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Increased Dietary Protein and Combined High Intensity Aerobic and Resistance Exercise Improves Body Fat Distribution and Cardiovascular Risk Factors

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We investigated the effectiveness of two lifestyle modification programs of exercise training and nutritional intake (ad libitum) on improving body composition and disease risk in overweight/obese men and women. Sixty-three subjects were weight matched and assigned to one of three groups for a 12 wk intervention: 1) high-intensity resistance and cardiovascular training and a balanced diet (RC+BD, 40% CHO: 40% PRO; n = 27, 16 female/11 male, age = 42 ± 9 y); 2) moderate-intensity cardiovascular training and a traditional food guide pyramid diet (C+TD, CHO 50 to 55%; PRO 15 to 20%; FAT < 30%; n =19, 10 female/9 male, age = 43 ± 10 y); and 3) an inactive control group (C, n = 17, 5 female/12 male, age 43 ± 11 y). RC+BD resulted in more favorable changes ($P < 0.01$) in percent body fat (–15.8% vs. –6.9%) and abdominal fat (–15.6% vs. –7.5%) compared to C+TD and C. Total cholesterol (–13.8%), LDL-cholesterol (–20.8%), and systolic blood pressure (–5.7%) declined ($P > 0.05$) in RC+BD, whereas C+TD and C remained unchanged. Our results suggest that RC+BD may be more effective than C+TD and C in enhancing body composition and lowering cardiovascular risk in obese individuals.

Key Words: dietary protein, regional fat distribution, energy expenditure, muscular strength

The current obesity epidemic presents an alarming paradox in light of the heightened focus on diet and exercise in today's society (14). For example, 65% of adults in the US are currently overweight or obese despite the fact that 45% of women and 30% of men in the US are trying to lose weight at any given time (37). Given obesity's link to metabolic and cardiovascular diseases and premature mortality there is a need for effective strategies aimed at effective weight reduction (15, 26). The importance of lifestyle regimens consisting of proper diet and regular physical activity in the prevention and treatment of obesity are well documented. Still, much

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controversy exists regarding the specific combinations of diet and exercise that are most efficacious in combating obesity and its associated complications. Current US dietary guidelines advocate a low-fat (FAT; < 30%), high-complex-carbohydrate (CHO; 55–60%), lower-protein (PRO; 10–15%) diet (23, 25) although several recent studies have reported that replacing a portion of carbohydrate intake with dietary protein and/or fat may be as, if not more, effective in promoting weight loss and reducing disease risk (16, 35, 43, 44)

Similarly, moderate-intensity aerobic exercise (50–70% HR_{max}) is recommended by several leading health organizations (23, 42), whereas some, but not all, data suggest that weight loss and cardiovascular improvements may be greater following higher-intensity aerobic exercise programs (39, 45). The inclusion of a resistance training component has also traditionally been underemphasized in most recommended exercise guidelines despite a growing body of literature supporting its role in weight management, metabolic and cardiovascular disease prevention, and maintenance of functional independence in older individuals (7, 13).

These discrepancies regarding current dietary and exercise recommendations are unresolved, in part, because most previous studies have only examined the effects of diet or exercise alone (16, 35, 41, 44), and thus there is a paucity of data comparing the efficacy of lifestyle modification programs consisting of different combinations of both diet and exercise. In addition, most large-scale studies have focused primarily on general weight loss and not specific changes in body composition and regional fat distribution. This lack of emphasis is unfortunate given the strong association between abdominal fat accumulation and the constellation of metabolic and cardiovascular-related diseases (10, 12).

To this end, we examined the body composition, cardiovascular and metabolic effects of two lifestyle modification programs in adult humans over 12 wk. Specifically, we assessed the effectiveness of two lifestyle modification programs, one consisting of a traditional food guide pyramid diet (CHO 50–55%; PRO 15–20%; FAT < 30%) and exercise (moderate intensity; 50–75% HR_{max}) regimen, the other a less conventional program comprised of high-intensity cardiovascular and resistance training combined with a balanced CHO/PRO (40%:40% respectively) diet on body composition, cardiovascular risk factors, and muscular strength in overweight/obese men and women. A subset of individuals who completed the 12 wk lifestyle interventions willingly volunteered to continue with the programs and were re-examined after 1 y of minimal contact to determine the long-term efficacy of these two programs in the absence of consistent investigator monitoring.

Methods

Subjects

Sixty-three persons (29 males, 34 females), 26 to 60 y of age were recruited using newspaper advertisements. All subjects were healthy, weight stable (± < 2 kg) during the previous 6 months, sedentary (< 30 min, 2d/wk of structured physical activity), non-smokers and free of overt metabolic and cardiovascular disease. Participants completed a comprehensive medical screening, including a medical history and a physical examination by a physician. Each participant provided informed written consent in adherence with the Skidmore College Human Subjects Review Board prior to participation.

Experimental Design

Subjects were weight matched and randomly assigned to one of three groups for a 12 wk exercise training and nutritional intervention study: 1) high-intensity resistance and cardiovascular training and a balanced carbohydrate and protein (40%:40%) diet (RC+BD, *n* = 27, 16 female/11 male, age = 42 ± 9 y); 2) moderate-intensity cardiovascular training and a traditional higher carbohydrate (50–55%) diet (C+TD, *n* =19, 10 female/9 male, age = 43 ± 10 y); and 3) an inactive control group (C, *n* = 17, 5 female/12 male, age 43 ± 11 y), which included two subjects with undiagnosed impaired glucose tolerance and elevated blood cholesterol. A subset of willing volunteers from the two intervention groups (RC+BD, *n* =17, C+TD, *n* = 12) returned for follow-up testing approximately 1 y (50–55 wk) after completion of the intervention. Follow-up subjects completed all laboratory tests except upper and lower body muscular strength testing. During the follow-up period, subjects were instructed to continue the interventions but no nutritional supplementation was provided and investigator-to-subject interaction was minimal. The recruitment of subjects, assignment to groups and 3 month interventions, including the laboratory testing, occurred in two phases so that the investigators were able to provide proper control and oversight of the nutritional and exercise interventions and administration of the laboratory testing. The first group was comprised of 40 subjects and the second group included the remaining 23 subjects, making a total of 63 subjects.

