Does the amount of endurance exercise in combination with weight training and a very-low-energy diet affect resting metabolic rate and body composition?[1,2]

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ABSTRACT Effects of large (LA; 400 min/wk) and moderate (MA; 200 min/wk) amounts of endurance exercise in combination with weight training (3 d/wk) were compared with the effects of no exercise (C) in 23 obese females after a 12-wk, 3360-kJ/d very-low-energy diet (VLED). The LA group lost 6.5 kg more weight, mainly as fat (6.4 kg), than the C group ($P < 0.05$). No measurable differences were found among groups for decreases in resting metabolic rate (−729 to −1233 kJ/d; NS) or fat-free mass (−2.9 to −3.9 kg; NS). No improvements in aerobic capacity were achieved with the addition of exercise to a VLED (−0.079 to −0.037 L/min; NS). Strength indexes were improved (+16 to +5 kg; $P < 0.05$) or maintained with exercise (−3 kg; NS) whereas a loss (−9.3 kg; $P < 0.05$) or maintenance (+4.5 kg; NS) was found for VLED alone. Large amounts of endurance exercise in combination with weight training added to a VLED appear to improve weight and fat loss compared with a VLED alone. *Am J Clin Nutr* 1994;59:1088–92.

KEY WORDS Exercise, obesity, diet, resting metabolic rate, body composition

Introduction

Declines in resting metabolic rate (RMR) during severe energy restriction have been attributed to numerous factors such as the magnitude of energy restriction, magnitude of weight loss, loss of fat-free mass (FFM), changes in sympathetic nervous system activity, and genetics (1–5). A decline in RMR indicates that there is an increased energy efficiency of the existing tissue. The combination of various endurance exercise programs and a very-low-energy diet (VLED) has been based on the hypothesis that exercise may offset the decline in RMR by its direct energy cost and indirectly by its potential to preserve FFM (6, 7). However, the ability of endurance-exercise programs to exert a positive effect on RMR and preserve FFM has shown equivocal results compared with VLED treatment alone (8–13). Endurance-type exercise may not be an adequate metabolic stimulus to override the adaptive responses of the body to an energy deficit caused by a VLED. The additional energy expenditure of endurance exercise increases the energy deficit and a critical point may exist that results in a further compensation of RMR to prevent lean tissue wasting.

The extent to which exercise contributes to an energy deficit is dependent on the amount, quality, type, and duration of exercise training (14). As demonstrated by Phinney et al (8), the combination of large amounts of endurance exercise and a VLED resulted in a greater decline in RMR and did not minimize the loss of FFM compared with a VLED alone. Resistance training has been shown to increase FFM during moderate energy restriction (15). Therefore, this study examines how the amount of endurance exercise in combination with resistance training and 12 wk of a nutrient-dense VLED affects RMR and FFM preservation in obese females.

Subjects and methods

Subjects

Twenty-three obese females (n = 5 African Americans, n = 18 whites) between the ages of 25 and 45 y with a body mass index (BMI; in kg/m^2) between 30 and 42 volunteered for the study. The physical characteristics of the subjects are shown in **Table 1.** All subjects were in good health with the exception of obesity, as ascertained from a complete medical evaluation. Subjects were weight stable (±5 kg) and had not participated in any purposeful exercise for the past 6 mon. Subjects were randomly assigned to one of three treatment groups. No significant differences were found among groups for baseline characteristics. Seven subjects comprised the control group, VLED only (C); eight subjects comprised an experimental group, VLED plus a supervised moderate-amount exercise program (MA); and eight subjects comprised an experimental group, VLED and a supervised large-amount exercise program (LA). Each subject was given an oral and written explanation of the study and possible risks and benefits involved before they signed an informed consent form. This study was approved by the New England

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TABLE 1
Baseline characteristics of subjects[1]

	Control (n = 7)	Moderate-amount exercisers (n = 8)	Large-amount exercisers (n = 8)
Age (y)	39.3 ± 3.5	38.9 ± 6.6	36.1 ± 4.3
BMI[2]	33.9 ± 3.7	36.0 ± 4.2	35.4 ± 4.6
Body weight (kg)	93.9 ± 13.2	96.7 ± 13.0	96.6 ± 11.9
Fat weight (kg)	41.1 ± 8.1	44.6 ± 9.2	42.3 ± 9.5
FFM (kg)	52.8 ± 6.7	52.1 ± 5.2	54.4 ± 6.8
Body fat (%)	43.6 ± 3.8	45.8 ± 4.2	43.5 ± 6.1
WHR	0.81 ± 0.04	0.81 ± 0.07	0.81 ± 0.07
RMR (kJ/d)	6780.0 ± 903.0	7008.75 ± 992.00	6942.60 ± 642.00
Peak $\dot{V}O_2$ (L/min)	1.9 ± 0.3	2.0 ± 0.3	2.2 ± 0.3

[1] $\bar{x}$ ± SD. FFM, fat-free mass; WHR, waist-to-hip ratio; RMR, resting metabolic rate; $\dot{V}O_2$, oxygen consumption.
[2] In kg/m^2.

