Severe vs moderate energy restriction with and without exercise in the treatment of obesity: efficiency of weight loss[1–3]

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ABSTRACT Thirty obese women were randomly assigned to either 40% [severe energy restriction (SER)] or 70% [moderate energy restriction (MER)] of their maintenance energy requirements and to no exercise, aerobic exercise (walking), or aerobic exercise plus circuit weight training. Body composition by hydrostatic weighing and energy expenditure by indirect calorimetry were measured at 0, 3, and 6 mo. In addition, we developed a deficit-efficiency factor (DEF), calculated as body energy loss/dietary energy deficit, to attempt to quantify the effectiveness of the weight-reduction interventions. Subjects in the SER group lost more weight ($\bar{x} \pm$ SE: 15.1 ± 1.4 vs 10.8 ± 1.0 kg), fat (11.7 ± 1.1 vs 8.3 ± 0.6 kg), and fat-free mass (2.8 ± 0.3 vs 1.8 ± 0.3 kg) than the MER group ($P \leq 0.05$). However, the overall DEF was greatest in the MER group (0.80 ± 0.07) compared with the SER group (0.52 ± 0.05; $P \leq 0.01$). Exercise had no significant effect. This study demonstrates that MER may offer an advantage over SER because it produces a greater energy loss relative to energy deficit. *Am J Clin Nutr* 1993;57:127–34.

KEY WORDS Obesity, energy restriction, exercise

Introduction

Obesity is a major health problem in the United States (1). It is associated with a significant increase in the incidence of hypertension, diabetes, coronary artery disease, and mortality from certain types of cancer (2, 3).

It is important in developing successful obesity-treatment programs to define parameters of such programs that may affect long-term treatment success. For example, there is no agreement about the optimum degree of energy restriction for maximizing loss of body weight and body fat and for long-term maintenance of weight reduction. Hammer et al (4) reported that severe energy restriction (3516 ± 377 kJ/d) produced a greater loss of total body weight and of fat and fat-free mass (FFM) when compared with a more moderate degree of food restriction (6069 ± 1205 kJ/d). However, the latter degree of energy restriction yielded a greater proportion of the energy loss predicted by the energy deficit. Other investigators have reported no differences in severe vs moderate energy restriction in loss of body weight (5) or body fat (6).

There is also disagreement about the results of adding exercise to food restriction in the treatment of obesity. Some investigators have reported that aerobic exercise combined with food restriction produces greater weight loss (7, 8), greater loss of body fat and preservation of FFM (9, 10), and a smaller drop in resting energy expenditure (11, 12) than does food restriction alone. However, other investigators have failed to find such effects with aerobic exercise (13–15). Whether or not exercise modifies weight loss, changes in body composition, and reduction in energy expenditure may depend on the degree of food restriction with which it is combined. For example, Phinney et al (16) found that aerobic exercise had no added effect when combined with very low-energy diets.

The goals of this study were as follows: *1*) to determine whether moderate energy restriction (MER) will lead to a more desirable treatment of obesity than more severe energy restriction (SER) in terms of weight loss, body composition, and energy balance; *2*) to determine how aerobic exercise, with and without circuit weight training (CWT), affects body composition and energy balance during energy restriction; and *3*) to determine whether the different treatments influence energy conservation to different degrees.

Subjects and methods

Subjects

Forty-seven moderately obese women were recruited for a 6-mo weight-reduction study. Subjects responded to advertisements in local newspapers and on local radio. Each underwent three separate interviews, the first by phone and the other two in person. Subject selection criteria were as follows: female, Caucasian, adult-onset obesity (postpubertal), 135–185% of ideal body weight (IBW), premenopausal, nonsmoker, no major health problems, and on no medications (including oral contraceptives), stable body weight (±4.6 kg) for 1 y before the study, and no

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regular exercise for 6 mo before the study. The majority of women responding to the advertisement were Caucasian; the study limitations did not allow us to include gender or ethnicity as a variable.

Thirty-nine subjects completed 3 mo and 30 completed the full 6 mo. Subject characteristics for the 30 women are shown in **Table 1.** Reasons for attrition included: *1*) lack of compliance with either the diet or exercise component ($n = 5$); *2*) job conflict ($n = 6$); *3*) concurrent medical illness ($n = 2$); or *4*) family or personal problems ($n = 4$). There was no difference between groups for attrition.

