Effects of a very-low-calorie diet and physical-training regimens on body composition and resting metabolic rate in obese females[1-3]

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ABSTRACT Sixty-nine obese females received 90 d of a liquid diet providing 2184 kJ/d in clinical trials. Groups were diet only (C), diet plus endurance exercise (EE), diet plus weight training (WT), or diet plus endurance exercise and weight training (EEWT). Changes in body weight, percent fat, fat weight, and fat-free mass were not different between groups. Declines in resting metabolic rate (RMR) were ~7% to ~12% of baseline values with no differences among groups. A significant increase in work capacity (~16%) was shown for EEWT. Strength index showed declines of ~6% for C and EE and gains of ~3% and ~10% for EEWT and WT, respectively. These clinical trials did not show advantages of any exercise regimen over diet alone for weight loss, body-composition changes, or declines in RMR. Improvements in work capacity were limited and strength improved in groups that participated in strength training. *Am J Clin Nutr* 1991;54:56–61.

KEY WORDS Very-low-calorie diet, exercise, body composition, resting metabolic rate, obesity, strength, work capacity

Introduction

Very-low-calorie diets (VLCDs) are efficacious for rapid weight loss (1–3). The safety of VLCDs appears to be established when intake and monitoring procedures are administered by qualified personnel (4). However, concerns still exist regarding loss of fat-free mass (FFM), which in turn may precipitate declines in resting metabolic rate (RMR) (5, 6). Declines in RMR may ultimately result in difficulty with subsequent weight loss and hinder maintenance of weight loss (5, 7). Exercise has been used with VLCDs by many investigators in an effort to maintain FFM and prevent or reduce the loss in RMR. Endurance exercise has shown equivocal results because some investigators report reductions in losses of FFM (8, 9) whereas others report no sparing of FFM above that for diet without endurance exercise (10–13).

The effect of weight training combined with a VLCD has not been reported. This is somewhat surprising because weight training is known to increase FFM when the diet is ad libitum (14) and increases in FFM were shown when dietary restriction was 4200 kJ below baseline requirements (15).

This study was initiated to determine if a VLCD with combinations of endurance exercise and weight training moderate declines of FFM and RMR compared with a VLCD alone as administered in the clinical setting.

Subjects and methods

Subjects

Sixty-nine obese females participated in a series of trials over 2 y. Characteristics of the subjects are shown in **Table 1.** Approval from the Human Subjects Committee was obtained and the subjects signed informed consent forms before any testing or participation. Study groups included a VLCD only (C), a VLCD with endurance exercise (EE), a VLCD with weight training (WT), and a VLCD with endurance exercise and weight training (EEWT).

The subjects were assigned to study groups at baseline by body weight, percent body fat, and RMR by using a matching design (16–18). Subjects were allowed to request a group of choice and the request was honored unless the resulting group means were no longer matched. This procedure gives the subject some responsibility in the decision-making process, has been shown to increase adherence to exercise (19, 20), and better represents the clinical situation where the individual has some freedom to select available services.

All subjects had a medical exam before participation, which included a health history and physical, chest x ray, pulmonary-function testing, a glucose-tolerance test, blood chemistry measurements, and renal- and hepatic-function testing. Subjects were excluded if they had metabolic disease or if they exhibited any condition that would jeopardize their health or hamper performance in subsequent physiological testing.

Diet

All subjects received a liquid-formula diet (Health Management Resources, Boston) that contained 2184 kJ/d for 90 d, including 50 g protein, 79 g carbohydrate, 1 g fat, and the recommended dietary allowance (21) of vitamins and minerals. The diet was ingested at five scheduled times during the day; a vitamin and mineral tablet were taken on rising and before bed.

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[3] Reprints not available.

