ± 6.0	163.1 ± 6.1	164.4 ± 6.9
Body mass (kg)	93.5 ± 16.3	75.4 ± 10.0†	74.5 ± 13.1	59.5 ± 8.9†
BMI (kg/m^2)	29.7 ± 4.6	23.7 ± 2.8†	27.9 ± 4.5	21.9 ± 2.5†
WC (cm)	104.4 ± 11.4	85.0 ± 8.4†	95.2 ± 12.4	76.4 ± 8.3†
Total fat (% body mass)	29.7 ± 5.7	16.6 ± 6.6†	37.1 ± 6.9	23.3 ± 6.6†
Total fat mass (kg)	27.8 ± 9.3	12.8 ± 6.0†	28.1 ± 9.8	14.2 ± 5.6†
CT total abdominal fat (cm^2)	471.8 ± 155.5	210.9 ± 180.2†	495.5 ± 152.7	234.9 ± 97.4†
CT visceral fat (cm^2)	153.2 ± 58.4	66.7 ± 34.4†	107.9 ± 54.2	42.9 ± 19.3†
CT abdominal subcutaneous fat (cm^2)	318.7 ± 128.7	144.3 ± 73.3†	387.6 ± 124.0	192.0 ± 87.0†
$V\text{O}_{2max}$ (L/min)	2.74 ± 0.53	3.32 ± 0.48†	1.75 ± 0.31	2.08 ± 0.31†
$V\text{O}_{2max}$ (mL/kg/min)	29.5 ± 4.2	44.3 ± 5.7†	23.8 ± 3.8	35.2 ± 3.8†

Data presented as group means ± SD.
* $p < 0.05$, low vs. moderate CFR groups.
† $p < 0.05$, low vs. moderate CRF groups, controlled for age.

women with moderate CRF had lower visceral fat than black women with low CRF (main effect, $p = 0.05$). This relationship was influenced by age (main effect, $p < 0.01$), and the difference between the low and moderate CRF groups increased with increasing BMI level (interaction effect, $p < 0.01$).

Independent Relationships for Total Fat Mass and CT Abdominal Fat

To determine the independent effects of total fat mass and CT abdominal fat on the aforementioned relationships, all analyses for total fat mass were re-run after including CT total abdominal fat in the general linear models, and all analyses for CT total abdominal fat were re-run after including total fat mass in the general linear models. Without exception, being in the moderate CRF group was associated with a lower total fat mass for a given BMI (main effect, $p < 0.05$) or WC (main effect, $p < 0.01$) after controlling for CT abdominal fat. Furthermore, being in the moderate CRF group was associated with lower CT abdominal fat for a given BMI (main effect, $p < 0.01$) or WC (main effect, $p < 0.05$) after controlling for total fat mass, independent of race and gender.