Laboratory Testing Procedures

All laboratory procedures were conducted between 6 and 9 AM, following a 12-h fast and a 48-h restriction of exercise, caffeine, and alcohol intake. Upon arrival at the laboratory, height and body weight (model FS-0900 scale, Befour, Inc., Saukville, WI) were measured with subjects clothed in shorts and a t-shirt.

Total Body and Regional Body Composition. Total and regional body composition was determined by dual energy X-ray absorptiometry (DXA; software version 4.1, model DPX-IQ; GE Lunar, Madison, WI) with subjects in the supine position as previously described (5). Total body adiposity is expressed as percent body fat (%BF). Although subcutaneous and visceral fat depots are indistinguishable using DXA, high correlations exist between values of visceral fat directly measured by MRI and CT and those estimated via DXA (21, 31). As such, regional adiposity was determined by creating regions of interest (ROI) for the abdomen (region 1) and hip (region 2) using the ROI option within the manual analysis menu of the Lunar software. Anatomical boundaries for each region were adapted from Gates et al. (19). Briefly, region 1 included the area just below the last rib to just above the iliac crest; region 2 was measured from the end-line of region 1 to just below the lesser trochanter of the femur. Abdominal adiposity is expressed as percent abdominal fat (% ab fat) and body fat distribution is expressed as ab:hip as previously described (19). Test–retest intraclass correlation (*r*) and coefficient of variation (CV) for whole body composition analysis in our laboratory with *n* = 12 is: DXA, FFM, and FM *r* = 0.99, CV = 0.64%, and *r* = 0.98, CV = 2.2%, respectively and for regional body composition analysis is: DXA, %FAT for regions 1 and 2 *r* = 0.99, CV = 2.4% and *r* = 0.98, CV = 1.9%, respectively.

Resting Metabolic Rate (RMR). RMR (kilocalories per day) was measured between 5 and 8 AM for 45 min after an overnight 12-h fast using the ventilated hood technique (4) with a computerized open-circuit indirect calorimeter (model Truemax 2400, Parvomedics, Salt Lake City, UT) at baseline and post week 12 (at least 48 h after the last exercise session). Participants were not allowed to sleep and all measurements were obtained in the supine position in a thermo-neutral (22–24 ºC), semi-dark room. Test–retest intraclass correlation (r) and coefficient of variation (CV) in n =14 is: RMR (Kcal/min) $r = 0.92$, 4.2%, respectively.

Changes in Lower and Upper Body Muscular Strength and Caloric Cost of Exercise Training. Upper and lower body muscular strength, as assessed by 1-repetition voluntary maximum strength (1RM) tests of chest and legs respectively, were measured for all participants under the supervision of a certified strength and conditioning specialist as previously described (5). Briefly, following an adequate warm-up, an attempt in the chest and leg press was considered successful when completed through a full range of motion as previously described (5). For the chest press, elbow flexion had to reach an angle > 90 º and for the leg press knee flexion had to reach and angle ≥ 90º. Test–retest intraclass correlation (r) and coefficient of variation (CV) in n = 15 is: chest 1-RM and leg 1-RM $r = 0.99$, CV = 1.6% and $r = 0.99$, CV = 2.7%, respectively.

Caloric cost of exercise training was calculated for all participants in RC+BD and C+TD groups. RC+BD participants recorded the repetitions, weight lifted, and duration (min) for all RT sessions and the intensity level achieved for all CT sessions (see Methods). C+TD subjects recorded their heart rate using a Polar heart rate monitor (model A3, Polar Electro, Inc., Lake Success, NY) every 10 min of exercise and the total duration (min) of all exercise sessions. Total exercise performed at baseline and week 12 was obtained from each subjects' daily exercise journal, and subsequently analyzed for calories expended using ACSM guidelines (1). Specifically, the resistance and cardiovascular exercise for RC+BD were assigned MET values of 10.0 and 12.5, respectively, whereas the cardiovascular exercise for the C+TD was given a MET value of 8.0. The caloric cost of the exercise was then calculated from the following formula: caloric cost (kcal/wk) = MET value (of given exercise) × body weight (kg) × time spent exercising/week (h).

To assess level of physical activity among the participants in both groups at the 1 y follow-up, the previously validated Aerobics Center Longitudinal Study Physical Activity Questionnaire was used to quantify physical activity over the previous 3 months (kcals/wk and day) (24).

Cardiovascular and Metabolic Parameters. Twelve-hour fasted blood samples were obtained via finger stick and subsequently analyzed for total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), triglycerides (TRG), and glucose (GLU) concentrations (mg/dL) using the Cholestech LDX blood analysis system (Cholestech Corp., Hayward, CA). Measured total blood cholesterol, HDL-C, and triglyceride values were used to calculate low-density lipoprotein cholesterol (LDL-C) according to the Friedewald equation (17) which has recently been validated to the National Health Laboratory Service and conforms with the National Cholesterol Education Program guidelines (30). Test–retest intraclass correlation (r) and coefficient of variation (CV) in our laboratory with n =15 is: TC, GLU, and HDL-C (mg/dL) $r = 0.95$, CV = 3.2%, $r = 0.94$, CV = 2.5%, and $r = 0.97$, CV = 5.3%, respectively.

Resting blood pressures were obtained by the same investigator (LZ) at the end of the resting metabolic rate test using an appropriately sized cuff and a standard mercury sphygmomanometer.

Three-Day Food Diary. Each subject was asked to record daily, the amount and time of day each food and beverage was ingested for the duration of their participation in the study. The Nutritionist IV for Windows software program (version 4.0, N-Squared Computing, First DataBank Division, The Hearst Corporation, San Bruno, CA) was used for analysis of each subject's diet 3 d prior to each testing date (two week days and one weekend day) as previously described (6). All dietary analyses were performed by the same laboratory technician.

Lifestyle Interventions

Exercise Training. All training sessions were monitored by a member of the research team and a certified strength and conditional specialist (MJO, RMP) and exercise compliance was reinforced through weekly inspection of exercise journals, monthly group meetings, and daily exercise monitoring and subject-researcher contact. Furthermore, all subjects recorded exercise time and heart rates were recorded, as noted (see Methods above). The RC+BD exercise program consisted of alternating days of high-intensity resistance (RT) and cardiovascular training (CT) 6 d/wk. RT sessions alternated between upper body (chest, back, shoulders, biceps, and triceps) and lower body (quadriceps, hamstrings, calves, abdominals) workouts performed on both free weight and weight machines (Paramount Fitness Corp., Los Angeles, CA) in the specific order listed above. Sessions were designed to target larger muscle groups first, followed by smaller muscle groups. Two exercises were performed for each muscle group: subjects performed four sets of the first exercise, increasing the resistance (kgs) and decreasing the repetitions (12-10-8-6). Subjects completed a fifth set of twelve repetitions of the first exercise at the same weight as the third set. A final (sixth) set of twelve repetitions of the second exercise was performed to complete the exercises for the respective muscle group.