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TABLE 1
Characteristics of the subjects at baseline*

	C (n = 26)	EE (n = 16)	WT (n = 18)	EEWT (n = 9)
Body weight (kg)	105.3 ± 17.8	99.9 ± 14.0	101.7 ± 20.5	100.3 ± 12.7
Fat (%)	47.0 ± 4.8	46.6 ± 4.5	45.5 ± 5.1	46.5 ± 6.3
BMI	38.2 ± 5.9	37.5 ± 6.0	38.2 ± 7.5	38.3 ± 5.2
Fat weight (kg)	49.9 ± 12.1	46.6 ± 10.0	46.9 ± 13.9	46.9 ± 10.4
FFM (kg)	55.3 ± 7.7	53.3 ± 5.4	54.7 ± 7.9	53.3 ± 6.7
RMR (kJ/d)	7198 ± 1105	7262 ± 1440	7140 ± 1394	6804 ± 1054
Peak $\dot{V}O_2$ (L/min)	2.099 ± 0.432	2.364 ± 0.490	2.246 ± 0.284	2.177 ± 0.403

* $\bar{x}$ ± SD. C, very-low-calorie diet (VLCD) only; EE, VLCD plus endurance exercise; WT, VLCD plus weight training; EEWT, VLCD plus endurance exercise and weight training; BMI, body mass index (in kg/m^2); FFM, fat-free mass; RMR, resting metabolic rate; $\dot{V}O_2$, oxygen consumption.

Subjects were allowed to consume noncaloric beverages ad libitum. Adherence to the diet was assumed if the subject averaged a minimum weight loss of 1.4 kg/wk for 90 d. Additionally, each subject signed a weekly declaration of adherence to the diet.

Physiological testing

All tests were performed at baseline and 90 d from initiation of the VLCD in the Human Performance Laboratory (HPL) at Kearney State College. Subjects were prohibited from smoking, eating, and drinking within 3 h of testing. Exercise was prohibited for 14 h before testing.

Resting metabolic rate. RMR was determined by indirect calorimetry by use of the open-circuit technique (22) while the subject was sitting. The subject reported to the HPL between 0600 and 1000 after a 12-h fast and a 14-h abstention from exercise. The subject sat quietly for 30 min in an isolated temperature-controlled room (21–24 °C). Subsequently, the subject breathed through a mouthpiece for two 15-min collection periods. Fractions of expired oxygen and carbon dioxide were obtained from a mixing chamber and measured by Beckman OM-11 and LB-2 gas analyzers (Beckman Instruments, Palo Alto, CA). Analyzers were calibrated before each test according to the specifications of the manufacturer. Gas volumes were obtained from expired air collected into a 130-L meteorological balloon and measured with a Rayfield gas meter (Rayfield Equipment LTD, Waitsfield, VT). All volumes were corrected standard temperature pressure dry (STPD) and metabolic rate (kJ/d) was calculated by using the Weir equations (23). Criteria for an acceptable RMR were modified from Consolazio (22). RMR was calculated from 15-min samples of expired air in duplicate, respiratory quotient was ≤ 0.85, and frequency of breaths did not exceed 20/min.

Assessment of work capacity. Subjects walked on a treadmill at 80.4 m/min at 0% grade for 5 min to provide acclimation to the treadmill and then rested until the heart rate was within 10 bpm of the resting value. To assess peak oxygen consumption, a modified Balke protocol was used where speed was constant at 80.4 m/min and grade was raised 2.5% at 2-min intervals (24). The subject walked until fatigue occurred and continuation was not possible despite encouragement. The heart rate was recorded during the last 15 s of each stage with a multiple-channel electrocardiograph. Expired air was measured for oxygen and carbon dioxide during the last 30 s of each stage by use of Beckman OM-11 and LB-2 analyzers calibrated before each test as described earlier. Expired volumes were measured during the last 30 s of each stage with a Rayfield gas meter. Measurement of expired volumes, percentages of oxygen and carbon dioxide, electrocardiograph, and treadmill were controlled with a microcomputer and custom software (25). Peak oxygen consumption was calculated as the highest observed value (26). Data from peak oxygen consumption were retained for subsequent analysis if the respiratory exchange ratio was ≥ 0.95, rated perceived exertion was ≥ 18, and heart rate was within 10 beats of the estimated age-adjusted maximum (27, 28).

Body composition. Body weight was recorded before testing by use of a model 707 scale (Seca Corporation, Columbia, MD). Hydrostatic weighing at residual volume was used to determine percent body fat. Ten trials were administered, with the mean of trials 8–10 used for subsequent calculations (29). Residual volume was determined by oxygen dilution by following the procedure of Wilmore et al (30) immediately before hydrostatic weighing. Body density was calculated by using the equation of Goldman and Buskirk (31), and percent body fat was calculated with the equation of Brozek et al (32).