All subjects gave informed consent after receiving both oral and written explanations concerning the nature and attendant risks of the study. The study was approved by the Institutional Review Board of Emory University Hospital.

Subjects were randomly assigned to either severe or moderate energy restriction and to one of three exercise conditions: sedentary (no regular exercise), aerobic exercise, or aerobic exercise plus CWT.

Study design

This was a 2 × 3 factorial experiment, with diet and exercise as independent variables. Total study duration was 6 mo and it combined both inpatient and outpatient phases. Each subject was admitted to the General Clinical Research Center (GCRC) for 2 wk of initial assessment. Subjects consumed a regular weight-maintenance diet (≈20% protein, 50% carbohydrate, 30% fat) during week 1, and baseline dependent variables were measured. Maintenance energy requirements were set at 1.4 × estimated resting metabolic rate (RMR) (17). During week 2, subjects began their diet and exercise program. They continued the diet and exercise program as outpatients over the following 3 mo, which included supervised 3 × weekly exercise sessions, and weekly meetings with the investigators at the GCRC to be weighed, return diet diaries, and discuss any problems. Subjects were also admitted to the GCRC for 1 wk at 3 mo and at 6 mo to measure all dependent variables. At the end of the study period subjects were instructed to maintain their weight over the next 6 wk as outpatients with weekly GCRC visits.

Diet

Two levels of energy restriction were studied. SER was 40% of the subjects' maintenance energy requirement. Those on MER consumed 70% of their maintenance energy requirement. Average energy consumption was 3273 kJ/d (782 kcal/d) for the SER and 5731 kJ/d (1369 kcal/d) for the MER group.

Individual meal patterns, based on the Exchange Lists for Meal Planning of the American Dietetic Association (18), were developed for each subject. Each individual diet plan was formulated based on the subject's rate of energy maintenance, rate of energy restriction, and food preferences. Composition of energy restriction programs was ≈15% protein, 55% carbohydrate, and 30% fat, and consisted of commonly available foods. A lower limit of 45 g protein/d was used if the calculated protein amount fell below this range. Diet instruction was given by the GCRC nutritionist during the initial hospital admission. Subjects who were randomly assigned to exercise were supplemented with additional energy per day that was calculated as: energy expenditure per exercise session (kJ) × 3 sessions per week divided by 7 d/wk = kJ/d.

Daily diet diaries were completed by each subject during the outpatient phases of the study. Subjects were required to list food items, amount, exchanges and grams of protein, carbohydrate, and fat during the first 3 mo. During the second 3-mo period, subjects were required to list food items, amount, and exchanges. These food records, as well as body weight, were reviewed weekly by the investigators to assess dietary compliance.

Exercise

Each subject was enrolled in a supervised exercise program at the Emory Health Enhancement Program that began during the second week.

At the beginning and end of the study, maximum aerobic capacity and maximum achieved heart rate were determined in all subjects by a maximal treadmill test with continuous oxygen consumption performed under physician supervision. Subjects exercised on the treadmill to maximal fatigue and until a rate of perceived exertion (RPE) of ≥ 18 was achieved. A target heart rate (THR) was determined for each subject by using the Karvonen formula [maximum heart rate − resting heart rate × (0.70 and 0.85) + resting heart rate = target heart rate range].

Each subject was instructed about how to measure pulse rate throughout the exercise session and how to compensate for rates above or below THR. Thus, each subject received an individual exercise prescription, and the relative intensity of exercise was constant for all subjects.

TABLE 1
Baseline subject characteristics*

	Severe energy restriction			Moderate energy restriction		
	Sedentary ($n = 5$)	Aerobic ($n = 5$)	CWT† ($n = 6$)	Sedentary ($n = 5$)	Aerobic ($n = 5$)	CWT ($n = 4$)
Age (y)	32.4 ± 3.1	39.7 ± 2.4	29.5 ± 2.8	31.5 ± 2.8	37.8 ± 1.0	35.7 ± 4.6
Body weight (kg)	93.0 ± 6.8	95.7 ± 4.0	100.1 ± 4.8	94.6 ± 3.2	93.2 ± 3.9	101.8 ± 5.3
BMI‡	34.3 ± 1.2	34.6 ± 2.2	36.7 ± 0.9	32.4 ± 1.7	35.1 ± 1.0	37.4 ± 1.5
Percent fat	45.1 ± 1.0	44.3 ± 1.1	44.9 ± 1.0	46.1 ± 1.4	45.0 ± 1.1	46.8 ± 3.4
RMR (kJ/h)	243.6 ± 12.9	254.1 ± 9.6	270.0 ± 17.2	252.4 ± 9.2	215.6 ± 7.0	244.8 ± 8.8
RMR/FFM ($kJ \cdot h^{-1} \cdot kg^{-1}$)§	4.86 ± 0.33	4.77 ± 0.17	4.90 ± 0.17	4.98 ± 0.25	4.23 ± 0.12	4.64 ± 0.42