Cardiovascular training sessions for the RC+BD were based on a high-intensity interval program in which participants rated their perceived exertion on a scale of 1 to 10 (1 = resting quietly, 5 = a warm-up level, 10 = an all-out exertion). Participants began with a 2-min warm-up at level 5 and increased their exertion each minute for 3 min until level 9 was perceived and then recovered at level 6 for 1 min. This same pattern was performed a total of four times. However, on the fourth cycle, participants increased their last minute of exertion to level 10, followed by a 1-min recovery at their initial warm-up level 5. The total time for the session was 20 min. A complete description of the program is available elsewhere (32).

The C+TD program followed the guidelines of the American Heart Association (AHA) Step 1 recommendations for daily exercise and consisted of 4-6 d/wk of CT at an intensity of 50-75% of maximal HR for 30-60 min (2). The C group was instructed to maintain their current physical activity level, which did not exceed 30 min 2d/wk.

Nutritional Intervention. All participants in RC+BD and C+TD were provided verbal and written instructions regarding the meal frequency, appropriate portion sizes, and specific foods that met their respective dietary guidelines. Participants in the two intervention groups were instructed to consume foods according to their respective programs but were encouraged to eat until satisfied, whereas C subjects were instructed to maintain normal dietary consumption patterns. The RC+BD diet consisted of six small protein (PRO; 40%), carbohydrate (CHO; 40%), and fat (FAT 20%) balanced meals 6 d/wk. The seventh day was treated as a "free day" in which participants were allowed to consume any food they desired. Participants were responsible for providing themselves with three of the six daily meals consistent with the macronutrient composition (40-40-20) and portion size. The remaining three daily meals were provided for them in the form of either supplemental powder shakes they mixed with water, ready-to-drink shakes, or bars. The C+TD group followed the recommendations of the USDA food guide pyramid as adapted by the American Heart Association (CHO, 55-60%; PRO, 10-15%; fat, < 30%). C+TD men and women were also provided "healthy snacks" in the form of "no sugar added applesauce" and AHA-approved cereal and granola bars in addition to preparing their own meals according to the food guide pyramid. A registered dietician met weekly with study participants on an individual basis to answer questions and clarify dietary guidelines. Dietary compliance was reinforced and monitored through daily subject-researcher contact, weekly inspection of nutrition journals, weekly return of empty supplement packets, and monthly group meetings.

Statistical Analysis

Data were evaluated using a 3 × 4 (group × time) repeated measures analysis of variance (ANOVA) to determine whether changes in variables differed significantly among groups (RC+BD, C+TD, C) and over time (baseline, 4, 8, and 12 wk). A multivariate general linear model for repeated measures was used to determine significant time and time × group interactions. Paired t-tests with Bonferroni correction were used to make post-hoc comparisons within groups if a time effect was demonstrated by the multivariate analysis. Statistical power for the major outcome variables (body composition, blood lipids) ranged from 0.70 to 0.90 assuming a P value equal to 0.05 and $N = 36$ participants (18 per treatment group). The significance was set at $P < 0.05$. All values are reported as means ± standard deviations unless otherwise noted. All statistics were analyzed using SPSS version 11.5 for Windows (SPSS, Inc., Chicago, IL).

Results

Baseline Characteristics and Attrition

Men and women did not differ in their response for all variables measured and thus, these data were analyzed together for each group. Of the 31 women participants, 5 were peri-menopausal and 6 were post-menopausal; however, statistical analysis showed that they did not differ in response from pre-menopausal women for any of the measured variables. Participant physical characteristics at baseline were similar among groups (see Tables 1 through 4). A total of 58 of the 63 subjects (91%) completed the 12 wk of the study (27, RC+BD; 19, C+TD; and 12, C) with

100% retention in the two treatment groups over the 12-wk testing period, as all dropouts ($n = 5$) were in the control group. Of the 46 subjects in the two treatment groups, 29 (17, RC+BD; 12, C+TD) completed 1 y follow-up testing, or 63% of the total subjects within each group. There were no significant differences between the two treatment groups with respect to either the number of subjects who completed 1 y follow-up testing or the characteristics of the subjects who did not participate in 1 y follow-up testing.

Assessment of Energy Intake

Self-reported dietary energy and macronutrient intakes (expressed as a percentage of energy intake) are shown in Table 1. Total caloric intake was not different among the groups at any time point. By design, the macronutrient composition during the study intervention was significantly different ($P < 0.01$) among the three groups. Specifically, protein intake increased and fat intake decreased from baseline to 12 wk in the RC+BD but remained unchanged in the C+TD and C. Thus, these differences imply that when instructed to consume a particular macronutrient ratio diet ad libitum, energy intake among participants is approximately equal, despite significant differences in macronutrient dietary composition as well as a decline in macronutrient intake over time.

Body Weight, Composition, and Fat Distribution

Mean changes in body weight and total and regional body composition during the 12 wk study interventions are shown in Table 2 and Figures 1 and 2. Within both intervention groups, significant losses of body weight, body-mass index, and percentage of body fat were observed from baseline to 12 wk, but the magnitude (time × group interaction) of decrease was significantly greater in RC+BD than C+TD (body weight, $P < 0.01$; body-mass index, $P < 0.05$; percentage body fat, $P < 0.001$). No significant changes occurred in the C group.

Changes in abdominal body fat (% AB fat) and body fat distribution (ab:hip ratio) are shown in Figure 2 and Table 2, respectively. When groups were analyzed separately, there was a significant decrease in % AB fat in RC+BD and C+TD, although the magnitude (time × group interaction) of decrease was significantly greater in RC+BD ($P < 0.01$). No significant change occurred in C. Abdomen to hip ratio (ab:hip) declined from baseline to week 12 in RC+BD (–5.3%; $P < 0.02$), whereas C+TD (–2.0%) and C (1.7%) remained unchanged from baseline.

