



# Physiological adaptations to a weight-loss dietary regimen and exercise programs in women

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**Kraemer, William J., Jeff S. Volek, Kristine L. Clark, Scott E. Gordon, Thomas Incledon, Susan M. Puhl, N. Travis Triplett-McBride, Jeffrey M. McBride, Margot Putukian, and Wayne J. Sebastianelli.** Physiological adaptations to a weight-loss dietary regimen and exercise programs in women. *J. Appl. Physiol.* 83(1): 270–279, 1997.—Thirty-one women (mean age 35.4 ± 8.5 yr) who were overweight were matched and randomly placed into either a control group (Con; *n* = 6), a diet-only group (D; *n* = 8), a diet+aerobic endurance exercise training group (DE; *n* = 9), or a diet+aerobic endurance exercise training+strength training group (DES; *n* = 8). After 12 wk, the three dietary groups demonstrated a significant (*P* ≤ 0.05) reduction in body mass, %body fat, and fat mass. No differences were observed in the magnitude of loss among groups, in fat-free mass, or in resting metabolic rate. The DE and DES groups increased maximal oxygen consumption, and the DES group demonstrated increases in maximal strength. Weight loss resulted in a similar reduction in total serum cholesterol, low-density lipoprotein cholesterol, and high-density lipoprotein cholesterol among dietary groups. These data indicate that weight loss during moderate caloric restriction is not altered by inclusion of aerobic or aerobic+resistance exercise, but diet in conjunction with training can induce remarkable adaptations in aerobic capacity and muscular strength despite significant reductions in body mass.

body composition; strength training; lipoproteins; endurance training; hormones

ONE OF THE GOALS of Healthy People 2000: National Health Promotion and Disease Prevention Objectives is to reduce overweight to a prevalence of no more than 20% among people aged 20 yr and older (37). Data obtained from the 1988–1991 National Health and Nutrition Examination Survey (NHANES III) (5) showed that the number of US adult women classified as overweight has risen to 35% compared with 25% reported from NHANES II (1976–1980) (31). No efficacious practical therapeutic solution has yet been identified addressing the increasing prevalence of overweight. Therefore, an increased understanding of dietary and exercise strategies used to promote the loss of body mass and maintenance of a healthy weight is needed if these weight-loss goals are to be realized by the year 2000.

Physical activity in conjunction with moderate dietary energy restriction and behavior modification has been promoted as an important component of a successful weight-loss regimen (7, 40). The results of many studies support the beneficial role of combined diet and exercise in accelerating weight loss (18, 22, 38), preserv-

ing fat-free mass (2, 15, 17, 23, 42, 43) and resting metabolic rate (RMR) (33, 36), and improving serum lipoprotein (19, 22, 38) and triglyceride (22) status. However, results of several studies also indicate that exercise in conjunction with food restriction provides no additional benefits in these parameters (9, 39, 52). Furthermore, studies evaluating the impact of high-intensity resistance exercise on body composition and other physiological adaptations during weight loss have reported inconsistent findings (3, 11, 12, 36, 43, 46). For example, conflicting results concerning the impact of dietary restriction combined with resistance training on lean body mass have been reported. Ross et al. (43) demonstrated that lean tissue is preserved, whereas Donnelly et al. (11) reported no advantages of a resistance training regimen to maintenance of lean body mass. The inconsistencies reported in previous diet/exercise studies may reflect differences in several important program design components, such as severity of the dietary energy restriction, nutritional composition and nutrient adequacy of the diet, mode and intensity of the exercise programs, dietary and exercise compliance, and total duration of the study. Thus the influence of exercise, but more specifically resistance training, in a dietary program directed at weight loss remains unclear.

Another limitation with regard to research examining the physiological effects associated with various forms of weight loss is that few studies have simultaneously reported data on body composition, exercise performance (muscular strength, endurance, power), metabolic rate, and blood lipid profiles, and no studies have examined all of these variables in response to resistance training. The outcome of a specific weight-loss program must be judged in terms of all of these variables to make comparisons among various programs. For example, a weight-loss program may improve body composition to a greater degree but have a negative impact on blood cholesterol compared with another weight-loss program. Because blood lipid measurements have been strongly correlated with coronary heart disease risk status, these become very informative in the selection of an optimal weight-loss strategy.

We hypothesized that a weight-loss diet/exercise regimen (i.e., high-fiber moderate caloric restriction combined with individually prescribed high-intensity endurance and resistance training programs performed over 12 wk) would have a positive influence on body composition, serum lipid profiles, and physical performance measurements compared with a treatment with diet alone. Therefore, the primary purpose of

this study was to examine the effects of diet alone and diet combined with endurance training and diet combined with endurance and resistance training on physiological and performance adaptations in overweight adult women.

## METHODS

**Experimental groups.** This study was conducted over a 12-wk period by utilizing the Matola weight-loss program with and without specific exercise training programs. Thirty-one healthy premenopausal women were screened by a physician and demonstrated no endocrine, orthopedic, or other pathological disorders, except for being overweight (i.e., either  $\geq 120\%$  of desirable weight, defined as the midpoint of the range of weights for a medium-frame woman on the basis of the 1983 Metropolitan Height and Weight Tables, or a body mass index  $\geq 27$ ). Women were matched according to body mass index and randomly placed into one of four groups that included a control group (Con;  $n = 6$ ), which just performed the testing, maintained body weight, and normal activities; a diet group (D;  $n = 8$ ), which maintained normal activities while reducing calories for weight loss; a diet group that performed an aerobic endurance exercise training program 3 days/wk (DE;  $n = 9$ ); and a diet group that performed an aerobic endurance exercise training program combined with a strength training program 3 days/wk (DES;  $n = 8$ ). Each woman was menstruating normally (i.e., every 29–36 days), as calculated according to methods previously described in detail, and testing was performed in the same phase of the menstrual cycle (27). The experimental testing took place before the program and after experimental familiarization, at 6 wk, and after 12 wk. Descriptive data for the experimental groups are presented in Table 1. No significant differences in any of the listed variables were observed among the groups at the beginning of the study.