Muscular strength. Bench press (BP), lateral pull-down (LP), knee extension (KE), and knee flexion (KF) were measured by use of the one-repetition maximum method (1RM) with Universal Gym Equipment (Universal Gym Equipment Inc, Cedar Rapids, IA) by following the procedures of Wilmore and Costill (33). One RM was determined by administering a series of trials to determine the greatest amount of weight that may be lifted a single time. The above strength activities were chosen because they represent major muscle groups and because the exercise session could be completed in ~20–25 min.

Exercise program

Endurance exercise was assigned according to the schedule shown in **Table 2** and was performed in the presence of a research assistant. Endurance exercise was conducted 4 d/wk and progressed from 20 min at baseline to 60 min at 90 d. Various modes of exercise, including treadmill walking, stationary bicycling, and stationary rowing, were provided to help increase adherence, to provide exercise to a variety of muscle groups, and to decrease overuse injuries, which are prevalent in repetitive activities. Intensity of exercise was set at 13 rated perceived exertion (34) from days 1 to 14 and was replaced with 70% heart-rate reserve from days 15 to 90, calculated with data obtained from the baseline treadmill test. Intensity was verified from days

TABLE 2
Endurance exercise schedule followed by groups EE and EEWT*

Days	Times/week	Intensity	Duration	Bike	Walk	Row
				min		
1–7	4	13 RPE	20	10	10	0
8–14	4	13 RPE	30	10	15	5
15–21	4	70% HRR	35	15	15	5
22–28	4	70% HRR	40	15	20	5
29–49	4	70% HRR	45	20	20	5
50–63	4	70% HRR	50	20	20	10
64–70	4	70% HRR	55	20	25	10
71–90	4	70% HRR	60	25	25	10

* RPE, rated perceived exertion; HRR, heart rate reserve.

15 to 90 by heart rates obtained by a research assistant using a stethoscope twice during each exercise session. Minimum attendance was 90% for all exercise sessions.

Strength training was conducted 4 d/wk according to the schedule shown in **Table 3.** Strength training was performed on Universal gym equipment and progressed from two sets of six to eight repetitions at 70% 1RM to three sets of six to eight repetitions at 80% 1RM. A research assistant was present each day to verify adherence to the protocol. Minimum attendance was 90% for all exercise sessions.

Statistical analysis

Data were analyzed by analysis of variance (ANOVA) to show differences in variables among groups (35). Changes in variables within groups from baseline to 90 d were compared by using Student's *t* tests. In some instances, percentages were calculated to further illustrate differences in more practical terms.

Results

Body weight and body composition

Weight loss for all groups from baseline to 90 d is shown in **Figure 1.** Weight loss at 90 d was 20.4 ± 5.7, 21.4 ± 3.8, 20.9 ± 6.2, and 22.9 ± 5.1 kg, for C, EE, WT, and EEWT, respectively ($P < 0.05$). The differences in weight loss among groups at 90 d were not statistically significant. Weight loss as a percentage of baseline weight was quite similar for all groups with 19.4%, 21.5%, 20.6%, and 22.8% for C, EE, WT, and EEWT, respectively.

Body-composition variables at baseline and 90 d for all groups are shown in **Table 4.** All groups showed significant decreases in percent body fat, fat weight, and FFM at baseline to 90 d ($P < 0.05$). Decreases in percent body fat were 7.8 ± 3.4%, 9.0 ± 2.4%, 9.3 ± 3.0%, and 10.1 ± 4.0% for C, EE, WT, and EEWT, respectively. Fat-weight losses at 90 d for C, EE, WT, and EEWT were 16.1 ± 5.1, 16.6 ± 3.6, 16.1 ± 4.1, and 18.0 ± 4.3 kg, respectively. FFM showed decreases at 90 d of 4.7 ± 4.3, 4.8 ± 2.4, 4.7 ± 4.6, and 4.1 ± 3.5 kg for C, EE, WT, and EEWT, respectively. Comparisons among groups at baseline and 90 d showed no significant differences for percent fat, fat weight, and FFM. When body composition was expressed as a percentage of fat-weight loss to total weight loss, 77.8%, 77.1%, 77.0%, and

TABLE 3
Weight training schedule followed by groups WT and EEWT

Days	Times/week	Sets	Repetitions/set	Percent 1RM*
				%
1–7	4	2	6–8	70
8–14	4	2	6–8	70
15–28	4	3	6–8	75
29–42	4	3	6–8	80
43–90	4	3	6–8	80

* One repetition maximum.