Cardiovascular and Metabolic Parameters

The effects of the 12 wk interventions on total cholesterol, lipoprotein sub-fractions (HDL-C and LDL-C), glucose, and resting blood pressure are shown in Table 3. Total cholesterol and LDL-C decreased significantly ($P < 0.01$) in RC+BD, but did not change in C+TD and C. HDL-C was unchanged in both groups and total cholesterol/HDL-C ratio decreased to a similar extent in both intervention groups. Fasting blood glucose remained unchanged in RC+BD but increased in C+TD (91 ± 11.6 vs. 101 ± 13.6 mg/dL, $P < 0.01$). There was no change in triglyceride levels over the course of the study. Systolic and diastolic blood pressure decreased significantly ($P < 0.01$) in RC+BD, whereas only diastolic blood pressure decreased ($P < 0.05$) in C+TD. No changes occurred in blood pressure in C.

Table 1 Dietary Intake at Baseline and Week 12

Variable	RC+BD	C+TD	C
Kcal/d			
Baseline	2223 ± 1019	2198 ± 827	2014 ± 476
Week 12	1588 ± 315*	1601 ± 456*	1793±369
% change (0-12)	–28.6	–27.2	–5.8
Protein (%)			
Baseline	18.3 ± 9.2	19.1 ± 4.4	18.5 ± 2.5
Week 12	41.2 ± 6.1*	19.6 ± 5.5	19.9 ± 2.9
% change (0-12)	125.1[a,b]	2.6	7.5
Protein (g)			
Baseline	94.5 ± 40.3	106.1 ± 46.9	94.2 ± 33.3
Week 12	166.0 ± 41.2*	81.1 ± 32.7	90.1 ± 18.7
% change (0-12)	75.7[a,b]	–23.5	–4.3
Protein (kg/BW)			
Baseline	1.2 ± 0.5	1.2 ± 0.5	1.1 ± 0.3
Week 12	2.1 ± 0.6*	1.0 ± 0.4	1.1 ± 0.2
% change (0-12)	75.0[a,b]	–23.0	0.0
Fat (%)			
Baseline	29.9 ± 10.3	28.0 ± 10.3	32.1 ± 4.5
Week 12	17.0 ± 5.7*	26.5 ± 6.9	28.1 ± 5.6*
% change (0-12)	–43.1[a,b]	–5.4	–12.4
Fat (g)			
Baseline	80.3 ± 53.9	71.6 ± 45.3	73.1 ± 22.1
Week 12	31.0 ± 14.4*	49.2 ± 20.3	56.5 ± 18.2*
% change (0-12)	61.4	–31.3	–22.7
Carbohydrate (%)			
Baseline	49.6 ± 7.8	49.8 ± 11.7	48.4 ± 5.7
Week 12	41.2 ± 6.2*	52.3 ± 6.5	50.0 ± 6.7
% change (0-12)	–16.9[a,b]	5.0	3.3
Carbohydrate (g)			
Baseline	278.6 ± 123.5	276.3 ± 96.2	244.8 ± 72.7
Week 12	163.3 ± 30.7*	213.6 ± 60.5*	230.0 ± 57.9
% change (0-12)	41.4	–22.7	–6.0
Cholesterol (mg)			
Baseline	287.8 ± 208.1	360.0 ± 340.4	283.5 ± 184.4
Week 12	216.7 ± 116.2	185.1 ± 107.9	278.0 ± 107.8
% change (0-12)	–24.7%	–48.6%	–2.0%
Saturated fat (g)			
Baseline	26.4 ± 19.8	26.3 ± 20.4	24.9 ± 9.1
Week 12	10.1 ± 4.9*	13.6 ± 6.2*	19.2 ± 8.0
% change (0-12)	–62%	–48%	–23%

Values are means ± standard deviation; % change = percent change from baseline to week 12; * significantly different from baseline; [a] RC+BD different than C+TD; [b] significantly different from control; significance for all variables set at $P < 0.05$.

Table 2 Body Weight, Composition, and Fat Distribution at Baseline and 12 Weeks

Variable	RC+BD	C+TD	C
Body weight (kg)			
Week 0	84.4 ± 17.8	81.6 ± 19.4	85.2 ± 17.5
Week 12	79.2 ± 16.7*	78.8 ± 19.7*	85.9 ± 17.0
% change (0-12)	–6.2 [a b]	–3.4 [b]	0.8
Body-mass index			
Week 0	28.4 ± 4.9	27.0 ± 4.5	27.2 ± 3.5
Week 12	26.7 ± 4.6*	26.0 ± 4.3*	27.4 ± 3.4
% change (0-12)	–6.0 [a b]	–3.7 [b]	0.7
% Body fat			
Week 0	32.9 ± 10.4	31.9 ± 8.5	26.3 ± 6.0
Week 12	27.7 ± 10.8*	29.7 ± 8.7*	26.1 ± 6.4
% change (0-12)	–15.8 [a b]	–6.9 [b]	–0.8
Fat mass (kg)			
Week 0	26.7 ± 11.5	24.8 ± 9.5	19.2 ± 3.0
Week 12	21.2 ± 10.6*	22.3 ± 8.8*	19.2 ± 3.3
% change (0-12)	–20.6 [a b]	–10.1 [b]	0.0
Fat-free mass (kg)			
Week 0	53.8 ± 13.7	52.5 ± 13.4	55.8 ± 13.3
Week 12	54.3 ± 13.1	52.3 ± 13.9	56.3 ± 13.4
% change (0-12)	0.9	–0.4	0.9
Abdomen (% fat)			
Baseline	34.6 ± 9.7	34.6 ± 8.4	29.8 ± 4.9
Week 12	29.2 ± 11.3*	32.0 ± 9.4*	29.5 ± 5.2
% change (0-12)	–15.6 [a b]	–7.5 [b]	–1.0
Abdomen fat (kg)			
Baseline	3.4 ± 1.5	3.3 ± 1.6	2.7 ± 0.8
Week 12	2.5± 1.4*	2.9 ± 1.4*	2.7 ± 0.9
% change (0-12)	–26.4 [a b]	–13.5 [b]	–0.7
Abdomen:Hip ratio			
Baseline	0.94 ± 0.13	0.96 ± 0.15	1.01 ± 0.13
Week 12	0.89 ± 0.18*	0.94 ± 0.18	0.99 ± 0.14
% change (0-12)	–5.3% [a b]	–2.0%	1.7

Values are means ± standard deviation; % change = percent change from baseline to week 12; * significantly different from baseline; [a] RC+BD different than C+TD; [b] significantly different from control; significance for all variables set at $P < 0.05$.