Deaconess Institutional Review Board and the Northeastern University Human Subjects Review Committee.

Diet

Each subject was placed on a nutrient-dense liquid formula diet providing 3360 kJ/d (Optifast 800; Sandoz Nutrition, Minneapolis) for 12 wk. The formula consisted of 100 g carbohydrate, 70 g protein, and 13 g fat, and it met the RDA for minerals and vitamins (16). Subjects were instructed to consume the liquid formula five times during the day and to consume ≥ 2 L of nonenergy-containing beverages daily. Weekly interviews by the research physician determined presence of intercurrent health events and dietary and exercise-protocol compliance.

Supervised exercise program

Subjects randomly assigned to the MA exercise group participated in walking and weight training 3 d/wk (Monday, Wednesday, and Friday). Subjects randomly assigned to the LA exercise group participated in walking 5 d/wk (Monday through Friday) and weight training 3 d/wk (Monday, Wednesday, and Friday). Exercise was supervised by the principal investigator and research physician. The progression of the walking program for the MA and LA groups is shown in **Table 2.** Intensity of walking was 50–65% of heart rate reserve (HRR), calculated from baseline graded exercise treadmill tests. Exercise heart rates were monitored and recorded by the subjects and routinely checked by the exercise supervisors to ensure maintenance of exercise intensity and walking progression. The weight-training program for both the MA and LA groups progressed from two sets of six repetitions at 70% one-repetition maximum (1RM) to three sets of eight repetitions at 80% 1RM over the 12-wk period. The amount of weight lifted was based on the results of baseline 1RM values for the bench press (BP), lateral pull-down (LP), knee extension (KE), and knee flexion (KF). The same weight machines were used for 1RM measurements and during each weight-training session. Exercise attendance was 90% for the MA group and 87% for the LA group. Subjects in the control group were discouraged from participating in any exercise during the study period.

Testing procedures

Body composition. Body weight was recorded at baseline and once a week thereafter by use of a balance-beam scale. Body density was estimated at baseline and week 12 by hydrostatic weighing at residual volume (RV). Ten trials for underwater weight were taken with the average of the last three trials used as the underwater weight (17). RV was determined by nitrogen-washout technique (18) immediately before hydrostatic weighing. Multiple trials were obtained until two trials were within 50 mL; the averages of these two trials were used as the RV. The equation of Goldman and Buskirk (19) was used to estimate body density. The equation of Siri (20) was subsequently used to estimate percent body fat from body density.

Waist-to-hip ratio (WHR). Circumference measurements recorded to the nearest 0.1 cm were measured at baseline and week 12 by using a nonelastic tape while the subject stood erect. Waist circumference was measured at the narrowest part of the torso. Hip circumference was measured at the level of maximum protrusion of the buttocks.

Resting metabolic rate. RMR was determined by indirect calorimetry by using the open-circuit technique (21). Testing times and procedures were similar at baseline and week 12 for all subjects. Subjects reported to the laboratory between 0600 and 1000 after an overnight fast and without engaging in exercise for ≥ 24 h. Subjects rested supine for 30 min in a moderately dark and quiet room and then underwent measurements under the venti-

TABLE 2
Progression of exercise for moderate-amount and large-amount exercise group[1]

Week (intensity of exercise)	Moderate-amount exercisers			Large-amount exercisers		
	Duration	Frequency	Total	Duration	Frequency	Total
	min	*d/wk*	*min/wk*	*min*	*d/wk*	*min/wk*
1 (50% HRR)	30	3	90	30	5	150
2 (50% HRR)	35	3	105	35	5	175
3 (65% HRR)	40	3	120	40	5	200
4 (65% HRR)	45	3	135	45	5	225
5 (65% HRR)	50	3	150	50	5	250
6 (65% HRR)	55	3	165	55	5	275
7 (65% HRR)	60	3	180	60	5	300
8 (65% HRR)	65	3	195	70	5	350
9–12 (65% HRR)	70	3	210	80	5	400

[1] HRR, heart rate reserve.

lated hood. Measurement of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and respiratory quotient (RQ) were taken at 1-min intervals until 15 min of steady-state values were collected. Ventilation and expired oxygen and carbon dioxide were measured by a metabolic cart (DeltaTrac; SensorMedics, Anaheim, CA). Energy expenditure (kJ/d) was calculated from the abbreviated equation of Weir (22).