78.7% of the weight loss was fat for C, EE, WT, and EEWT, respectively.

Resting metabolic rate

Baseline and 90-d measurements of RMR for all groups are shown in Table 4. RMR (kJ/d) showed significant decreases ($P < 0.05$) from baseline to 90 d of 8.1%, 9.2%, 11.0%, and 13.4% for C, EE, WT, and EEWT, respectively. No statistical differences in RMR (kJ/d) were shown with among-groups comparisons at baseline and 90 d. RMRs were also expressed as $kJ \cdot kg^{-1} \cdot d^{-1}$ and as $kJ \cdot kgFFM^{-1} \cdot d^{-1}$. Significant increases in RMR (in $kJ \cdot kg^{-1} \cdot d^{-1}$) of 10.20 ± 12.89, 12.47 ± 15.54, and 8.86 ± 10.21 were found from baseline to 90 d for C, EE, and WT, respectively ($P < 0.05$). No significant changes were found in RMR (in $kJ \cdot kgFFM^{-1} \cdot d^{-1}$) from baseline to 90 d. Among-group comparisons at baseline and 90 d for RMR expressed as $kJ \cdot kg^{-1} \cdot d^{-1}$ and $kJ \cdot kgFFM^{-1} \cdot d^{-1}$ showed no statistical differences.

Strength training

Baseline and 90-d measurements of strength for all groups are shown in Table 4. A strength index (SI) was calculated as the sum of 1RM values (kg) from the BP, LP, KE, and KF. SI expressed per kilogram of body weight (kg BW) and per kilogram FFM are also shown in Table 4. SI showed a decrease from baseline to 90 d of 6.7% for group C ($P < 0.05$) and a decrease of 5.8% for group EE (NS). Increases in SI baseline to 90 d of 9.7% ($P < 0.05$) and 2.6% (NS) were shown for groups WT and EEWT, respectively. Significant changes in SI/kg BW of 16.5–

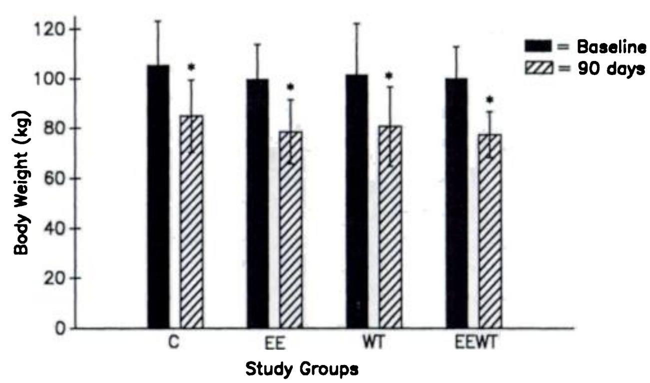

FIG 1. Body-weight loss from baseline (■) to 90 d (□). $\bar{x}$ ± SD. *$P < 0.05$.

TABLE 4
Changes in body-composition data, RMR, SI, and work capacity from baseline to 90 d*