* $\bar{x}$ ± SE. There were no significant differences between groups.
† CWT, aerobic plus circuit weight training group.
‡ In kg/m^2.
§ RMR, resting metabolic rate; FFM, fat-free mass.

All subjects recorded exercise performed, noting the type of activity, distance, duration, and both resting and immediate postexercise heart rate. The subjects also kept a record of any extra activities performed during the course of each study day.

Intensity and duration of exercise performed was steadily increased throughout the study to minimize injuries and allow subjects to adapt to the rigors of the exercise program.

All exercising subjects reported to the exercise area 3 d/wk every week. Weight, resting HR, and blood pressure were recorded. All subjects participated together in a 15-min warm-up session. Afterwards, each subject then performed her aerobic workout for the appropriate duration. Brisk walking ($\approx$24–27 min/km) performed at THR was the aerobic exercise chosen for this study.

Subjects in the aerobic group began their exercise program by walking 1.2 km around an indoor track, maintaining a THR range of 50% to 60%. At 2 wk, THR range was increased to 70% to 85% and distance was increased at weekly intervals until a distance of 8.8 km/session was achieved. Subjects in the CWT groups followed the same protocol for the first 2 wk, then increased their distance more gradually until a distance of 6.8 km/session was achieved.

Subjects in the CWT group performed fewer minutes of aerobic exercise each week to ensure that both exercising groups expended the same amount of energy. After week 6, subjects were allowed to substitute riding the bicycle ergometer for up to 15 min of walking.

At the end of the aerobic exercise, those subjects in the CWT group reported to weight machines (Paramount Fitness Equipment Corp, Los Angeles) to perform seven weight-training station exercises plus one sit-up station in the following order: bench press, leg press, latissimus pull, leg flexion, shoulder press, leg extension, arm curl, and sit-ups. The circuit was designed to exercise all muscle groups of the body, with upper- and lower-body exercises following an alternating pattern in order to reduce stress on any given muscle group.

Maximum strength [one repetition maximum (1 RM)] tests were given at weeks 0, 4, 12, 18, and 24, in order to assess strength improvement at each station and to adjust the amount of weight lifted during training. The amount of weight lifted and the number of repetitions performed at each station were recorded by the subject throughout the 24-wk program.

For the first 2 wk, subjects lifted at 30% of their 1 RM level; thereafter, the weight load was increased to 40% 1 RM. Subjects performed at each station as many repetitions as possible for 30 sec with a 15-sec rest period between stations. Subjects gradually increased their regimen until they were completing three sets at 40% 1 RM. Each set took $\approx$5 min and 45 s to complete and consumed $\approx$167 kJ (40 kcal) (3.3 kJ/kg of FFM per set). The energy expenditure of weight training was based on the lean body mass (LBM) of the subjects. Wilmore et al (19) determined the energy cost of CWT in females to be 34.3 kJ/kg of LBM per h when following the above-described protocol.

Dependent variables

Body weight was determined to the nearest 100 g weekly, with the same GCRC metabolic scale (ACME Scale Co, Oakland, CA).

Body composition was measured at baseline, 3 mo, and 6 mo at the Human Performance Laboratory at Georgia Technical Institute. The hydrostatic weighing method that uses Chatillon spring scales (John Chatillon and Son, New Gardens, NY) was used to determine body density. Residual lung volume by using a closed-circuit nitrogen dilution method was measured simultaneously with the underwater procedure (20). Nitrogen concentration during rebreathing was measured with a Med Science 505D Nitrolyzer (Med Science, St Louis). Fat, FFM, and percent fat were calculated by using Brozek's revised equation: percent fat = (4.57/body density − 4.142) × 100 (21). Waist and hip measurements were calculated from photographs of patients made during their GCRC stays by using the method described by Ashwell (22).