Aerobic functional capacity. A graded exercise test on a motor-driven treadmill (Q60; Quinton Instruments, Seattle) was performed with continuous electrocardiograph monitoring (Q4000; Quinton Instruments). A modified Balke treadmill protocol was used in which the speed of the treadmill remained constant at 80.4 m/min and the slope was gradually increased by 1.25% at 1-min intervals after an initial stage of 40.2 m/min at 0% grade for 2 min. Expired air was measured continuously, breath-by-breath, for volume, oxygen, and carbon dioxide, and averaged each 30 s by a metabolic measurement cart (MMC Horizons System 4400; SensorMedics). Peak $\dot{V}O_2$ was calculated as the highest observed value.

Muscular strength. One-repetition maximum BP, LP, KE, and KF were performed by using Universal Gym Equipment by the methods described by Wilmore and Costill (23). After a brief warm-up, each subject progressively lifted increments of ≈2.3–4.5 kg, with the heaviest weight successfully lifted taken as their 1RM. An upper-body strength score (UBS) was calculated by adding BP and LP and a lower-body strength score (LBS) was calculated by adding KE and KF.

Statistical analysis

The analyses were based on 23 subjects except for the aerobic capacity and muscular-strength test. One subject from the C group and one subject from the MA group did not complete week-12 tests for aerobic capacity and muscular strength. Data were analyzed by using analysis of variance (ANOVA) for differences among treatment groups with a significance level set at 0.05. Post hoc Sheffé comparisons were performed when significant F ratios were found. Within-group differences from baseline to week 12 were analyzed by using the Student's t test with a significance level set at 0.05. When data were analyzed by using a two-factor repeated-measures ANOVA with time and treatment as factors, no significant group × time interactions were found. All values are reported as mean ± SD. Pearson correlation coefficients were calculated to determine the relationship between RMR, body composition, and minutes of exercise. Multiple regression was used to determine the variables that predicted the change in RMR. Statistical analysis was performed by using the *SAS* computer program (SAS Institute, Inc, Cary, NC).

TABLE 3
Change scores from baseline to week 12[1]

	Control (n = 7)	Moderate-amount exercisers (n = 8)	Large-amount exercisers (n = 8)
Body weight (kg)	−13.1 ± 2.4[2]	−15.8 ± 4.2[2]	−19.6 ± 4.2[2,3]
Fat weight (kg)	−9.3 ± 3.1[2]	−12.9 ± 3.8[2]	−15.7 ± 4.5[2,3]
FFM (kg)	−3.8 ± 1.4[2]	−2.9 ± 1.3[2]	−3.9 ± 2.4[2]
WHR	−0.028 ± 0.026[2]	−0.036 ± 0.057	−0.020 ± 0.026
RMR (kJ/d)	−930.0 ± 294.0[2]	−729.75 ± 1033.00	−1233.75 ± 533.00[2]
$\dot{V}O_2$ peak (L/min)	−0.037 ± 0.510	−0.079 ± 0.180	−0.048 ± 0.240
UBS (kg)	−9.3 ± 5.5[2]	+5.3 ± 6.6[2,3]	−3.0 ± 7.3
LBS (kg)	+4.5 ± 8.2	+13.0 ± 7.2[2]	+16.0 ± 10.8[2]

[1] $\bar{x}$ ± SD. FFM, fat-free mass; WHR, waist-to-hip ratio; RMR, resting metabolic rate; $\dot{V}O_2$, oxygen consumption; UBS, upper-body strength; LBS, lower-body strength.

[2] Significantly different from baseline, $P < 0.05$.

[3] Significantly different from control, $P < 0.05$.