**Training protocols.** Each subject was familiarized with the training protocols before starting her program. The cardiovascular conditioning programs followed customary guidelines for intensity, frequency, and duration of exercise (24). Subjects in the DE and DES groups participated in a supervised program of whole body aerobic endurance exercise individually designed to elicit a target heart rate of 70–80% of the functional capacity as determined by treadmill testing. During the first week, each session lasted  $\sim 30$  min (not including warm-up and cool-down), and this was gradually increased to 50 min over the subsequent weeks. Intensity and duration of exercise were individually increased for each subject as improvement and tolerance occurred. For variety, endurance activities included a cross-training mix of treadmill walking/jogging, stationary cycling, seated rowing, and stationary stair climbing.

Table 1. Descriptive data of experimental groups

Variable	Con	D	DE	DES
<i>n</i>	6	8	9	8
Age, yr	31.0 $\pm$ 9.6	34.6 $\pm$ 10.2	35.6 $\pm$ 8.5	36.5 $\pm$ 7.6
Height, m	1.7 $\pm$ 6.9	1.6 $\pm$ 7.1	1.7 $\pm$ 6.8	1.6 $\pm$ 13.1
Body mass, kg	77.9 $\pm$ 12.1	71.4 $\pm$ 12.3	77.7 $\pm$ 12.2	76.1 $\pm$ 13.0
Body mass index	28.2 $\pm$ 4.0	27.3 $\pm$ 3.1	28.3 $\pm$ 4.2	30.5 $\pm$ 5.1
Body fat, %	37.4 $\pm$ 6.8	38.0 $\pm$ 5.5	39.3 $\pm$ 4.1	35.0 $\pm$ 6.7
Fat-free mass, kg	48.3 $\pm$ 5.5	43.8 $\pm$ 5.3	47.1 $\pm$ 7.6	49.0 $\pm$ 5.8
Fat mass, kg	29.6 $\pm$ 9.2	27.6 $\pm$ 7.8	30.6 $\pm$ 6.3	27.2 $\pm$ 8.8

Values are means  $\pm$  SD; *n* = no. of subjects. Con, control group; D, diet-only group; DE, diet + endurance exercise group; DES, diet + endurance exercise + strength training group.

The heavy-resistance training program, performed by the DES group, consisted of a squat exercise performed on a Tru-Squat machine (Southern Exercise, Cleveland, TN) and additional Nautilus machine (Nautilus, Huntersville, NC) exercises as follows for each of the major muscle groups: military press, bench press, lat pull-down, seated rows, sit-ups, lower back, leg press, hamstring curls, calf raises, and arm curls. Progressive resistance training took place three times per week and followed typical repetition maximum (RM) resistance training principles for progression in the resistance and volume of exercise in a program (25). The resistance training protocol also utilized a nonlinear periodization model, that is, the loads were changed within the week with subjects varying their resistance loads for the exercises on different days, alternating between heavy-day (5- to 7-RM) and moderate-day (8- to 10-RM) loads. Subjects progressed from one to three sets with a short rest between sets and exercises when using moderate loads (i.e., 1 min) and longer rest periods (2–3 min) when using the heavier loads. This program variation reduced boredom and has been shown to enhance strength training responses compared with constant-loading programs (28).

**Experimental tests.** All experimental tests demonstrated very good test-retest reliability over the duration of the study because intraclass correlation coefficients (*r*) were determined for all tests and ranged from 0.94 to 0.98. All subjects were completely familiarized with all testing procedures before the experiment to reduce the influence of any learning effects due solely to the mechanics of performing the test protocol.

Body mass was measured on a balance scale to the nearest 100 g, and body density was determined via hydrodensitometry. A detailed description of the equipment and methodology used for underwater weighing tests performed in this investigation has appeared previously (1). In general, underwater weight of the subject was determined with the use of a scale utilizing four electronic force cubes (load cells) attached to a chart recorder. After a maximal exhalation, subjects were weighed underwater, and their residual volume measurements were performed by the use of an open-circuit nitrogen washout technique while the subjects were still in the tank. Percent body fat was calculated from body density by using the Siri equation (44). Fat mass was determined by multiplying percent fat times body mass, and fat-free mass was determined by subtracting fat mass from body mass.

Maximal force production was assessed by the determination of 1-RM strength for upper and lower body exercise as previously described (29). We tested 1 RM for upper body and lower body strength by using the Nautilus bench press and Tru-Squat machines, respectively. It is important to note that these tests provided a specific representation of gains in muscular strength of the upper body and lower body musculature because "training-specific" exercises were used in the testing.

Maximal oxygen consumption was determined by using a graded exercise test on a Quinton (Seattle, WA) motor-driven treadmill by using a modified Bruce protocol (29). During each stage of the test, heart rate was monitored continuously via a 12-lead electrocardiograph (model Case-15, Marquette, Milwaukee, WI), and ratings of perceived exertion were recorded each minute. Blood pressure was obtained every 2 min via brachial auscultation. Expired gases were analyzed during the last 6 min of the test by using an automated metabolic system. The gas analyzers consisted of a Beckman LB-2 CO<sub>2</sub> analyzer (Beckman Instruments, Schiller Park, IL) and S3A O<sub>2</sub> analyzer (Applied Electrochemistry, AEI Technologies, Pittsburgh, PA) and were calibrated before each test



with standard gases. Standard gases were calibrated via Scholander methodology. Flow was measured by a Hans Rudolph pneumotachometer (model 4813) and transduced to volume by a Fitco Micro-Flow instrument (model FLO-1, Farmingdale, NY). These signals were integrated in a software package by Fitco.

Power production capabilities in the lower body were determined by using a 30-s Wingate anaerobic test performed on a computerized Monark cycle ergometer against an opposing force of 0.49 N (0.05 kg)/kg body mass by using a protocol previously described in detail by Kraemer et al. (29). Flywheel revolutions were electronically monitored during the test via computer interface (model 55sx, IBM Personal System/2). Peak power (highest 1-s value), mean power (average power over the time curve), and percent decline (decline from the highest to the lowest points on the curve) were calculated by associated software.