Resting Metabolic Rate (RMR)

RMR expressed in absolute (kcals/d) and relative (kg/FFM) (RC+BD 1.3 ± 0.2 vs. 1.4 ± 0.1 kcal · kg $\text{FFM}^{-1} \cdot \text{h}^{-1}$, $P < 0.01$; C+TD 1.2 ± 0.2 vs. 1.3 ± 0.2 kcal · kg $\text{FFM}^{-1} \cdot \text{h}^{-1}$, $P < 0.05$) terms was similar among the three groups at baseline and increased to a similar extent following the 12 wk interventions in RC+BD and C+TD but remained unchanged in C (Table 4). Respiratory exchange ratio decreased

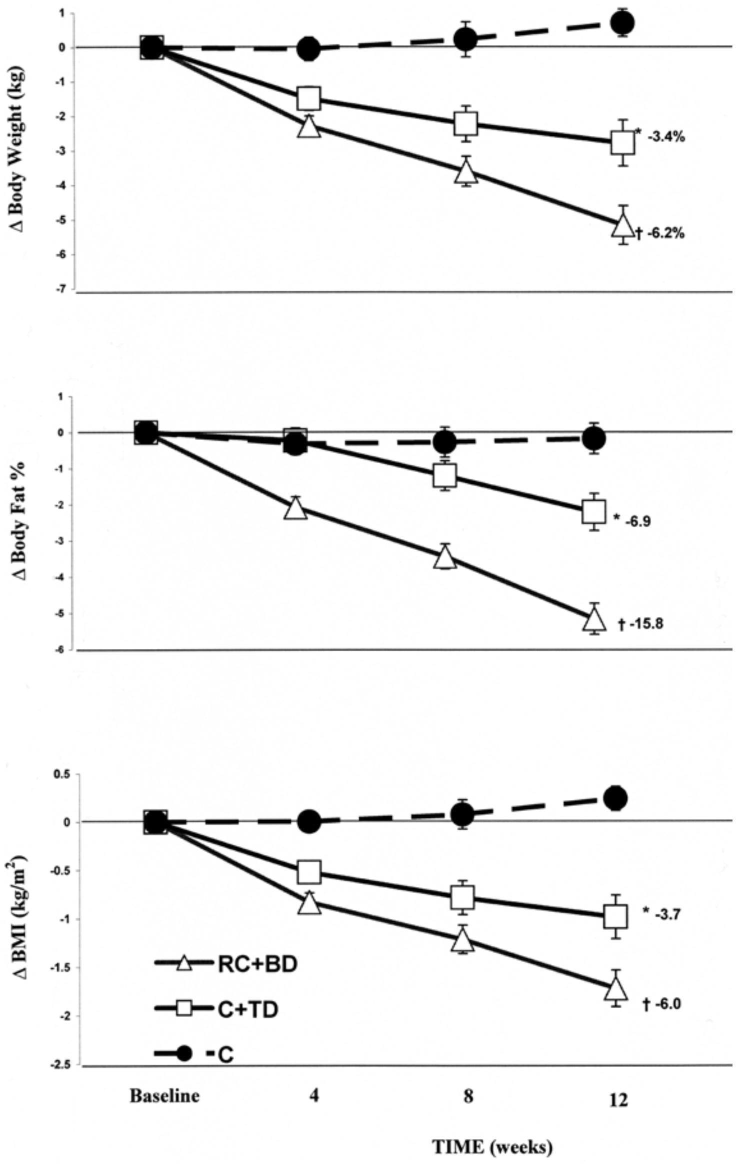

Figure 1 — Mean changes in body weight, percentage body fat, and body mass index (BMI) in comparison to baseline (day 0) in participants following the control lifestyle (C); the high-intensity resistance and cardiovascular exercise and balanced protein and carbohydrate diet lifestyle program (RC+BD); and the moderate-intensity cardiovascular exercise and traditional food guide pyramid lifestyle regimen (C+TD). The time × group interaction term was significant for all three variables ($P < 0.01$, $P < 0.001$, and $P < 0.05$, respectively). * Significant decrease over time (Baseline to week 12 comparison, $P < 0.01$). † Significant decrease over time in this group (Baseline to week12 comparison $P < 0.001$). Error bars represent standard error of the mean.

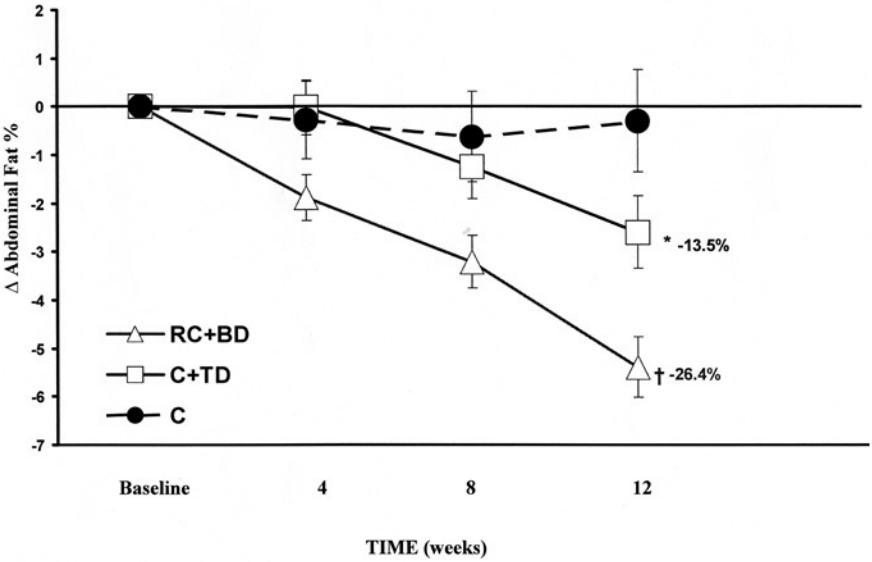

Figure 2 — Mean changes in abdominal fat percentage in comparison to baseline (day 0) in participants following the control lifestyle (C); the high-intensity resistance and cardiovascular exercise and balanced protein and carbohydrate diet lifestyle program (RC+BD); and the moderate-intensity cardiovascular exercise and traditional food guide pyramid lifestyle regimen (C+TD). The time × group interaction term was significant ($P < 0.01$). * Significant decrease over time (Baseline to week 12 comparison, $P < 0.01$). † Significant decrease over time in this group (Baseline to week12 comparison $P < 0.001$). Error bars represent standard error of the mean.

significantly ($P < 0.001$) in both treatment groups (RC+BD, 0.88 ± 0.04 vs. 0.84 ± 0.05; C+TD, 0.91 ± 0.01 vs. 0.86 ± 0.01) but remained unchanged in C (0.91 ± 0.04 vs. 0.90 ± 0.03) (data not shown in table form).