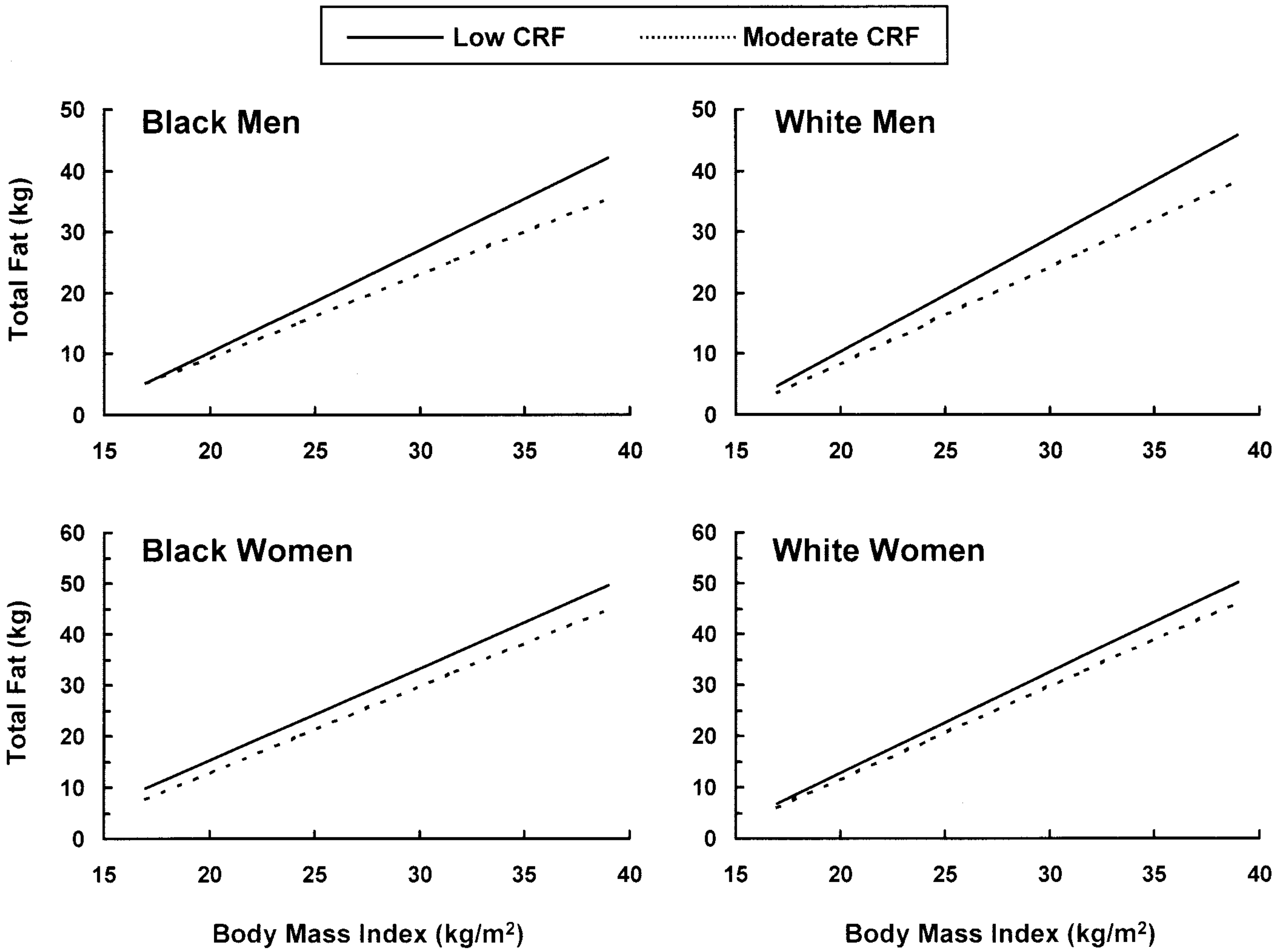

Figure 1: Relationship between BMI and total fat mass in low and moderate CRF subjects, according to race and sex. Solid lines, regression lines for the low CRF subjects; dashed lines, regression lines for the moderate CRF subjects. All regression lines are standardized to a 40 year old from the HERITAGE Family Study.

Influence of Exercise Training

The changes in adiposity (48) and CRF (47) in the HERITAGE Family Study have been explained in greater detail elsewhere. Table 2 shows the pretraining, post-training, and change scores for adiposity variables and CRF according to race and sex in this sample. The mean improvements in $V\text{O}_{2\max}$ in response to the 20-week aerobic exercise program ranged from 0.34 L/min in black women to 0.48 L/min in white men. The black men and white men had small ($\leq$0.5 kg) but significant ($p < 0.05$) reductions in body mass, whereas body mass was unchanged in the black women and white women ($p > 0.1$). WC was reduced in all groups ($p < 0.01$), with the exception of white women. After controlling for reductions in both BMI and WC, total fat (percentage body mass and fat mass), CT total abdominal fat, CT visceral fat, and CT abdominal subcutaneous fat were significantly ($p < 0.01$) reduced in all groups (exception: CT abdominal subcutaneous fat was reduced in black men after controlling for reductions in BMI but not WC). Depending on race and sex, the mean reductions for total fat mass, CT total abdominal, CT visceral, and CT abdominal subcutaneous fat were 2.5% to 4.8%, 3.0% to 5.0%, 4.2% to 7.3%, and 2.7% to 4.3%, respectively.