RMR was only determined before and after the 12-wk experimental protocol via indirect calorimetry. After a 10-h fast, subjects reported to the laboratory from 0500 to 0600 and were placed in a semirecumbent position on a bed. After a 30-min stabilization period, oxygen consumption was determined at 1-min intervals for 30 min by using the same online metabolic system used for maximal treadmill testing.

**Nutritional protocol.** One time per week all intervention participants attended a 1-h group-format nutrition education meeting led by a registered dietitian. The weekly sessions focused on behavior-modification techniques and educating subjects how to implement a healthy well-balanced eating plan designed for loss of body mass. Weekly meetings addressed various nutritional topics, including sessions on protein, carbohydrate, fat, fiber, eating on the road, holiday eating, portion sizes, and so on. Our objective was to create a 6- to 9-kg weight loss in each subject by moderate caloric restriction over the 12-wk experimental period. Forms for documenting daily food intake were provided at each session, and these food records were reviewed for dietary compliance at the beginning of each new week. In addition, subjects were given a 1-wk supply of Matola products at each meeting. Briefly, the Matola products included prepackaged high-fiber meal replacement bars, shakes, and cereal. The macronutrient composition of these products is shown in Table 2. These products were consumed in place of certain meals in a 4-day rotational sequence. In addition to other meals ingested during the day, subjects consumed the Matola products in the following order: one product on *day 1*, two products on *day 2*, three products on *day 3*, and no products on *day 4*. Thus a total of ~12 products were consumed each week. Subjects were strongly encouraged to drink copious amounts of water throughout the day. Body mass was also recorded and charted at each meeting to ensure a steady rate of weight loss (0.5–1.0

kg/week) over the 12-wk experimental period. The goal of the study was not to strictly control what subjects consumed outside of their scheduled Matola products. Sample menus were provided to help subjects select a variety of foods for their non-Matola product meals. If weight loss was not progressing at an appropriate rate or if subjects were having problems adhering to the dietary regimen, individual counseling was provided.

**Blood collection and analyses.** Blood was obtained from a forearm vein between 0500 and 0600 after a 10-h fast at baseline, after 6 wk, and after the completion of the 12-wk dietary program. Whole blood was processed, and the resultant serum samples were stored at  $-80^{\circ}\text{C}$  until analyses were performed. Serum glucose, blood urea nitrogen (BUN), total cholesterol, and high-density lipoprotein (HDL) cholesterol and triglyceride concentrations were determined via spectrophotometry (Novaspec II, Pharmacia Biochrom, Cambridge, UK), and testosterone and cortisol concentrations were determined by using standard radioimmunoassay procedures. Serum glucose was assayed in duplicate by using an enzymatic (hexokinase) technique at an absorbance of 340 nm (Sigma Diagnostics, St. Louis, MO). Total cholesterol, HDL cholesterol, tryglycerides, and BUN were enzymatically determined in duplicate by using commercially available kits (Sigma Diagnostics). Low-density lipoprotein (LDL) cholesterol concentrations were calculated according to the method of Friedewald et al. (14). Serum testosterone and cortisol concentrations were assayed by using solid-phase  $^{125}\text{I}$  single-antibody radioimmunoassays (Diagnostic Products, Los Angeles, CA) with detection limits of 0.14 and 5.5 nmol/l, respectively. Immunoreactivity was measured with an LKB 1272 Cline-gamma automatic gamma counter with an online data-reduction system (Pharmacia Wallac, Wallac Oy, Finland). Intra- and interassay variances for all assays were  $<5$  and  $<10\%$ , respectively.

**Statistical analyses.** Comparisons between values obtained at baseline, *week 6*, and *week 12* within each group and between groups at each time point were made by using a two-way analysis of variance. In the presence of a significant *F*-value, post hoc comparisons of means were provided by Fisher's least significant differences test. Statistical power calculations demonstrated power ranges in this investigation from 0.75 to 0.78. The relationship between changes in selected variables was made by using simple regression. The level of significance was  $P \leq 0.05$ .

## RESULTS

Table 3 shows the estimated daily nutrient intake for the three dietary groups. There were no significant differences among groups in any of the examined nutritional variables. Mean energy intake in the three dietary groups was 1,194 kcal/day. Greater than 70% of the total energy was composed of carbohydrate, and  $<15\%$  was composed of fat. Mean dietary fiber was  $>28$  g/day.

Figure 1 shows the changes in body composition over the 12-wk program in the three intervention groups. No changes were observed in the control group. A significant reduction in body mass was observed at 6 wk in all intervention groups. At *week 12*, all three dietary groups (D, DE, and DES) significantly reduced body mass by  $-6.2$ ,  $-6.8$ , and  $-7.0$  kg, respectively (Fig. 1A). In the D and DE groups, body mass at *week 12* was significantly decreased relative to their *week 6* values.

Table 2. Nutrient composition of Matola products

Nutrient	Bar	Cereal	Shake
Serving size, g	85	61	64
Energy, kcal	272	215	210
Protein, g	7	6	13
Carbohydrate, g	49	39	31
Fat, g	5	4	4
Saturated fat, g	1.1	NA	1.6
Monounsaturated fat, g	2.5	NA	1.8
Polyunsaturated fat, g	1.4	NA	0.5
Cholesterol, mg	5	0	15
Dietary fiber, g	11	8	12

Individual products provide 10–50% of the US recommended daily allowance of vitamins and minerals. NA, not available.

**Table 3. Estimated daily nutrient intake for the 3 experimental groups**

Nutrient	D	DE	DES
Energy, kcal	1,246 ± 148	1,139 ± 111	1,179 ± 191
Protein, %	15.7 ± 2.8	15.3 ± 1.3	15.2 ± 2.2
Carbohydrate, %	71.6 ± 4.5	71.8 ± 2.5	70.0 ± 3.5
Fat, %	12.7 ± 3.1	13.0 ± 1.6	14.8 ± 4.4
Saturated fat, g/1,000 kcal	4.4 ± 1.6	5.0 ± 1.2	5.0 ± 1.5
Monounsaturated fat, g/1,000 kcal	6.8 ± 2.0	7.0 ± 1.5	7.6 ± 1.7
Polyunsaturated fat, g/1,000 kcal	4.0 ± 0.7	4.5 ± 1.1	5.0 ± 2.2
Cholesterol, mg	74 ± 32	73 ± 18	89 ± 28
Dietary fiber, g	27.8 ± 2.4	28.7 ± 1.9	28.2 ± 4.0

Values are means ± SD. Daily intake was calculated from 3 days of food records obtained from each subject. Percentages are based on total energy intake.