RMR was determined by indirect calorimetry. Measurements were made after subjects fasted overnight in the GCRC within 1 h after gentle awakening. Expired air was collected for 5 min for three consecutive measurements by using a Douglas bag. Volume was measured with a pneumotachograph (VR-1; Accutach, American Hospital Supply Corporation, Irvine, CA). Expired air was then analyzed for oxygen consumption and carbon dioxide production by using Beckman oxygen (OM-11) and carbon dioxide (LB-2) gas analyzers (Beckman Instruments, Palo Alto, CA). Volume of expired air was corrected to standard dry temperature and pressure. Metabolic rate was determined by using the equation of Weir (23). We calculated the average RMR for each subject over three consecutive measurements of 5 min each.

Exercise tests were performed at the Emory Health Enhancement Program on a Quinton 18-49C Treadmill (Marquette series 2000; Quinton Instrument Co, Seattle) by using the standard Bruce protocol, which increases speed and incline at 3-min stages. All women exercised to volitional exhaustion (RPE $\geq$ 18). No subjects developed subjective symptoms or displayed electrocardiographic evidence of coronary disease or arrhythmias. Resting electrocardiographs showed no significant abnormalities throughout the study.

Oxygen uptake and carbon dioxide production were sampled at each minute using a Rayfield expiratory gas flow meter with the Applied Electrochemistry system (Ameteck/Thermox, Pittsburgh) (24).

Metabolic balance

Twenty-four urine and stool samples were collected during each GCRC admission. Each subject underwent a 3- to 4-d equilibration period followed by a 4-d metabolic-balance period. Balances were determined during week 1 when subjects were on a regular weight-maintaining diet, after 1 wk, 3 mo, and 6 mo of energy restriction. A 1-d sample of each subject's diet was analyzed at the beginning of each balance period. Each subject consumed the same predetermined daily diet during each balance period based on their energy restriction. Samples were analyzed for nitrogen content by using the micro-Kjeldahl technique. Nitrogen balance was calculated as intake − (urine + fecal + insensible losses). Insensible losses were calculated as 7 mg/kg body weight (25).

Energy-deficit–efficiency factor

To attempt to quantify efficiency of weight reduction, we developed the energy-deficit–efficiency factor (DEF). This index was calculated as loss of body energy storage/energy deficit created by dietary restriction. Body energy was estimated from body composition. Body fat was assumed to consist of triglyceride with a gross energy value of 39 344 kJ/kg (9400 kcal/kg) (26, 27). FFM was assumed to consist of a combination of protein, ash, carbohydrate, and water. We assumed a gross energy value of 5525 kJ/kg (1320 kcal/kg) for FFM (27). The energy deficit was calculated as estimated energy requirement minus target energy intake. If efficiency of weight loss were 100%, the DEF value would be 1.0, reflecting that 1 kJ body energy was lost for every 1 kJ of energy restriction. Higher values of the DEF index would indicate greater loss of body energy for a given energy deficit and would be associated with higher efficiency of weight loss. Theoretically, DEF values can range between 0 and 1. However, values > 1 could be obtained if the actual energy deficit is greater than the calculated energy deficit, ie, if maintenance energy requirements were underestimated.

Energy expenditure secondary to exercise was not used in the calculation, because exercising groups consumed additional energy to compensate for that expended during exercise.

Statistics

Data were stored and analyzed by using the GCRC Clinfo System (BBN Software Products Corp, Cambridge, MA). One-way analyses of variance (ANOVAs) were used to relate demographic data and initial body-measurement data to exercise, diet, and group. When necessary, Tukey's pair-wise comparisons were used to help explain the results. Exercise by diet by time repeated-measures ANOVAs were used to relate data collected over time to combinations of exercise and diet. When the exercise by diet interaction was not significant, an exercise by time repeated-measures ANOVA and diet by time repeated-measures ANOVA were used. In either method of analysis, paired *t* tests with changes (and percent changes), ANOVAs with changes (and percent changes), and Tukey's pair-wise comparisons were used to help explain the results. Pearson correlation was used to relate body measurements to each other. All analyses were performed by using the *Statistical Analysis Package* (SAS Institute, Cary, NC).