Discussion

The results of this study indicate that individuals with moderate CRF had lower levels of total fat mass, CT abdominal subcutaneous fat, and CT visceral fat than individuals with low CRF for a given BMI. Furthermore, for a given WC value, individuals with moderate CRF had lower levels of total fat mass and CT abdominal fat than individuals with low CRF. With few exceptions, these observations were true for all groups studied. These cross-sectional findings were supported by the observation that exercise-induced reductions in total fat mass and CT abdominal fat

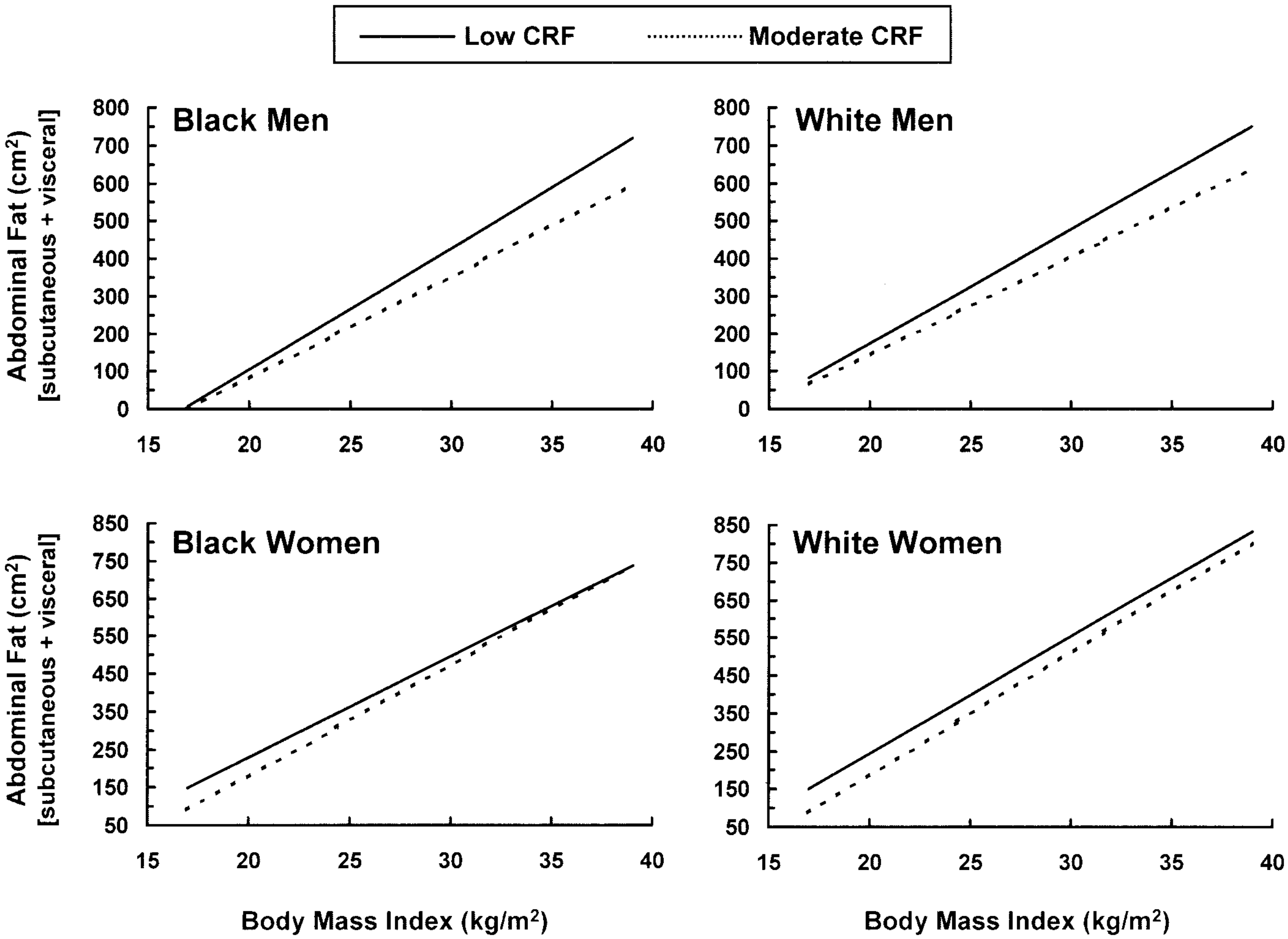

Figure 2: Relationship between BMI and total abdominal fat (abdominal subcutaneous + visceral fat) in low and moderate CRF subjects, according to race and sex. Solid lines, regression lines for the low CRF subjects; dashed lines, regression lines for the moderate CRF subjects. All regression lines are standardized to a 40 year old from the HERITAGE Family Study.

were independent of reductions in BMI and WC. These findings suggest that reductions in total fat mass and CT abdominal fat may be a means by which CRF attenuates the health risk attributable to obesity, as determined by BMI and WC.

The findings support our hypothesis that, within both races and sexes, total fat mass, CT abdominal subcutaneous fat, and CT visceral fat are lower in individuals with moderate levels of CRF compared with individuals with low levels of CRF, independent of BMI. These findings are consistent with those of Ross and Katzmarzyk (10), who examined a similar hypothesis in a sample of 7537 Canadian men and women. They reported that high CRF was associated with lower levels of total and abdominal obesity for a given BMI compared with those with low CRF. In that study, total and abdominal adiposity were estimated from skinfolds and WC, respectively, and CRF was estimated from heart rates obtained during a submaximal aerobic fitness test. In this study, we used a more precise measure of CRF (maximal exercise tests) and total adiposity (underwater weighing), and we also used accurate measures of abdominal subcutaneous and visceral fat (CT). Furthermore, we extended these observations to include both blacks and whites. The findings of these two studies are consistent with those of prior intervention studies that demonstrate that, when performed for a sufficient duration, aerobic exercise in the absence of a change in BMI is associated with reductions in total fat mass (17,18), abdominal subcutaneous fat (49,50), and visceral fat (20,49,50). In this study, we also observed that a 20-week aerobic exercise program with little or no change in body weight (−0.1 to −0.5 kg) was associated with significant reductions in total fat mass (2.0% to 3.9%) and CT abdominal subcutaneous (3.0% to 5.5%) and visceral (4.2% to 7.3%) fat.

A novel observation presented here was that total fat mass and CT abdominal fat were lower for any given WC in