Significant reductions in percent body fat (Fig. 1B) and fat mass (Fig. 1C) were observed at *week 6* in the D and DE groups and by *week 12* in the DES group. Additionally, the DE and DES groups demonstrated a significant decrease in percent body fat and fat mass at *week 12* relative to their *week 6* values. At *week 12*, the D, DE, and DES groups significantly reduced percent body fat by  $-5.8$ ,  $-8.0$ , and  $-4.3\%$ , respectively. No significant changes were observed in fat-free mass over the 12 wk in any of the groups (Fig. 1D). There were no differences in the magnitude of changes in body mass, percent body fat, fat mass, and fat-free mass among groups.

The results of the 1-RM strength testing in the bench press and squat exercise are shown in Table 4. No changes were observed in the Con, D, or DE groups. The DES group demonstrated significant increases in the 1-RM bench press and squat at *week 6*, with

**Table 4. Repetition maximum strength in bench press and squat exercise at baseline, 6 wk, and 12 wk**

Group	Baseline	6 Wk	12 Wk
Con			
Bench press, kg	38.4 ± 6.4		39.2 ± 6.3
Squat, kg	70 ± 20		72 ± 27
D			
Bench press, kg	38.3 ± 4.7	37.9 ± 5.2	39.9 ± 5.1
Squat, kg	72 ± 30	68 ± 23	75 ± 31
DE			
Bench press, kg	38.8 ± 7.7	36.5 ± 9.1	38.2 ± 10.0
Squat, kg	74 ± 51	78 ± 45	78 ± 27
DES			
Bench press, kg	37.3 ± 2.6	47.5 ± 6.6*	51.3 ± 5.2*†
Squat, kg	71 ± 28	82 ± 26*	89 ± 28*†

Values are means ± SD. \*Significantly different from corresponding value at baseline,  $P \leq 0.05$ . †Significantly different from corresponding value at 6 wk,  $P \leq 0.05$ .

continued improvement at *week 12* (+14% in the bench press and +25% in the squat). Maximal oxygen consumption, expressed relative to body mass ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ), improved significantly in the DE (+25%) and DES (+28%) groups at *week 12*, but not in the Con or D groups (Table 5). When expressed in absolute terms ( $\text{l}/\text{min}$ ), maximal oxygen consumption in the DES group significantly increased by 15% and in the DE group by 10% ( $P = 0.12$ ). There were no changes in Wingate anaerobic power performances in the Con, D, and DES groups after 6 or 12 wk. However, at 6 wk the D group demonstrated a significant increase in peak power (+25%). There was no significant difference in RMR when expressed as kilocalories per day or kilocalories per kilogram of fat-free mass in any group at *week 12*; however, the DES group demonstrated a lower respiratory exchange ratio at *week 12* (Table 6). Because it has

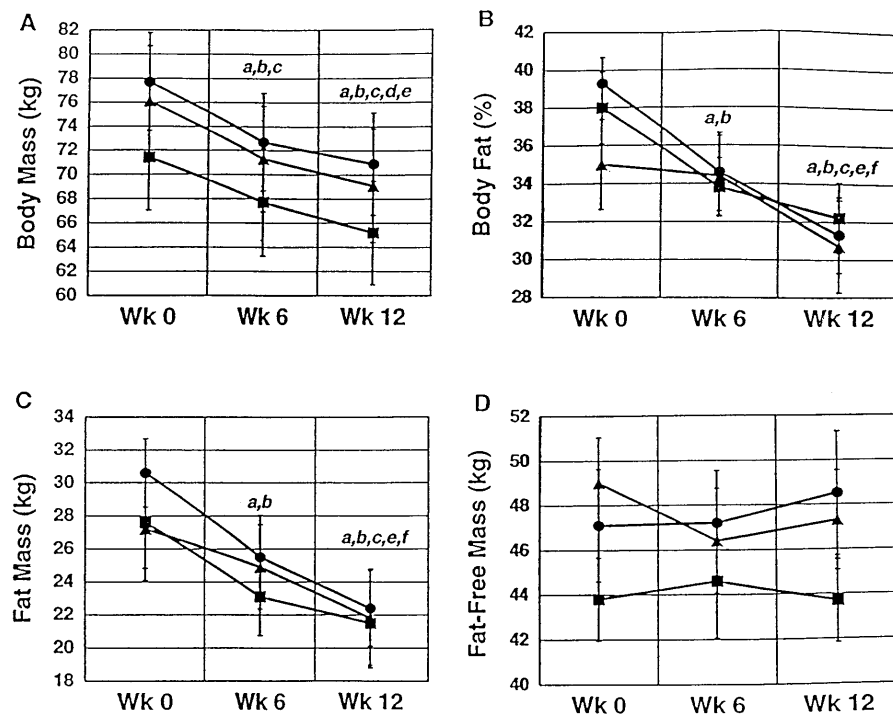


Fig. 1. Mean ( $\pm$ SE) body mass (A), %body fat (B), fat mass (C), and fat-free mass (D) in intervention groups at *week 0* (baseline), *week 6*, and *week 12*. ■, Diet-only group (D); ●, diet+endurance group (DE); ▲, diet+endurance+strength group (DES). Significantly different ( $P \leq 0.05$ ) from corresponding value at baseline: <sup>a</sup>D group, <sup>b</sup>DE group, <sup>c</sup>DES group. Significantly different ( $P \leq 0.05$ ) from corresponding value at *week 6*: <sup>d</sup>D group, <sup>e</sup>DE group, <sup>f</sup>DES group.