Muscular Strength and Caloric Cost of Exercise

Upper and lower body muscular strength data are presented in Table 4. Upper and lower body muscular strength was significantly ($P < 0.01$) increased from baseline to 12 wk in both treatment groups, whereas C showed no change in upper and an increase in lower body strength. The magnitude of increase in upper and lower body strength from baseline to 12 wk was significantly greater ($P < 0.01$) in the RC+BD (upper, 21%; lower, 37%) compared to C+TD (upper, 13%; lower, 21%) and C (upper, 2%; lower 11%). Estimated caloric cost of the exercise sessions was significantly increased ($P < 0.01$) from baseline to 12 wk in the two treatment groups. Interestingly, the total amount of estimated caloric expenditure due to the exercise sessions was greater ($P < 0.01$) for C+TD compared to RC+BD, which was likely due to the greater ($P < 0.05$) amount of time spent exercising (C+TD, 38.7 ± 2.2 and RC+BD, 26.2 ± 1.2 min/d) and not necessarily the frequency per week (C+TD, 5.9 ± 0.8 and RC+BD, 5.9 ± 0.5 d/wk).

Table 3 Cardiovascular and Metabolic Parameters

Variable	RC+BD	C+TD	C
Total cholesterol (mg/dL)			
Baseline	195 ± 38.4	194 ± 44.0	205 ± 37.1
Week 12	168 ± 32.0*	185 ± 40.9	202 ± 30.1
% change (0-12)	–13.8 [b]	–4.6 [b]	–1.5
HDL-C (mg/dL)			
Baseline	51 ± 17.9	48 ± 15.3	46 ± 18.7
Week 12	50 ± 16.5	51 ± 16.1	50 ± 18.9
% change (0-12)	–2.0	6.3	8.7
TC vs HDL ratio			
Baseline	4.3 ± 1.8	4.3 ± 1.3	4.9 ± 2.3
Week 12	3.7 ± 1.3*	3.9 ± 1.4*	4.6 ± 1.7
% change (0-12)	–14.0	–9.3	–6.1
LDL-C (mg/dL)			
Baseline	125 ± 30.4	129 ± 36.7	127 ± 42.3
Week 12	99 ± 24.8*	117 ± 40.8	125 ± 35.5
% change (0-12)	–20.8 [b]	–9.3	–1.6
SBP (mm/Hg)			
Baseline	123 ± 8.4	122 ± 11	120 ± 11.8
Week 12	116 ± 5.0*	118 ± 8.6	123 ± 13.7
% change (0-12)	–5.7 [b]	–3.3	2.5
DBP (mm/Hg)			
Baseline	78 ± 7.8	75 ± 5.3	71 ± 11.3
Week 12	69 ± 5.6*	71 ± 7.8*	74 ± 8.7
% change (0-12)	–11.5 [b]	–5.3	4.2
Glucose (mg/dL)			
Baseline	93 ± 8.5	91 ± 11.6	106 ± 44.2
Week 12	97 ± 9.7	101 ± 13.6*	109 ± 25.6
% change (0-12)	4.3	10.9	2.8

Values are means ± standard deviation; % change = percent change from baseline to week 12; * significantly different from baseline; [a] RC+BD different than C+TD; [b] significantly different from control; significance for all variables set at $P < 0.05$.

One-Year Follow-up Findings

One-year follow-up data are presented in Tables 5 and 6. Total kilocalories and percentage of carbohydrate intake remained significantly lower ($P < 0.05$) than baseline values and percentage of protein intake remained higher ($P < 0.01$) than baseline in RC+BD, whereas all dietary intake variables returned to baseline values in C+TD. Protein intake (percent) remained higher in RC+BD compared to C+TD, all other nutritional intake variables were similar between the groups (Table 6). Total cholesterol, glucose, and blood pressure returned to baseline values in both treatment groups, whereas HDL-C increased from baseline in both groups and LDL-C decreased in C+TD. The level of physical activity during the preceding 3 months from the 1 y follow-up test day, estimated via questionnaire, was not different ($P = 0.26$) between the two treatment groups.

Table 4 Upper and Lower Body Muscular Strength and Caloric Cost of Exercise

Variable	RC+BD	C+TD	C
Upper body strength (kg)			
Baseline	53.4 ± 24	44.6 ± 18	66.7 ± 31
Week 12	64.6 ± 25*	50.4 ± 21*	67.8 ± 33
% change (0-12)	20.6[a b]	13.0	1.6
Lower body strength (kg)			
Baseline	205.9 ± 73	183.6 ± 56	238.0 ± 80
Week 12	281.7 ± 88*	221.9 ± 68*	260.8 ± 83*
% change (0-12)	36.8[a b]	20.9	9.2
Resting metabolic rate (kcal/d)			
Baseline	1642 ± 323	1482 ± 307	1804 ± 324
Week 12	1763 ± 326*	1600 ± 414*	1856 ± 291
% change (0-12)	7.4[b]	7.9[b]	2.9
Caloric cost of exercise (kcal/wk)†			
Baseline	842.9 ± 207	1038.0 ± 384	–
Week 12	1112.3 ± 271*	1560.1 ± 471*	–
% change (0-12)	32.0[a]	50.3	–

Values are means ± standard deviation; % change = percent change from baseline to week 12; * significantly different from baseline; †caloric cost (kcal/wk) = MET value (of the given exercise) × body weight (kg) × time spent exercising/week (h); [a] RC+BD different than C+TD; [b] significantly different from control; significance for all variables set at $P < 0.05$.