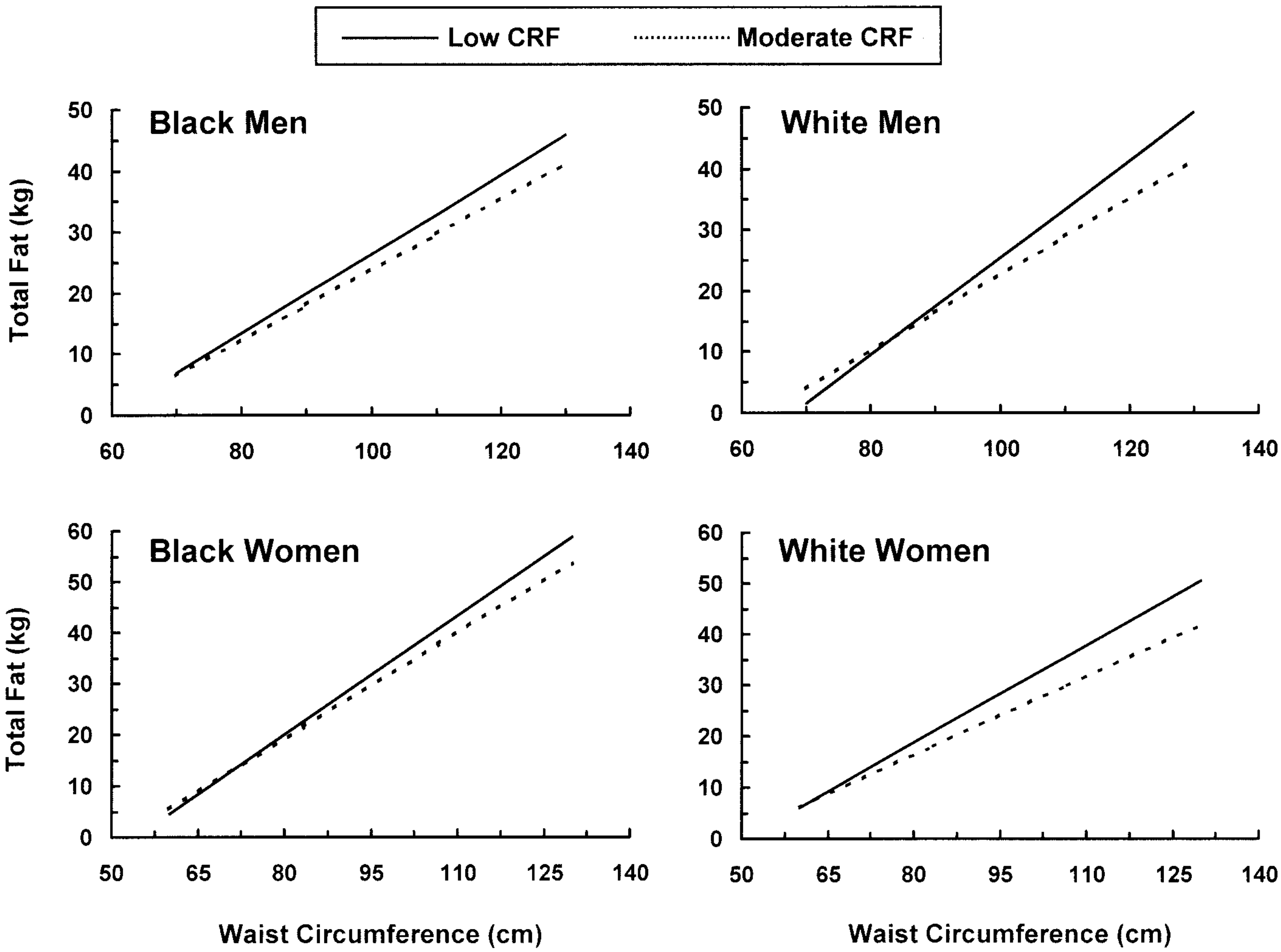

Figure 3: Relationship between WC and total fat mass in low and moderate CRF subjects, according to race and sex. Solid lines, regression lines for the low CRF subjects; dashed lines, regression lines for the moderate CRF subjects. All regression lines are standardized to a 40 year old from the HERITAGE Family Study.

individuals with moderate CRF compared with individuals with low CRF. Furthermore, aerobic exercise training was associated with significant reductions in total fat mass and CT abdominal subcutaneous and visceral fat after controlling for changes in WC. Again, with few exceptions, these observations were true for all groups studied. It can be implied from these findings that the proportion of lean-to-fat tissue increases with increasing CRF and that obtaining an anthropometric WC measure may mask the effects of fitness and regular exercise on total adiposity and abdominal fat content. Lee et al. (9) reported that, independent of WC category (low, moderate, or high), fit men had a lower relative risk of all-cause and cardiovascular disease mortality than unfit men. Our findings suggest that this may be partially explained by lower total fat mass and CT abdominal fat in the individuals with high CRF, because total (24–26) and abdominal (25–31) fat are strong markers of health risk. However, given the magnitude of the differences in relative risk in the low and high CRF groups in that study (e.g., relative risks of 2.00 to 4.88 for low CRF) (9), it is likely that fitness has an influence on mortality risk independent of its effects on total adiposity and abdominal obesity.