	C (n = 26)			EE (n = 16)		
	Baseline	90 d	Mean difference	Baseline	90 d	Mean difference
Fat (%)	47.0 ± 4.8	39.2 ± 6.2†	−7.8 ± 3.4	46.6 ± 4.5	37.6 ± 5.6†	−9.0 ± 2.4
Fat weight (kg)	49.9 ± 12.1	33.8 ± 9.9†	−16.1 ± 5.1	46.6 ± 10.0	30.0 ± 8.7†	−16.6 ± 3.6
FFM (kg)	55.3 ± 7.7	50.6 ± 7.0†	−4.7 ± 4.3	53.3 ± 5.4	48.5 ± 5.6†	−4.8 ± 2.4
RMR						
(kJ/d)	7198 ± 1105	6619 ± 1197†	−579 ± 1268	7262 ± 1440	6598 ± 1108†	−664 ± 1310
($kJ \cdot kg^{-1} \cdot d^{-1}$)	68.16 ± 8.4	78.37 ± 14.19†	10.21 ± 12.89	72.62 ± 10.29	85.09 ± 14.70†	12.47 ± 15.54
($kJ \cdot kg\ FFM^{-1} \cdot d^{-1}$)	128.89 ± 13.90	130.24 ± 20.58	1.35 ± 25.2	136.04 ± 21.63	136.16 ± 17.97	0.12 ± 25.99
(SI/kg)	108.8 ± 29.1	101.9 ± 24.4†	−6.9 ± 12.4	101.4 ± 26.0	95.6 ± 24.5	−5.8 ± 13.8[a]
(SI/kg body wt)	1.03 ± 0.26	1.20 ± 0.27†	0.17 ± 0.11[a]	1.01 ± 0.21	1.21 ± 0.24†	0.20 ± 0.16[b]
(SI/kg FFM)	2.14 ± 0.48	2.00 ± 0.41†	−0.14 ± 0.23[a]	2.07 ± 0.39	1.96 ± 0.36	−0.11 ± 0.28[b]
Peak $\dot{V}O_2$						
(L/min)	2.099 ± 0.432	1.996 ± 0.438	−0.103 ± 0.424[a]	2.364 ± 0.490	2.334 ± 0.583	−0.030 ± 0.515[a]
($mL \cdot kg\ FFM^{-1} \cdot min^{-1}$)	37.53 ± 6.12	39.22 ± 7.89	1.69 ± 6.87[ab]	44.41 ± 8.42	47.78 ± 9.02	3.37 ± 11.46[a]

	WT (n = 18)			EEWT (n = 9)		
	Baseline	90 d	Mean difference	Baseline	90 d	Mean difference
Fat (%)	45.5 ± 5.1	36.2 ± 6.8†	−9.3 ± 3.0	46.5 ± 6.3	36.4 ± 7.7†	−10.1 ± 4.0
Fat weight (kg)	46.9 ± 13.9	30.8 ± 12.7†	−16.1 ± 4.1	46.9 ± 10.4	28.9 ± 8.7	−18.0 ± 4.3
FFM (kg)	54.7 ± 7.9	50.0 ± 6.1†	−4.7 ± 4.6	53.3 ± 6.7	49.2 ± 5.2†	−4.1 ± 3.5
RMR						
(kJ/d)	7140 ± 1394	6358 ± 978†	−782 ± 1033	6804 ± 1054	5896 ± 1125†	−908 ± 1272
($kJ \cdot kg^{-1} \cdot d^{-1}$)	70.72 ± 8.19	79.59 ± 7.85†	8.87 ± 10.21	68.12 ± 8.86	78.04 ± 22.5	9.92 ± 16.4
($kJ \cdot kg\ FFM^{-1} \cdot d^{-1}$)	130.53 ± 16.54	127.43 ± 15.41	−3.1 ± 19.11	127.51 ± 10.12	121.13 ± 26.12	−6.38 ± 24.57
(SI/kg)	108.8 ± 22.7	119.4 ± 19.3†	10.6 ± 18.0[a]	108.7 ± 24.9	111.5 ± 24.9	2.8 ± 10.0
(SI/kg body wt)	1.10 ± 0.26	1.52 ± 0.32†	0.42 ± 0.21[ab]	1.08 ± 0.18	1.45 ± 0.32†	0.37 ± 0.16
(SI/kg FFM)	2.18 ± 0.41	2.39 ± 0.33†	0.21 ± 0.38[ab]	2.19 ± 0.32	2.25 ± 0.35	0.06 ± 0.21
Peak $\dot{V}O_2$						
(L/min)	2.246 ± 0.284	2.131 ± 0.369	−0.115 ± 0.383	2.177 ± 0.403	2.376 ± 0.535	0.199 ± 0.339
($mL \cdot kg\ FFM^{-1} \cdot min^{-1}$)	41.73 ± 7.39	42.57 ± 4.93	0.84 ± 8.45	41.08 ± 8.09	48.53 ± 11.15†	7.45 ± 8.81[b]

* $\bar{x}$ ± SD. Significant differences among groups (by ANOVA) indicated by a common superscript letter, $P < 0.05$.
† Significantly different from baseline (by Student's t test), $P < 0.05$.