Table 5. Maximum oxygen consumption at baseline, 6 wk, and 12 wk

Group	Baseline	6 Wk	12 Wk	Change
Con				
ml · kg <sup>-1</sup> · min <sup>-1</sup>	28.43 ± 8.12		31.75 ± 8.12	+3.32 ± 4.07
l/min	2.18 ± 0.39		2.42 ± 0.24	+0.24 ± 0.26
D				
ml · kg <sup>-1</sup> · min <sup>-1</sup>	30.38 ± 5.88	32.80 ± 5.34	34.47 ± 4.51	+4.10 ± 4.24
l/min	2.21 ± 0.37	2.23 ± 0.42	2.27 ± 0.42	+0.06 ± 0.27
DE				
ml · kg <sup>-1</sup> · min <sup>-1</sup>	28.20 ± 3.88	33.59 ± 4.22*	35.29 ± 4.01*	+7.09 ± 6.19
l/min	2.23 ± 0.53	2.42 ± 0.39	2.45 ± 0.25	+0.22 ± 0.43
DES				
ml · kg <sup>-1</sup> · min <sup>-1</sup>	27.80 ± 4.52	31.95 ± 3.90*	35.42 ± 3.61*†	+7.62 ± 4.97
l/min	2.10 ± 0.34	2.25 ± 0.27*	2.41 ± 0.27*†	+0.31 ± 0.23

Values are means ± SD. \*Significantly different from corresponding value at baseline,  $P \leq 0.05$ . †Significantly different from corresponding value at 6 wk,  $P \leq 0.05$ .

been suggested that dividing RMR by fat-free mass is inappropriate as the intercept of the relationship does not intersect zero (41), Fig. 2 illustrates the relationship between RMR and fat-free mass at baseline and week 12 in the D (Fig. 2A), DE (Fig. 2B), and DES (Fig. 2C) groups.

Serum triglyceride, glucose, BUN, and cortisol and testosterone concentrations are presented in Table 7. There were no significant changes observed for serum triglycerides, glucose, BUN, and testosterone in any group. Cortisol concentrations were not affected in any group, except for significantly higher levels at 6 and 12 wk for the DE group. Percent changes in serum concentrations of total cholesterol, HDL cholesterol, and LDL cholesterol are shown in Fig. 3. Total serum cholesterol, HDL cholesterol, and LDL cholesterol at week 12 were significantly reduced, when all dietary groups are combined. However, the decrease in total cholesterol was only significant in the DE ( $-31.9 \pm 10.4$  mg/dl) and DES ( $-36.8 \pm 30.3$  mg/dl) groups but not in the D group ( $-25.6 \pm 26.2$  mg/dl). HDL cholesterol was significantly reduced in the D ( $-9.7 \pm 8.6$  mg/dl) and DES ( $-9.4 \pm 6.1$  mg/dl) groups at week 12 but not in the DE group ( $-4.9 \pm 6.9$  mg/dl). Although the D, DE, and DES

groups all demonstrated a decrease in LDL cholesterol at 12 wk ( $-17.7 \pm 20.2$ ,  $-23.0 \pm 24.6$ , and  $-26.6 \pm 31.2$  mg/dl, respectively) only results in the DE group were statistically significant. There were no differences in the magnitude of changes in any of the serum measurements among groups.

Significant correlations were observed between changes in several of the measured variables when combined among groups (Table 8). The strongest relationship with change in body mass was total cholesterol (Fig. 4) and LDL cholesterol. The change in body mass accounted for 60% of the variation in total cholesterol and 48% of the variance in LDL cholesterol.

## DISCUSSION

Many investigations have examined the physiological effects associated with diet-induced and diet plus exercise-induced weight loss. A variety of physiological effects have been examined, including assessment of body composition, exercise performance, RMR, and serum lipid profile. However, few studies have looked at all these physiological effects simultaneously, and no studies have examined all these variables in response to heavy-resistance exercise. Thus, because of methodological differences among studies, the clinical (i.e., risk for coronary heart disease) and functional (i.e., muscular strength and aerobic capacity) significance of a particular weight-loss regimen may not be known and must be interpolated from other studies. In this study, we report several important findings related to the effects of diet alone and diet combined with endurance exercise or endurance plus heavy-resistance exercise on 1) body composition, 2) aerobic capacity, 3) muscular strength, 4) muscular power, 5) RMR, 6) serum lipids and lipoprotein fractions, and 7) anabolic and catabolic hormone responses in overweight adult women.

Surprisingly, all dietary groups experienced similar reductions in body mass ( $-6.2$ ,  $-6.8$ , and  $-7.0$  kg for D, DE, and DES groups, respectively) and body composition ( $-5.8$ ,  $-8.0$ , and  $-4.3\%$  in D, DE, and DES groups, respectively), whereas fat-free mass remained relatively constant ( $-0.1$ ,  $+1.4$ , and  $-1.7$  kg in D, DE, and DES groups, respectively) over the 12-wk period. Our findings of no difference in the magnitude of loss in

Table 6. Resting metabolic rate determinations

Group	Baseline	12 Wk	Change
Con			
RER	0.86 ± 0.04	0.82 ± 0.04	-0.04
kcal/day	1,425 ± 277	1,557 ± 256	+132
kcal · kg FFM <sup>-1</sup> · day <sup>-1</sup>	29.81 ± 5.62	31.75 ± 1.26	+1.94
D			
RER	0.83 ± 0.04	0.85 ± 0.08	+0.02
kcal/day	1,475 ± 104	1,400 ± 302	-75
kcal · kg FFM <sup>-1</sup> · day <sup>-1</sup>	33.81 ± 3.12	31.90 ± 6.31	-1.91
DE			
RER	0.84 ± 0.05	0.83 ± 0.06	-0.01
kcal/day	1,517 ± 208	1,487 ± 280	-30
kcal · kg FFM <sup>-1</sup> · day <sup>-1</sup>	32.67 ± 2.37	31.66 ± 3.65	-1.01
DES			
RER	0.83 ± 0.05	0.78 ± 0.07*	-0.05
kcal/day	1,470 ± 184	1,327 ± 199	-143
kcal · kg FFM <sup>-1</sup> · day <sup>-1</sup>	30.07 ± 5.20	27.85 ± 3.40	-2.22

Values are means ± SD. RER, respiratory exchange ratio; FFM, fat-free mass. \*Significantly different from corresponding value at baseline,  $P \leq 0.05$ .