The finding that CRF attenuates obesity-related health risk (determined by BMI and WC) is of great importance to public health. Although the proportion of adults attempting to lose weight in North America is quite high, many individuals have little success in achieving or maintaining weight loss or in preventing weight gain with advancing age (51–53). Indeed, over 65% of Americans (1) and 50% of Canadians (2) are overweight or obese according to BMI, and ~40% of adult Americans are abdominally obese according to WC (>102 cm in men, >88 cm in women) (54). Thus, it is reasonable to suggest that overweight, obese, and abdominally obese persons who are not able to achieve or maintain a reduced BMI or WC could substantially reduce

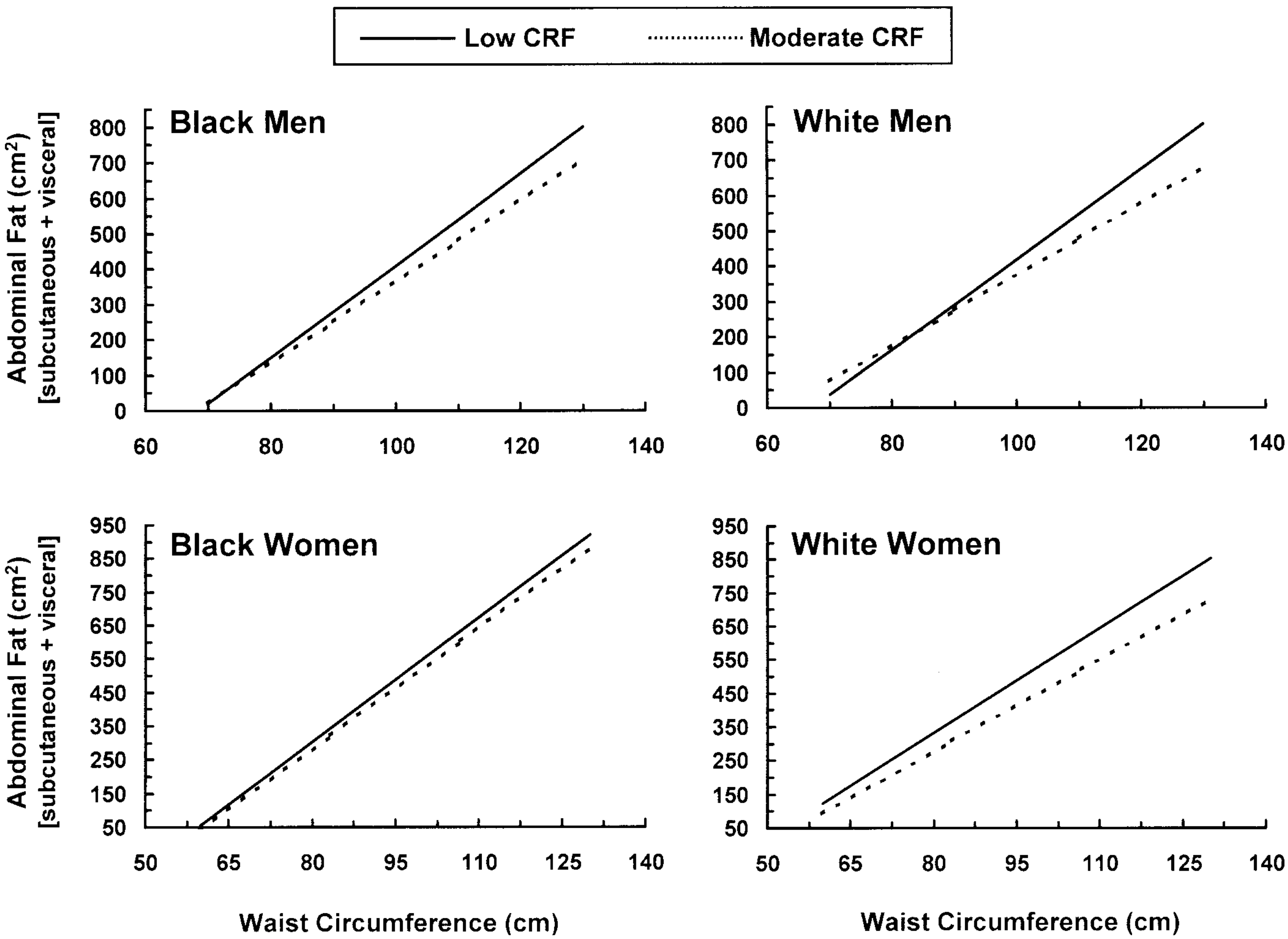

Figure 4: Relationship between WC and total abdominal fat (abdominal subcutaneous + visceral fat) in low and moderate CRF subjects, according to race and sex. Solid lines, regression lines for the low CRF subjects; dashed lines, regression lines for the moderate CRF subjects. All regression lines are standardized to a 40 year old from the HERITAGE Family Study.