38.2% were shown from baseline to 90 d for all groups. SI/kg FFM at 90 d showed declines of 6.6% ($P < 0.05$) for group C and 5.6% for group EE (NS). Increases at 90 d in SI/kg FFM were shown for WT and EEWT of 9.6% ($P < 0.05$) and 2.7% (NS), respectively.

Changes among groups at 90 d for SI showed significant difference for EE with a 5.8% decrease compared with WT with a 9.7% increase ($P < 0.05$). No other among-group comparisons for SI showed statistical differences. Changes at 90 d among groups for SI/kg BW showed a significant increase for WT of 38.2% compared with increases of 16.5% and 19.8% for groups C and EE, respectively ($P < 0.05$). Other comparisons for SI/kg BW among groups were not statistically significant. Changes at 90 d among groups for SI/kg FFM showed significant differences for group WT with an increase of 9.6% compared with groups C and EE with a decrease of 6.6% and 5.6%, respectively ($P < 0.05$). Comparisons among other groups did not show statistical significance.

Work capacity

Measurements of peak oxygen consumption at baseline and 90 d expressed as L/min and L/kg FFM are shown in Table 4. Peak oxygen consumption (L/min) showed decreases at 90 d of 5.0%, 1.3%, and 5.2% (NS) for groups C, EE, and WT, respectively. An increase at 90 d of 9.1% (NS) was shown for group EEWT. Comparisons among groups showed no differences for peak oxygen consumption expressed as L/min at baseline and at 90 d.

Peak oxygen consumption expressed as $mL \cdot kg\ FFM^{-1} \cdot min^{-1}$ showed a significant increase at 90 d for group EEWT of 18.1% ($P < 0.05$); however, increases of 4.5%, 7.5%, and 2.0% for groups C, EE, and WT, respectively, were not statistically significant. Comparisons among groups at baseline showed a significant difference ($P < 0.05$) with 37.53 ± 6.12 $ml \cdot kg\ FFM^{-1} \cdot min^{-1}$ for group C vs 44.41 ± 8.42 $ml \cdot kg\ FFM^{-1} \cdot min^{-1}$ for group EE. No other among-group differences were shown at baseline. Comparisons among groups at 90 d showed significant differences in peak oxygen expressed as $mL \cdot kg\ FFM^{-1} \cdot min^{-1}$ when group C with a 4.5% increase was compared with groups EE and EEWT with 7.5% and 18.1% increases, respectively ($P < 0.05$). No other among-group comparisons showed significant differences at 90 d.

Discussion

A VLCD by itself or combined with exercise produced similar body-weight changes at 90 d. No statistically significant changes in percent body fat, fat weight, FFM, or percentage of fat-weight loss to total body weight loss were found among groups at 90 d. These findings are in agreement with reports where no significant differences were shown for weight loss or loss of FFM between diet alone and diet plus endurance exercise (10–13, 36, 37). However, these findings are not unequivocal because other investigators reported increased weight loss (38) and decreased loss of FFM (8, 9, 39) for diet and endurance exercise compared with diet alone. No direct comparisons for weight loss and body-composition changes with weight training or weight training in addition to endurance exercise in conjunction with a VLCD are available in the literature. Ballor et al (15) reported increases in lean body weight (LBW) in response to weight training in obese women with a caloric deficit of 4200 kJ below baseline caloric requirements. Diet plus weight training in the Ballor study produced an increase of 0.43 ± 0.26 kg LBW compared with a loss of FFM of 4.7 ± 4.6 kg for WT and 4.1 ± 3.5 kg for EEWT in the present study. However, remarkable differences exist between the studies. The subjects in the Ballor study were neither as heavy (~74 vs ~101 kg) nor as fat (~36% vs ~46%), and did not lose as much weight (~2.3 vs ~21 kg) as the subjects in the present study. Additionally, Ballor used a weight-training program with about twice the number of exercises used in the present study. It is possible to speculate that the subjects in the Ballor study had increases in LBW because of the increased number of weight-training exercises, the increased daily caloric intake (~5040 vs 2184 kJ/d), or both.