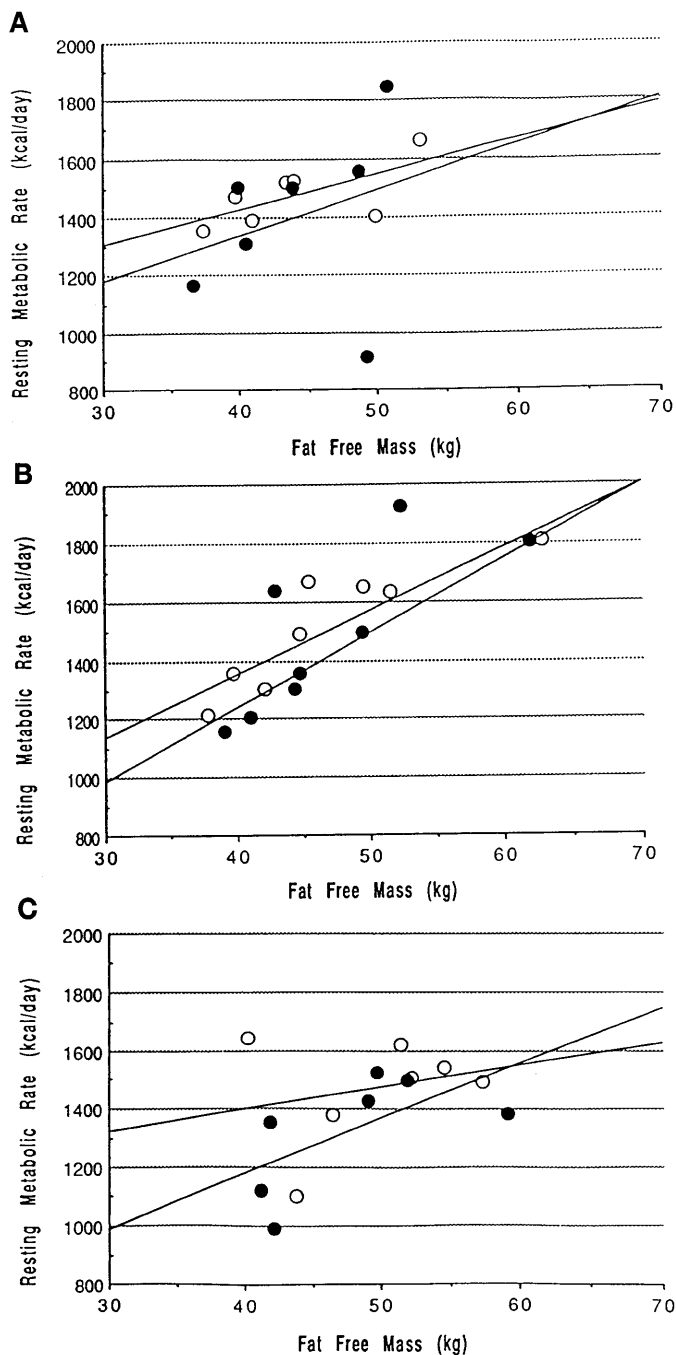


Fig. 2. Relationship between resting metabolic rate and fat-free mass at baseline (○) and at week 12 (●) in D (A), DE (B), and DES (C) groups. A:  $y = 943.48 + 12.08x$ ,  $r = 0.65$  (baseline);  $y = 710.42 + 15.61x$ ,  $r = 0.28$  (week 12). B:  $y = 442.74 + 23.00x$ ,  $r = 0.89$ ,  $P \leq 0.05$  (baseline);  $y = 88.574 + 29.77x$ ,  $r = 0.79$ ,  $P \leq 0.05$  (week 12). C:  $y = 1091.35 + 7.66x$ ,  $r = 0.25$  (baseline);  $y = 417.55 + 19.02x$ ,  $r = 0.63$  (week 12).

total body mass, percent fat, and fat mass among dietary groups is in agreement with the results of Ballor and Poehlman (2), who reported in a meta-analysis of 46 studies that exercise training does not influence the loss in body mass, percent fat, or fat mass compared with dietary restriction without exercise. However, the data from the meta-analysis did show

Table 7. Serum concentrations of glucose, BUN, cortisol, testosterone, and triglycerides at baseline, 6 wk and 12 wk

Group	Baseline	6 Wk	12 Wk
<b>Con</b>			
Glucose, mg/dl	94.7 ± 12.0		93.8 ± 8.6
BUN, mg/dl	10.7 ± 2.1		10.6 ± 2.8
Cortisol, nmol/l	476.2 ± 115.9		578.3 ± 97.3
Testosterone, nmol/l	1.4 ± 0.3		1.5 ± 0.4
Triglycerides, mg/dl	79.1 ± 20.1		84.0 ± 28.5
<b>D</b>			
Glucose, mg/dl	129.6 ± 21.9	123.3 ± 20.3	117.3 ± 27.1
BUN, mg/dl	11.3 ± 4.0	10.6 ± 2.7	9.7 ± 3.0
Cortisol, nmol/l	418.1 ± 156.4	399.8 ± 103.1	460.8 ± 126.6
Testosterone, nmol/l	1.1 ± 0.5	1.1 ± 0.5	1.4 ± 0.6
Triglycerides, mg/dl	65.7 ± 11.8	69.1 ± 34.9	74.4 ± 19.2
<b>DE</b>			
Glucose, mg/dl	108.9 ± 18.4	116.5 ± 23.1	120.1 ± 21.5
BUN, mg/dl	9.8 ± 3.3	9.0 ± 2.5	10.5 ± 3.0
Cortisol, nmol/l	405.9 ± 165.9	626.4 ± 257.9*	612.1 ± 209.7*
Testosterone, nmol/l	1.2 ± 0.5	1.2 ± 0.6	1.2 ± 0.4
Triglycerides, mg/dl	90.7 ± 60.7	82.7 ± 46.4	83.7 ± 38.3
<b>DES</b>			
Glucose, mg/dl	114.1 ± 14.3	119.0 ± 26.9	115.7 ± 20.6
BUN, mg/dl	10.0 ± 2.4	9.0 ± 2.8	11.5 ± 3.6
Cortisol, nmol/l	527.6 ± 127.5	587.9 ± 80.6	581.6 ± 174.1
Testosterone, nmol/l	1.5 ± 0.7	1.6 ± 0.9	1.4 ± 0.6
Triglycerides, mg/dl	97.7 ± 75.7	90.5 ± 71.5	80.9 ± 27.1