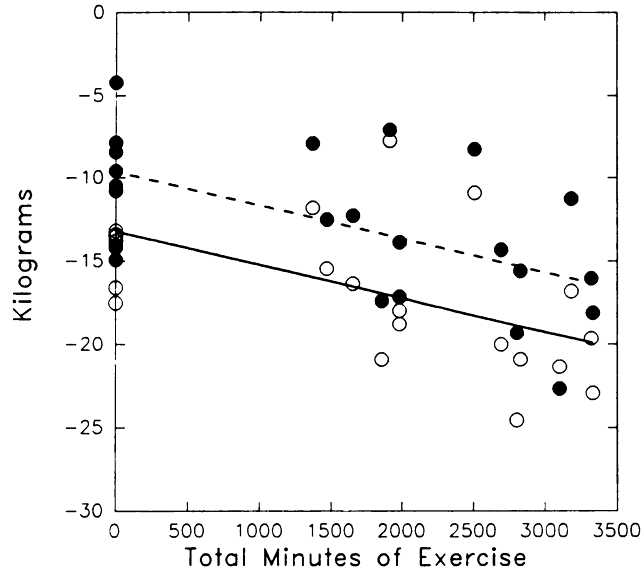

FIG 1. Relationship between the change in body weight (●, $r = -0.59$; $P < 0.05$); change in fat weight (○, $r = -0.58$; $P < 0.05$), and total minutes of exercise.

Results

Weight loss and body composition variables for groups from baseline to week 12 are shown in **Table 3.** All groups showed significant decreases in body weight, percent body fat, fat mass, and FFM ($P < 0.05$) from baseline to week 12. Comparison among groups showed a significantly greater decrease for body weight, percent body fat, and fat mass for the LA group than for the C group ($P < 0.05$). No differences were found among groups for the decrease in FFM. The percentage of body weight lost as FFM was 29.0%, 18.4%, and 19.9% for the C, MA, and LA groups, respectively. **Figure 1** shows the correlation between total exercise minutes and change in weight ($r = -0.59$, $P < 0.05$) and the correlation between total exercise minutes and change in fat mass ($r = -0.58$, $P < 0.05$). No correlation was found between total exercise minutes and change in FFM ($r = -0.018$, $P > 0.05$).

WHR from baseline to week 12 are shown in Table 3. A significant decrease in WHR was found for the C group ($P < 0.05$) from baseline to week 12. No significant difference was found for the MA or LA group from baseline to week 12. Comparisons among groups showed no significant difference in the decrease in WHR.

RMRs from baseline to week 12 are shown in Table 3. Absolute RMR decreased significantly from baseline to week 12 for the C and LA groups ($P < 0.05$). No change was found for the MA group from baseline to week 12 for absolute RMR. No statistical differences were found among groups for changes in absolute RMR from baseline to week 12. At baseline the association between FFM and RMR was respectively, $r = 0.589$ and $r^2 = 0.347$ and at week 12 $r = 0.575$ and $r^2 = 0.331$ ($P < 0.05$). Multiple regression found no association between change in FFM, fat weight, body weight, BMI, WHR, or total minutes of endurance exercise with the change in RMR from baseline to week 12 ($r = 0.001-0.175$, $P > 0.05$).

Peak $\dot{V}O_2$ (L/min) from baseline to week 12 is shown in Table 3. No statistical differences were found for peak $\dot{V}O_2$ from baseline to week 12 within each group. Comparisons among groups showed no significant differences from baseline to week 12 for peak $\dot{V}O_2$.

Muscular-strength variables from baseline to week 12 are shown in Table 3. Significant increases were found in UBS for the MA group and in LBS for the MA and LA groups ($P < 0.05$). A significant decrease was found in UBS for the C group ($P < 0.05$). No changes were found in UBS for the LA group and in LBS for the C group. Comparisons among groups showed no significant differences in LBS changes. A significant difference was found between the MA and C groups for changes in UBS ($P < 0.05$).

Discussion

The findings of this study show that the addition of large amounts of exercise (LA) significantly increased weight and fat loss compared with a VLED alone (C). The LA group lost 6.5 kg more weight than the C group at week 12, representing a greater weight loss of ≈32%. This greater weight loss was accounted for by a greater fat loss of 6.4 kg by the LA group compared with the C group. A good relationship exists between the total minutes of endurance exercise and weight loss and total minutes of exercise and fat loss (Fig 1). No measurable difference was found for FFM loss between the LA and C groups (-3.9 ± 2.4 and -3.8 ± 1.4 kg, respectively). This suggests that the additional energy cost of exercise was met by an increase in fat oxidation, which in turn may have decreased the need to deaminate amino acids for glycogen, thus sparing lean tissue (15). The resting RQ significantly decreased from baseline to week 12 (0.80–0.76), which provides further evidence that fat oxidation increased for the LA group.