In RC+BD, body weight, body-mass index, and total percent body fat remained significantly lower than baseline at follow-up, whereas in C+TD total percent body fat and abdomen percent body fat remained lower than baseline (Table 6). All other body composition parameters returned to baseline values in the two groups. Resting metabolic rate returned to baseline values in both groups; however, respiratory exchange ratio remained significantly lower ($P < 0.001$) than baseline in both treatment groups (RC+BD, 0.88 ± 0.04 vs. 0.82 ± 0.05; C+TD, 0.91 ± 0.01 vs. 0.83 ± 0.06).

Discussion

The primary finding of the current study is that a lifestyle modification program consisting of high-intensity cardiovascular and resistance training combined with a balanced CHO/PRO (40%:40%, respectively) diet results in greater improvement in body composition, cardiovascular risk factors, and muscular strength than a program comprised of a traditional diet and moderate-intensity exercise regimen commonly recommended for weight loss. It should be emphasized that the primary purpose of the current study was to determine if current exercise and dietary guidelines were indeed the most efficacious for improved body composition and cardiovascular risk reduction. As such, dissection of the two intervention programs in an attempt to determine the specific component(s) (i.e., dietary and exercise components) responsible for the effectiveness of each program was of secondary importance.

Table 5 1-Year Follow-up Comparisons for Dietary Intake and Cardiovascular Variables for Subgroups

Variable	RC+BD *n* = 17 (10 female/7male)	C+TD *n* = 12 (7 female/5 male)
Kilocalories/d		
Baseline	2080.4 ± 742.2	2359 ± 802
1y follow-up	1672.5 ± 445.3	1888 ± 489
Dietary protein (%)		
Baseline	17.7 ± 5.1	18.6 ± 4.3
1y follow-up	26.3 ± 8.2*,[a]	20.4 ± 4.4
Dietary carbohydrate (%)		
Baseline	52.2 ± 7.6	49.2 ± 13.2
1y follow-up	45.2 ± 7.1*	47.5 ± 13.6
Dietary fat (%)		
Baseline	28.4 ± 9.4	28.9 ± 10.9
1y follow-up	27.3 ± 5.8	30.5 ± 10.1
Total cholesterol (mg/dL)		
Baseline	179 ± 28.5	183 ± 42.3
1y follow-up	183 ± 40.0	176 ± 29.5
HDL-C (mg/dL)		
Baseline	49 ± 21.0	44 ± 12.3
1y follow-up	55 ± 22.0*	52 ± 13.8*
LDL-C (mg/dL)		
Baseline	112 ± 26.2	124 ± 29.9
1y follow-up	110 ± 32.2	109 ± 29.4*
Glucose (mg/dL)		
Baseline	93 ± 7.5	90 ± 12.2
1y follow-up	92 ± 4.7	92 ± 11.0
SBP (mm/Hg)		
Baseline	120 ± 7.0	122 ± 12.7
1y follow-up	121 ± 4.0	121 ± 7.8
DBP (mm/Hg)		
Baseline	76 ± 6.6	75 ± 5.1
1y follow-up	77 ± 5.0	76 ± 5.8
Estimated physical activity at 1y follow-up, kcal/wk; kcal/d	4277 ± 2217; 611 ± 317	3288 ± 1838; 470 ± 263

Values are mean ±SD. *, Significantly different from baseline value. [a], RC+BD significantly different from C+TD. Significance set for all variables at P<0.05.

Moreover, we recognize the difficulty in discerning the factor(s) mediating the greater benefits seen in RC+BD given the differences in both the exercise (intensity and estimated caloric cost) and dietary (macronutrient) component of the two intervention programs. In an attempt to provide some mechanistic insight into the current findings, however, possible explanations for the results are discussed.

Table 6 1-Year Follow-up Comparisons for Body Composition Variables for Subgroups

Variable	RC+BD *n* = 17 (10 female/7male)	C+TD *n* = 12 (7 female/5 male)
Body weight (kg)		
Baseline	83.1 ± 13.3	79.9 ± 17.3
1y follow-up	80.1 ± 13.6*	76.4 ± 18.2
Body-mass index		
Baseline	27.9 ± 4.6	27.1 ± 4.1
1y follow-up	27.1 ± 4.6*	25.8 ± 4.0
% body fat		
Baseline	32.1 ± 10.2	33.3 ± 8.2
1y follow-up	29.7 ± 10.3*	31.4 ± 6.5*
Abdomen % fat		
Baseline	33.8 ± 9.1	36.8 ± 6.4
1y follow-up	32.2 ± 9.1	34.9 ± 5.2*
Abdomen:Hip ratio		
Baseline	0.95 ± 0.15	0.99 ± 0.09
1y follow-up	0.94 ± 0.15	0.98 ± 0.12

Values are means ± standard deviation. *, Significantly different from baseline value. [a], RC+BD significantly different from C+TD. Significance set for all variables at $P < 0.05$.

The validity of our findings garner support by several methodological strengths of the current study, including: 1) the use of randomized, controlled interventions; 2) measurement of not only weight, but also body fat and its distribution in an attempt to more fully assess adiposity-related disease risk; 3) in-house monitoring of all exercise training sessions; 4) consumption of food ad libitum and lack of subject instruction to restrict food or lose weight, as this would confound the effects of the respective macronutrient and exercise regimens; and 5) use of a control group during the 12 wk intervention to account for seasonal changes and other environmental fluctuations.