Values are means ± SD. BUN, blood urea nitrogen. \*Significantly different from corresponding value at baseline,  $P \leq 0.05$ .

that exercise training reduces the percentage of body mass lost as fat-free mass during weight-loss regimens (2). In contrast, our data showed no loss in fat-free mass and no difference among groups. In support of our findings on fat-free mass, a number of studies using various methods of body composition such as magnetic resonance imaging (42, 43), hydrostatic weighing (3, 34), and bioelectric impedance (38) have also reported that the loss in fat-free mass is not only attenuated but maintained or increased when exercise is added to dietary restriction.

The retention of fat-free mass in the D group was unexpected because dietary restriction without exercise has been shown to result in reductions of both fat mass and fat-free mass (see Ref. 15 for review). The mechanism(s) that mediate this observation remains

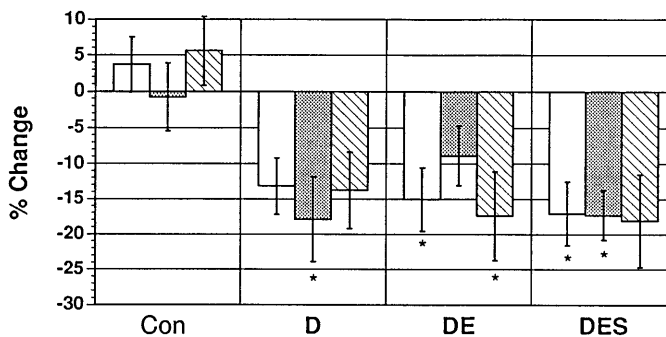


Fig. 3. Percent changes (±SE) after 12 wk in total serum cholesterol (open bars), high-density lipoprotein (HDL; shaded bars) cholesterol, and low-density lipoprotein (LDL; hatched bars) cholesterol. Con, control. \*Significantly different from baseline for absolute change,  $P \leq 0.05$ .

Table 8. Significant correlation coefficients between changes in measured variables

Variable	Correlation
<i>n</i>	29
Body mass vs. cholesterol	0.77
Body mass vs. LDL cholesterol	0.70
Body mass vs. HDL cholesterol	0.43
Body mass vs. $\dot{V}O_{2\max}$	0.63
Percent fat vs. resting metabolic rate	0.39
Fat-free mass vs. cholesterol	0.37
Fat mass vs. resting metabolic rate	0.41
$\dot{V}O_{2\max}$ vs. cholesterol	0.42
$\dot{V}O_{2\max}$ vs. LDL cholesterol	0.38

*n*, No. of subjects; LDL, low-density lipoprotein; HDL, high-density lipoprotein;  $\dot{V}O_{2\max}$ , maximal  $O_2$  consumption.  $P < 0.05$ .

unclear. It is possible that the high-fiber nature of the diet resulted in an enhanced insulin sensitivity and lower insulin levels (i.e., by reduction of the glycemic response of meals) throughout the day. The role of dietary fiber and insulin in obesity is discussed in detail by Ullrich and Albrink (51). Lower insulin concentrations may release the normal inhibitory action of insulin on the synthesis of adenosine 3',5'-cyclic monophosphate, thereby inhibiting lipogenic enzymes (e.g., acetyl-CoA carboxylase, pyruvate dehydrogenase, glycerol phosphate transferase) and stimulating lipolytic enzymes (e.g., hormone-sensitive lipase). This scenario may have created an environment in the body enabling subjects to preferentially mobilize adipose tissue stores as opposed to skeletal muscle. We have no data on the insulin responses or enzyme activities of the subjects in this study. Future studies may concentrate on these potential mechanisms in the context of preservation of fat-free mass during weight loss. Alternatively, the less severe caloric restriction, moderate rate of weight loss, repletion of vitamin and mineral intakes to recommended daily allowance levels, and/or individualized programs of nutritional intervention may have also contributed to our findings.

Strength increases were observed in the bench press and squat exercise in the group that participated in

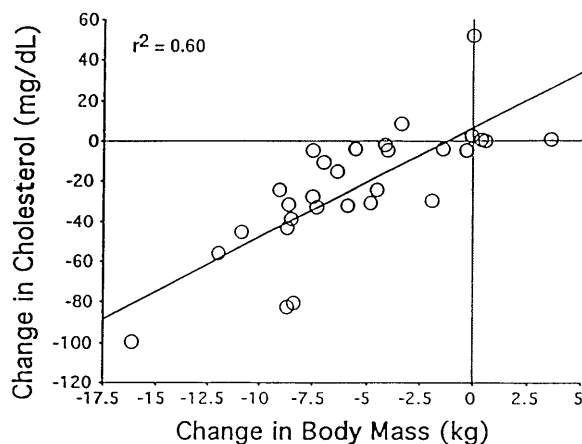


Fig. 4. Correlation between changes in body mass and changes in total serum cholesterol after 12 wk in all groups combined ( $n = 29$ ).  $\circ$ , Individual data points.  $r^2 = 0.60$ ;  $P \leq 0.05$ .

the resistance training program. The highest gains were made in the first 6 wk, with continued improvement by 12 wk of training. Little attention has been given to performance changes with nutritionally sound weight-loss programs. Furthermore, most resistance exercise training programs have not utilized the higher intensities of exercise, nor have they varied the program over time (i.e., periodized training). These data demonstrate that with proper exercise prescription and a sound weight-loss program, despite the reduction in body mass, positive adaptational responses can be achieved with a periodized heavy resistance training program on strength performance. The benefit of adding exercise comes from the fact that the functional capacity is improved. Also, changes occur in the actual composition and density of the muscle and nerve tissue quality (e.g., type of myosin heavy chains, type of muscle enzymes, nervous system changes, nerve branches, more neurotransmitters, and so on) when an exercise program is added to the weight-loss protocol (10, 45). In fact, an increase in the cross-sectional area of both type I (~22%) and type II (~28%) muscle fibers has been demonstrated in subjects despite severe dietary restriction (~800 kcal/day) and large-scale weight loss (~15 kg) if resistance training is performed (12).