their risk of morbidity and mortality by increasing their physical activity levels and improving their CRF. Nonetheless, physical activity levels are slightly lower in obese individuals, as demonstrated in the 2000/2001 Canadian Community Health Survey (55), which reported that the risk of being sedentary in leisure time was 16% higher in obese persons compared with nonobese persons. Taken together, these findings highlight the need to advocate physical activity as a means of reducing health risk independent of its effects on body mass and WC in overweight and obese persons. Current guidelines from the Centers for Disease Control and Prevention indicate that every adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week for disease prevention (56).

Although we found that total fat mass, CT total abdominal, and CT abdominal subcutaneous fat were lower for any given WC in individuals with moderate CRF compared with individuals with low CRF, this was not the case for CT visceral fat. We were surprised with this finding for two reasons. Namely, in vitro studies have demonstrated that visceral adipocytes are more responsive to the mobilizing effects of catecholamines than subcutaneous adipocytes (57,58), and second, recent intervention trials have demonstrated that the relative reduction in visceral fat with aerobic exercise training is greater than the relative reduction in abdominal subcutaneous fat (20,59). Although it has been hypothesized that the health risk associated with obesity is determined primarily by the amount of visceral fat (29–31), this is an ongoing topic of debate (32,33), and many studies have demonstrated that total fat mass (24,25) and abdominal subcutaneous fat (24,25,27,28) are also independent predictors of insulin resistance. Thus, the fact that total fat mass and CT abdominal subcutaneous fat were lower for a given BMI and WC in the moderate CRF groups may have a meaningful clinical implication.

Table 2. Changes in body mass and composition and CRF in response to 20 weeks of aerobic exercise training

	Men			Women		
	Pre-training	**Post-training**	**Difference (post − pre)**	**Pre-training**	**Post-training**	**Difference (post − pre)**
Black						
BMI (kg/m^2)	27.0 ± 4.8	26.8 ± 4.8	−0.2 ± 0.8*	28.2 ± 6.1	28.0 ± 5.9	−0.1 ± 1.1
Body mass (kg)	83.9 ± 16.3	83.4 ± 16.0	−0.5 ± 2.4*	73.8 ± 16.3	73.5 ± 16.0	−0.4 ± 3.0
WC (cm)	91.7 ± 14.0	90.5 ± 13.9	−1.2 ± 2.7†	89.5 ± 14.6	88.9 ± 14.4	−0.7 ± 3.9
Total fat (% body mass)	22.8 ± 7.2	21.9 ± 7.1	−0.9 ± 1.7‡	22.8 ± 9.0	21.9 ± 9.0	−0.9 ± 1.7‡
Total fat mass (kg)	20.6 ± 10.5	19.4 ± 10.5	−1.0 ± 2.0‡	28.2 ± 12.4	27.3 ± 11.9	−0.7 ± 2.5‡
CT total abdominal fat (cm^2)	297.0 ± 186.4	284.7 ± 180.3	−15.2 ± 32.8‡	416.5 ± 206.4	401.7 ± 199.3	−14.8 ± 43.1‡
CT visceral fat (cm^2)	77.5 ± 5.1	71.9 ± 52.2	−6.4 ± 14.7‡	69.1 ± 40.8	65.4 ± 37.9	−3.8 ± 13.4‡
CT abdominal subcutaneous fat (cm^2)	219.5 ± 145.0	210.4 ± 142.9	−9.1 ± 24.8†	347.4 ± 177.4	336.3 ± 173.1	−11.0 ± 35.8‡
$V\text{O}_{2max}$ (L/min)	2.73 ± 0.51	3.15 ± 0.54	0.41 ± 0.20†	1.74 ± 0.35	2.07 ± 0.34	0.34 ± 0.15†
White						
BMI (kg/m^2)	26.7 ± 4.9	26.5 ± 4.9	−0.1 ± 0.7*	24.9 ± 4.8	24.9 ± 4.7	−0.0 ± 0.8
Body mass (kg)	84.3 ± 16.3	83.9 ± 16.2	−0.3 ± 2.1*	67.0 ± 13.6	66.8 ± 13.4	−0.1 ± 2.1
WC (cm)	94.7 ± 13.9	93.9 ± 14.0	−0.9 ± 2.3†	85.8 ± 14.2	84.6 ± 13.9	−1.2 ± 3.2†
Total fat (% body mass)	35.8 ± 8.7	35.1 ± 8.5	−0.7 ± 2.1‡	30.0 ± 9.8	29.2 ± 9.7	−0.8 ± 2.0‡
Total fat mass (kg)	20.1 ± 10.8	19.8 ± 6.1	−0.9 ± 1.9‡	21.1 ± 11.0	20.7 ± 10.8	−0.6 ± 1.8‡
CT total abdominal fat (cm^2)	340.1 ± 182.2	323.0 ± 179.5	−17.1 ± 32.7‡	363.1 ± 184.3	352.2 ± 181.9	−10.9 ± 33.7‡
CT visceral fat (cm^2)	109.5 ± 63.6	102.4 ± 61.2	−7.1 ± 17.9‡	75.4 ± 52.7	72.2 ± 49.1	−3.2 ± 13.4‡
CT abdominal subcutaneous fat (cm^2)	230.6 ± 134.0	220.6 ± 132.2	−10.0 ± 21.9‡	287.7 ± 146.2	280.0 ± 145.9	−7.7 ± 28.4‡
$V\text{O}_{2max}$ (L/min)	3.03 ± 0.59	3.48 ± 0.65	0.48 ± 0.24†	1.91 ± 0.35	2.26 ± 4.14	0.35 ± 0.18†