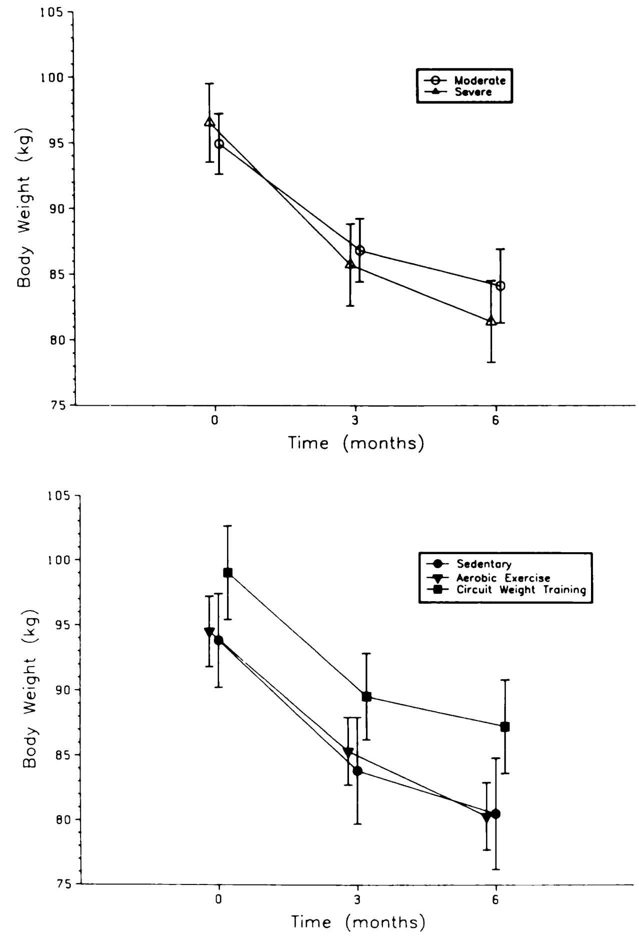

FIG 1. Effect of severe (n = 14) vs moderate (n = 16) energy restriction (*upper panel*) and no exercise (sedentary) (n = 10), aerobic exercise (n = 10), and circuit weight training (n = 10) (*lower panel*) on body weight in obese women. $\bar{x}$ ± SE. Those in the severe energy restriction group lost a significantly greater amount of body weight at 3 mo and over the entire 6 mo than those in the moderate energy restriction group ($P \leq 0.05$). There was no difference between exercise groups.

Results

Body weight

None of the groups differed in body weight or body composition at the beginning of the study (Table 1). All groups lost body weight during the study ($P \leq 0.0001$). **Figure 1** shows that there was a significant main effect for diet in loss of body weight. Weight loss was greater in the SER group than in the MER group during the first 3 mo (10.8 ± 0.8 vs 8.1 ± 0.4 kg; $\bar{x}$ ± SE, $P \leq 0.05$) and during the entire 6-mo period (15.1 ± 1.4 vs 10.8 ± 1.0 kg, $P \leq 0.05$). Weight loss during the last 3 mo of the study did not differ between diet conditions.

Weight loss did not differ because of exercise condition (Fig 1). Neither aerobic exercise nor CWT led to an amount of weight loss at 3 or 6 mo that was different from sedentary subjects.

Body composition

All groups lost significant amounts of fat and FFM during the study ($P \leq 0.0001$). **Figure 2** shows the effect of diet on body-fat content. Total loss of body fat was not different between the SER and MER groups during the first 3 mo of the study, but was greater for SER than MER subjects during months 3–6 ($P \leq 0.05$). Over the entire period, loss of body fat was greater for SER than MER subjects (11.7 ± 1.1 vs 8.3 ± 0.6 kg, $P \leq 0.05$). Loss of body fat did not differ because of exercise condition (Fig 2).

Overall, SER subjects lost significantly more FFM than MER subjects (2.8 ± 0.3 vs 1.8 ± 0.3 kg, $P \leq 0.01$). Subjects in the CWT group lost less FFM ($P \leq 0.01$) during the first 3 mo of the study than the other two groups (1.7 ± 0.4 kg for CWT group; 2.9 ± 0.4 kg for sedentary group, 2.5 ± 0.3 kg for aerobic exercise group). FFM loss did not differ because of exercise condition during months 3–6, or during the entire 6-mo period.