Both lifestyle modification programs resulted in significant reductions in body weight, body-mass index, and total and abdominal body fat over the 12 wk intervention period, although the magnitude of these reductions was greater in the RC+BD group compared to C+TD. Furthermore, individuals in the RC+BD group experienced a significant decrease in central fat distribution (ab:hip) whereas no change was observed in C+TD. These enhanced body composition improvements in RC+BD cannot be accounted for simply by a greater reduction in energy intake, as caloric consumption throughout the intervention period was similar in both groups (RC+BD, 1588 ± 315; C+TD, 1601 ± 456 kcals/d), although we recognize the inherent limitations associated with self-reported food intake. Similarly, the greater improvements cannot be due merely to a higher caloric cost of exercise in the RC+BD program, as individuals in this group expended significantly fewer calories during exercise than those in the C+TD program (estimated caloric expenditure:

1112.3 ± 271 and 1560.1 ± 47 kcal/wk at week 12 in RC+BD and C+TD, respectively). It is therefore possible that the greater body composition effects observed in RC+BD were due to metabolic differences attributable to dietary macronutrient composition and exercise metabolism between the two interventions. For example, several recent studies have suggested that a higher protein, low-carbohydrate diet may be more beneficial for short-term weight loss (16, 35, 45) and maintenance of weight after weight loss (43). The primary metabolic effects of these diets may be due specifically to the elevated protein rather than the reduced carbohydrate intake (3, 9, 43). Indeed, greater improvements in body composition in moderately obese individuals (similar to those in the present study) have been observed following a high-protein (~ 1.5g/kg) diet, even when a moderate level carbohydrate intake, as used in the current study, is maintained (27, 38, 43). A recent investigation, using moderately obese subjects, showed that a 20% higher protein intake during weight maintenance after weight loss results in a 50% lower body weight regain, primarily consisting of fat-free mass which coincided with a 50% decrease in energy efficiency (43). Second, RC+BD consumed less fat than C+TD, which may have contributed to a greater improvement in body composition and cardiovascular risk. Although we cannot discern whether the beneficial effects seen in the current study were due to the reduced fat versus the increased protein intake, our results suggest that a lifestyle modification program consisting of a diet in which carbohydrate intake is reduced (e.g., 40%) may be more beneficial than the currently recommended, higher carbohydrate intake (e.g., 60%). Third, the RC+BD group exercised at a higher intensity and thus may have expended a greater number of calories during the hours immediately following the exercise sessions (excess post-exercise oxygen consumption). For example, previous research has suggested that intensity of exercise is the primary determinant of the magnitude and duration of excess post-exercise oxygen consumption (28, 36). Future studies using doubly-labeled water or physical activity questionnaires to measure non-exercise energy expenditure in response to combined lifestyle modification interventions are needed to fully address this issue. Finally, by design, the RC+BD program consisted of a greater number of daily meals than C+TD. Some (40), but not all (18), previous studies examining the relation between meal frequency and body weight have suggested that body weight control is enhanced when caloric intake is spread evenly throughout the day, although this is an issue that warrants further study. Thus, all these factors may have contributed to the observed greater weight loss in RC+BD despite similar increases in RMR in both groups.

Systolic and diastolic blood pressure decreased in both groups following the 12 wk intervention period, although the reduction in systolic pressure did not reach statistical significance in C+TD. Given the well-established relation between body weight and blood pressure (29), the greater reduction in SBP observed in RC+BD was likely due to the enhanced body composition in this group. More specifically, the greater reduction in blood pressure may have been due to more pronounced loss of abdominal fat in RC+BD, as the relation between blood pressure and body weight has recently been shown to be mediated largely via visceral adiposity (20). The strength-training component of RC+BD may also have positively influenced blood pressure, as a recent meta-analysis concluded that resistance training results in small but significant blood pressure reductions in adults (22).

HDL-C levels were not significantly altered in the two intervention groups. This finding contrasts with recent studies suggesting more favorable changes in these parameters following a low-carbohydrate compared to low-fat diet (41, 44). However, other studies examining the effects of diet and weight loss on HDL levels have reported markedly inconsistent results and the lack of an effect is not without precedence (11). LDL-C decreased significantly only in the RC+BD group, which, as with the reduction in blood pressure, may reflect the enhanced total body and abdominal fat loss compared to C+TD (RC+BD, –16% vs. C+TD, 7%). No change in plasma glucose levels was observed in RC+BD, whereas C+TD experienced a small but significant increase. The reason for this increase is unclear, but may be related to the increased total carbohydrate (and sugar) intake this group consumed during the duration of the study.

Considerable controversy exists surrounding the effects of chronic, long-term exercise training on RMR. Our finding of increased RMR, measured > 48 h following the last training session, in both RC+BD and C+TD following the 12 wk interventions is consistent with other studies using either resistance (28) or aerobic exercise training (8), but not in agreement with others (33). Fat-free mass, the primary determinant of RMR, did not change in either group over the 12 wk, suggesting that other factors not measured in the present study may be responsible for the increase in RMR, including enhanced protein turnover (34).

Upper and lower body muscular strength increased in RC+BD (chest, 21%; legs, 37%) and C+TD (chest, 13%; legs, 21%), however, the magnitude of increase was significantly greater in RC+BD. While lower body muscular strength also increased in C, albeit modestly (11%), this may be due to a learned effect, given that subjects performed 1-RM testing at baseline and 12 wk. Although the increase in muscular strength in RC+BD is not surprising given the resistance training component of RC+BD, it nonetheless has important implications for older populations with impaired functional capacity and mobility and stresses the need for lifestyle modification programs involving high-intensity resistance and cardiovascular training combined with increased protein intake, to allow adequate muscle protein synthesis and aid recovery.

One-year follow-up testing in RC+BD showed that body weight, total body fat, and BMI remained lower than baseline, whereas in C+TD, total body fat and abdominal fat remained lower than baseline. All other body composition parameters returned to baseline values in the two groups. Both groups experienced a heightened HDL-C at follow-up compared to baseline suggesting the cumulative cardiovascular benefits of long-term exercise adherence. Moreover, blood pressure, resting metabolic rate, and total cholesterol returned to baseline values in both groups at 1-y follow up. Thus, many of the improvements observed during the intervention period were no longer different from baseline values. These findings support previous studies highlighting the necessity for close subject monitoring if significant metabolic and cardiovascular improvements following lifestyle modification programs are to be maintained over the long term (16, 41). The design of the present study precludes inferences regarding which lifestyle modification program would result in the greatest long-term changes under more closely monitored conditions.

In summary, our results demonstrate that 12 wk of combined high-intensity resistance and cardiovascular training and balanced macronutrient intake improves body composition, cardiovascular risk factors, and muscular strength significantly more than a program of moderate-intensity cardiovascular exercise training and the traditional food guide pyramid diet in overweight and obese men and women. These findings suggest that for individuals attempting to lose body fat and decrease cardiovascular risk, replacing a portion of carbohydrate with protein in combination with high-intensity resistance and aerobic exercise training may elicit greater improvements over the short term (3 months) than most traditional dietary and exercise recommendations. However, suggestions regarding the longer-term (1 y) efficacy of these programs must be withheld until studies are conducted in which subjects are closely monitored over this prolonged period of time.

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