Data presented as group means ± SD.
* $p \leq 0.05$, pre-training vs. post-training.
† $p < 0.01$, pre-training vs. post-training, controlled for changes in body weight.
‡ $p < 0.01$, pre-training vs. post-training, controlled for changes in body weight and WC.

Although a reduction in total adiposity and CT abdominal subcutaneous and visceral fat provides a possible mechanistic explanation for why CRF attenuates the health risk associated with an elevated BMI and WC, it is important to highlight that other mechanisms for CRF are also at work. This is demonstrated by the fact that low CRF is associated with at least a 2-fold increased risk of morbidity and mortality, independent of BMI or WC (7,9). Although we observed differences in total fat mass and CT abdominal fat in the moderate and low CRF groups, after accounting for differences in BMI and WC, these differences were modest compared with the 2-fold increase in morbidity and mortality risk associated with low CRF. Adaptations in skeletal muscle morphology and metabolism likely play a role in the health benefits associated with high CRF. For example, exercise training increases the number of glucose transporters (e.g., GLUT4) (60), muscle blood flow (61), and glycogen synthase activity (62). All of these adaptations are associated with a reduction in insulin resistance, a primary risk factor for type 2 diabetes and cardiovascular disease.

Exercise-mediated improvements in the functional and metabolic capacities of cardiac muscle (63,64) may also contribute to the lower health risk in individuals with high CRF. Finally, exercise training is associated with reduced production of atherogenic cytokines (e.g., tumor necrosis factor-α, interleukin-1β, interferon-γ), increased production of atheroprotective cytokines (e.g., transforming growth factor-β, interleukin-4, interleukin-10) (65,66), and reduced production of adipocyte-derived hormones such as leptin (67,68).

In summary, we found that, for a given BMI or WC, individuals with moderate CRF have less total fat mass, CT abdominal subcutaneous fat, and CT visceral fat than individuals with low CRF. These cross-sectional findings are consistent with the results of a 20-week exercise training intervention, indicating that aerobic exercise training in the absence of a meaningful weight loss is associated with significant reductions in total adiposity and CT abdominal fat. These findings highlight a limitation inherent in the use of BMI and WC alone for assessing obesity-related health risk. They also underscore the importance of obtaining measures of CRF and more precise measures of total and regional adiposity when predicting health risk. The feasibility of adding these measures to standard clinical practice needs to be explored.

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