As expected, both groups that performed aerobic conditioning demonstrated a significant increase in maximal oxygen consumption expressed per kilogram body mass at 6 and 12 wk. The fact that both DE and DES groups increased maximal oxygen consumption by 10 and 15%, respectively, after 12 wk when expressed in absolute terms (l/min) suggests that the increase is a true enhancement of cardiovascular and respiratory endurance capacity and not an artifact of standardizing maximal oxygen consumption by body mass. The reason for the slightly greater increase in maximal oxygen consumption in the DES group relative to the DE group is unclear. This enhanced aerobic training response in the DES group may reflect additional benefits of increased volume of exercise, as shown by Donnelly et al. (12) in subjects who participated in both endurance and weight training. Alternatively, greater leg strength may have allowed the DES group to run longer on the treadmill, thus contributing to the increase in maximal oxygen consumption. In support of this finding, Hickson et al. (20, 21) have also reported similar benefits in endurance capacity when resistance training is performed in addition to the endurance training program.

No statistically significant changes were observed over the 12-wk training program in anaerobic power performance. The mechanisms responsible for enhancing fast-velocity strength changes have been shown to be different from those that mediate slow-velocity strength changes (28). Thus the lack of improvement in the power component of performance is most likely attributable to the fact that neither the weight training nor the cycle exercise used in the endurance training was specifically designed with power development in mind. Nevertheless, no reductions in power performance were observed in any of the groups despite significant reductions in body mass.



The fact that all dietary groups demonstrated a remarkable retention of fat-free mass is also supported in part by the findings in our analysis of RMR. The RMR data, expressed as kilocalories per day or kilocalories per kilogram fat-free mass, were not different after 12 wk in any of the diet groups. When RMR is expressed relative to fat-free mass, larger subjects tend to have lower values because of an overestimate of their metabolically active mass compared with smaller subjects (41). Thus it has been suggested to regress RMR across fat-free mass and compare the regression lines before and after weight loss (Fig. 2; see also Ref. 41). The only significant regression lines were obtained at baseline and in the DE group after 12 wk. Furthermore, the change in fat-free mass was not significantly correlated with the change in RMR, which is in agreement with the findings of a meta-analysis on the effects of diet and exercise on metabolic rate (49). The lower respiratory exchange ratio ( $\text{CO}_2$  production divided by  $\text{O}_2$  consumption) in the DES group at *week 12* may indicate a proportionally greater utilization of fat at rest. Increased utilization of fat may be a metabolic adaptation reflecting the increased volume of exercise performed by this group.

When all diet groups are considered, there was a significant decrease in total serum cholesterol, LDL cholesterol, and HDL cholesterol. The significant correlation ( $r = 0.77$ ) between the change in body mass and the change in total cholesterol would indicate that the greatest reductions in serum cholesterol are achieved in those individuals who reduce body mass to the greatest extent. The reductions in total serum cholesterol and LDL cholesterol are consistent with a number of studies investigating the impact of weight loss on serum lipids (19, 22, 38). Examination of the literature on HDL cholesterol would predict that this lipoprotein fraction should either increase or remain unchanged in women engaged in regular vigorous exercise (see Ref. 48 for review) and possibly decrease after weight reduction if body mass has not stabilized (8, 50). Because subjects in this study may still have been losing body mass at *week 12*, firm conclusions regarding the potential response of HDL should be made with caution. Although exercise typically increases HDL, a few studies have shown that dietary restriction in conjunction with exercise results in a small reduction in HDL cholesterol in women (4, 19). The fact that HDL cholesterol was reduced despite a high activity level in this study may be due to the low-fat, high-carbohydrate nature of the diet or the low dietary cholesterol intake of the subjects (13, 47). Mensink and Katan (35) have shown that a high-fiber diet rich in complex carbohydrates resulted in a significant reduction in HDL cholesterol and an increase in serum triglycerides compared with a high-fiber diet rich in olive oil (higher in fat), which resulted in a specific fall in non-HDL cholesterol while leaving HDL cholesterol and triglyceride values unchanged. Furthermore, a marked reduction in dietary fat and isocaloric increase in carbohydrate has been shown to result in a decrease in HDL cholesterol and an increase in triglyceride concentra-

tions (30). Thus data from this study and others (6, 32) might suggest that reducing total fat per se may not be the best way to prevent coronary heart disease because a low HDL cholesterol level is associated with an increase in the risk of coronary heart disease (16).

The lack of a response in serum testosterone concentrations is consistent with the findings of Staron et al. (45), who reported a significant increase in testosterone in men, but not women, engaged in progressive resistance exercise. The DES group demonstrated a slight increase in serum cortisol (+10%), whereas the DE group showed a significant elevation (+51%) after 12 wk of training. Kraemer et al. (26) reported a similar increase in resting cortisol concentrations after a 10-wk program of either sprint interval or sprint interval combined with endurance training in men and women. The attenuation in cortisol response in the DES group relative to the DE group may indicate a protective effect of resistance training (i.e., weight training provides an anabolic stimulus that counteracts the catabolic response of endurance training). This has been shown in a previous study in men (29).

In summary, these data indicate that moderate dietary restriction alone has the same effect on the magnitude and composition of body mass alterations, serum lipid profile, RMR, and muscular power production as dietary restriction combined with exercise in overweight women. However, diet in conjunction with endurance and high-intensity resistance exercise significantly improves maximal oxygen consumption and maximal (1-RM) strength despite a significant reduction in body mass. Thus exercise, especially high-intensity resistance exercise, is an important component for weight management programs because it improves functional capacity and quality of life.

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