Few studies using a combination of VLED and exercise find a significantly greater weight loss compared with VLED alone (6). There is some evidence to support an increased loss of fat and a preservation of FFM with the addition of exercise to a VLED compared with a VLED alone (1, 11, 24); however, this is not a consistent finding (8, 9, 12, 25). Many factors may account for the discrepant body composition changes among studies using exercise and a VLED. The duration of this study appears to be an important factor because a significant difference in weight loss was not found until week 12. Short-duration studies of 3–8 wk may be insufficient for exercise to exert a measurable effect on weight loss (8–10), whereas studies of longer duration (13–16 wk) show a trend for greater weight loss during exercise plus VLED compared with VLED alone (12, 24). It appears that a significant amount of effort over a long duration is necessary for a measurable effect of exercise on weight loss to occur.

Although the use of weight training during moderate energy restriction increases FFM (15), weight training does not appear to enhance retention of FFM during a VLED (24). The present study found no measurable difference in the absolute loss of FFM; however, expression of the loss of FFM as a percentage of total weight loss demonstrates that both exercise groups preserved FFM to a greater extent than did the C group. The proportion of weight lost as FFM was 18.4%, 19.9%, and 29.0% for the MA, LA, and C groups, respectively. Expressing the loss of FFM as a percentage of total weight loss appears more appropriate because FFM loss is a function of total weight loss (26). This small proportion of weight lost as FFM is similar (24) or less than that found in studies using endurance exercise plus VLED (1, 9, 25). Perhaps the addition of weight training enhanced the retention of FFM to a greater extent than did studies using endurance exercise only with a VLED.

The ability of exercise to offset the decline in diet-induced RMR is not consistently found (24, 27–29). Several investigators have found a greater decline in RMR (kJ/d) with the addition of exercise to a VLED (8–10). In contrast, the present findings show no measurable differences among groups for the decline in absolute RMR. This finding suggests that despite the larger energy deficit resulting from a combination of exercise and VLED, there was not a greater decline in RMR. Several hypotheses exist that may explain these results. First, the increased energy demands of exercise were met by an increase in fat oxidation, resulting in an increased loss of fat tissue, thus sparing FFM. Therefore, no greater compensating metabolic adjustment was needed despite the greater energy deficit created by the combination of exercise and a VLED. Second, the exercising subjects may have decreased their activity during nonexercising hours to compensate for the energy expended during the required exercise training, resulting in an energy deficit similar to that associated with the VLED condition only. Finally, the small sample size used in this study decreased the ability to find a statistically significant difference among groups (power = 0.6).

Although declines in RMR have been thought to be due to changes in body composition, particularly FFM (30), the declines in RMR in the present study were not explained by the changes in FFM ($r = 0.036$). No relationship was noted with change in RMR and fat, BMI, WHR, or total minutes of endurance exercise ($r = 0.001-0.175$). The mechanisms responsible for the decline in RMR in the present study are unknown. Variables such as genetics or changes in sympathetic hormones (5) may explain the increase in metabolic efficiency, but were not measured in the present study.

Despite the addition of exercise in the MA and LA groups, no measurable difference was found in aerobic fitness compared with the C group. Other studies have also failed to show measurable improvements in aerobic capacity during a VLED combined with various exercise routines (24). The low intensity of the exercise (50–65% HRR) may have contributed to the lack of significant improvement in aerobic capacity. Intensity rather than frequency may be the most important variable for increasing aerobic fitness (31). The present results do show, however, that the greatest improvement in aerobic fitness was found in the LA group, consistent with engaging in a greater quantity of exercise. Perhaps tests of fitness other than $\dot{V}O_2$ should be examined to determine fitness benefits, such as changes in anaerobic threshold or physiological response to an absolute submaximal steady-state exercise bout (eg, heart or ventilation response).

LBS was significantly increased in both exercise groups and was maintained in the C group. The ability to maintain LBS during a VLED may result from the use of lower-body muscles during daily ambulation, as suggested by Pronk et al (32) UBS was preserved or increased in the exercise groups. A decrease in UBS was found in the C group and may reflect the absence of daily upper-body exercise. These UBS results concur with the results of Donnelly et al (24), who found that a concurrent endurance and weight-training protocol resulted in improvements in strength compared with a VLED alone.

In summary, the findings of this study show a benefit of large amounts of exercise in combination with a VLED for weight and fat loss compared with a VLED alone. It appears that the effects of exercise may be realized in studies of ≥ 12 wk. Exercise appears to have no detrimental effect on RMR or FFM despite a larger energy deficit compared with a VLED alone. In contrast, no benefit of exercise was found for improvements in aerobic capacity compared with a VLED alone. Strength was either maintained or increased in the exercising subjects, whereas the nonexercising group decreased UBS and preserved LBS. ■

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