When the proportion of total 6-mo weight loss coming from fat vs FFM is considered (**Table 2**), there was no significant effect of diet. SER subjects lost an average of 78.3 ± 1.9% of weight from fat whereas MER subjects lost an average of 78.4 ± 3.3% of weight from fat (**Fig 3**).

Although exercise condition did not influence the proportion of weight loss derived from fat when the entire 6-mo period is considered, there were some effects observed during the first 3 mo (Table 2). During the first 3 mo of the study, subjects in the CWT group lost significantly more ($P \leq 0.01$) of their body weight from fat (84.1 ± 3.0%) than subjects in the aerobic (72.2 ± 3.2%) or sedentary (71.4 ± 3.2%) conditions.

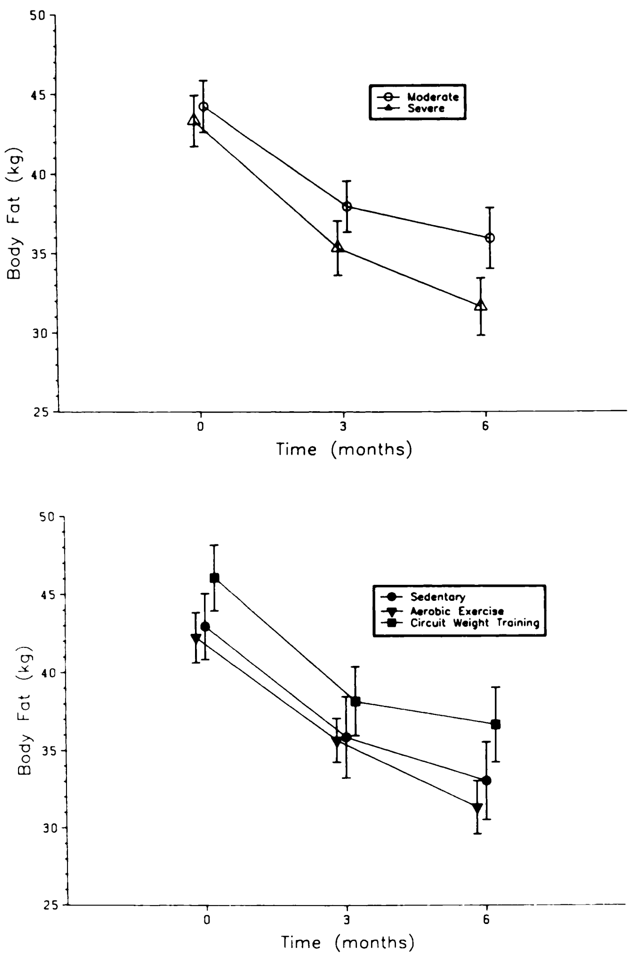

FIG 2. The effect of severe (n = 14) vs moderate (n = 16) energy restriction (*upper panel*) and no exercise (sedentary) (n = 10), aerobic exercise (n = 10), and circuit weight training (n = 10) (*lower panel*) on body fat in obese women. $\bar{x}$ ± SE. Loss of body fat was greatest in the severe energy restriction group over the 3- to 6-mo period and over the entire 6-mo study ($P \leq 0.05$). There was no difference between exercise groups.

The waist-to-hip ratio tended to decrease with weight loss in all subjects, but was not affected by diet condition. Subjects in the aerobic exercise group had a greater ($P \leq 0.01$) reduction in the waist-to-hip ratio over the 6-mo study period (from 0.84 ± 0.02 to 0.80 ± 0.01) than subjects in the CWT group (from 0.81 ± 0.01 to 0.80 ± 0.01), or sedentary group (from 0.80 ± 0.02 to 0.79 ± 0.01).

Resting metabolic rate

RMR decreased in all groups over the entire study period with weight loss (−4.1 ± 4.4%, $P \leq 0.01$). SER tended to produce a greater total decline in RMR (−6.5 ± 7.6%) than MER (−1.7 ± 5.0%; $P \leq 0.05$) over 6 mo, but this was explained by the greater loss of FFM in that group. When expressed per unit FFM, RMR did not differ because of diet condition at any time during the study. Similarly, exercise condition did not affect RMR (expressed as kJ/h or $kJ \cdot kg\ FFM^{-1} \cdot h^{-1}$) at any time during the study.