The decreases within groups at 90 d in RMR (kJ/d) were somewhat smaller than those reported by others (40–44), with an average decrease of ~9% of baseline values. Exercise combined with diet was no more effective than diet alone in preventing declines at 90 d in RMR (kJ/d). RMR normalized to FFM showed no significant declines at 90 d for diet-only or diet-plus-exercise groups. The finding that RMR normalized to FFM does not decline during a VLCD was reported by others (44, 45). This suggests that basic energy turnover is not adversely affected by a VLCD or by a VLCD combined with exercise and that absolute declines in RMR expressed per unit of time simply reflect losses in body mass. However, this finding is not universal because other investigators report significant decreases in RMR (kg FFM/d) (8, 36). The finding that exercising subjects showed no greater declines in RMR (kJ/d or $kJ \cdot kg\ FFM^{-1} \cdot d^{-1}$) than did nonexercising subjects, regardless of increased total caloric expenditure, was reported elsewhere. Hill et al (8) found no differences in the decline of RMR between obese females participating in endurance exercise or those that were sedentary. The present study supports the suggestion of Hill et al that additional caloric deficit produced by increasing energy expenditure may not produce declines in RMR equal to those found with food restriction (46). The inability for various combinations of exercise to reverse the decline in RMR at 90 d should not be considered a negative factor. Conversely, it suggests that one may receive the health benefits of vigorous exercise during a VLCD without additional adverse effects on RMR.

Strength changes at 90 d, expressed as SI, showed decreases of ~5% and ~6% for C and EE, respectively, and increases of ~3% and ~10% for WT and EEWT, respectively. Strength was preserved or increased in the two groups that received weight training. Because endurance exercise is not known to increase strength, the ~6% decline shown in EE is not surprising.

Strength changes at 90 d, expressed as SI/kg, showed increases between ~16% and ~38% in all groups. Increases in C and EE illustrate that strength normalized to body weight (SI/kg) gives misleading information regarding strength gains during weight loss. This is further emphasized by expressing strength as SI/kg FFM where groups C and EE show declines at 90 d of ~5% and ~6%, respectively; however, WT and EEWT show gains of ~3–~9%.

Peak oxygen consumption expressed as L/min showed declines of ~5%, ~1%, and ~5% for C, EE, and WT, respectively. EEWT showed an ~9% increase over the baseline value. It was somewhat surprising that EE did not show improvements similar to EEWT; however, other investigators reported no changes or declines in oxygen consumption (expressed as L/min) associated with a VLCD or with a VLCD and endurance exercise (47–49). Whether the addition of weight training was the cause for increased peak oxygen consumption (in L/min) with EEWT is unclear because the weight-training program was not designed to elicit an endurance-training response. Additionally, it is observed that group WT did not show an endurance-training effect. Weight training in addition to endurance may simply reflect additional benefits of increased volume of exercise.

The expression of oxygen consumption as $mL \cdot kg\ FFM^{-1} \cdot min^{-1}$ may be useful to determine the ability to use oxygen per unit of muscle mass. In response to training, groups EE and EEWT show the largest gains (~8% and ~18%) whereas group C and WT show smaller gains (~2% and ~5%), which reflect the abstinence from regular endurance exercise. These findings agree with other reports that show ~4% and ~6% increases in oxygen consumption expressed as $mL \cdot kg\ FFM^{-1} \cdot min^{-1}$ with various combinations of diet and exercise (9, 36).

In summary, this clinical study did not identify any advantage of using various exercise regimens in combination with a VLCD over a VLCD alone with respect to RMR, body-weight loss, or body-composition changes. The use of weight training did not appear to moderate declines in FFM or RMR compared with diet alone or diet plus endurance exercise. However, increases were realized for work capacity and strength by the groups that underwent exercise training compared with those on a VLCD only.

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