TABLE 2
Weight loss as Fat*

Group	Time 0–3 mo	3–6 mo	0–6 mo
		%	
Diet			
Severe energy restriction (n = 14)	73.6 ± 2.1	76.3 ± 6.3	78.3 ± 1.9
Moderate energy restriction (n = 16)	78.6 ± 3.6	70.1 ± 7.3	78.4 ± 3.3
Exercise			
Sedentary (n = 10)	71.4 ± 3.2	73.5 ± 9.7	76.5 ± 3.9
Aerobic (n = 10)	72.2 ± 3.2	82.2 ± 3.4	76.1 ± 2.1
Circuit weight training (n = 10)	84.1 ± 3.0†	64.5 ± 9.7	82.4 ± 3.2

* $\bar{x}$ ± SE.
† Significantly different from sedentary and aerobic exercise groups at 0–3 mo, $P \leq 0.01$.

Nitrogen balance

When all subjects were considered over the 6-mo study, nitrogen balance declined significantly from baseline. Nitrogen balance was more negative in SER subjects than MER subjects after 1 wk of energy restriction (−0.07 ± 0.45 vs 0.74 ± 0.28 g N/d; $P \leq 0.05$), at 3 mo (−1.12 ± 0.30 vs −0.41 ± 0.40 g N/d; $P \leq 0.05$), and at 6 mo (−0.89 ± 0.56 vs 0.15 ± 0.40 g N/d; $P \leq 0.05$). Exercise condition did not significantly affect nitrogen balance.

Efficiency of weight loss

DEF is shown by group in **Table 3.** Subjects in the MER group demonstrated greater DEF at any time period when compared with those in the SER group. This was significant at both the 0- to 3-mo and 0- to 6-mo periods ($P \leq 0.005$). The greater the DEF, the greater the energy loss via fat and FFM loss for the calculated energy deficit. The MER group showed a mean energy deficit for the 6-mo period of 2394.02 ± 65.63 kJ/d

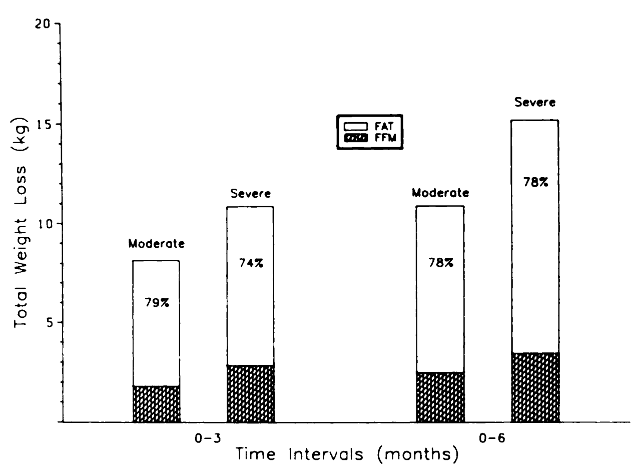

FIG 3. The composition of weight loss in severe (n = 14) vs moderate (n = 16) energy restriction over the first 3 mo (0–3) and the total study period (0–6). FFM, fat-free mass. Total weight loss was greater in the severe energy restriction group ($P \leq 0.01$) during both time periods.

TABLE 3
Energy-deficit–efficiency factor (DEF)*

Group	Time		
	0–3 mo	3–6 mo	0–6 mo
Diet			
Severe energy restriction (n = 14)	0.72 ± 0.06	0.32 ± 0.01	0.52 ± 0.05
Moderate energy restriction (n = 16)	1.20 ± 0.07†	0.43 ± 0.10	0.80 ± 0.07†
Exercise			
Sedentary (n = 10)	0.96 ± 0.12	0.35 ± 0.06	0.66 ± 0.08
Aerobic (n = 10)	0.95 ± 0.11	0.56 ± 0.13‡	0.75 ± 0.10
Circuit weight training (n = 10)	0.92 ± 0.11	0.20 ± 0.05	0.54 ± 0.08

* $\bar{x}$ ± SE.
† Significantly different from severe energy restriction group $P \leq 0.01$.
‡ Significantly different from sedentary and circuit-weight-training groups at 3–6 mo.

(571.98 ± 15.68 kcal/d). Their mean energy lost as fat equaled 1822.74 ± 142.56 kJ/d (435.49 ± 34.06 kcal/d) and mean energy lost as FFM was 70.02 ± 13.44 kJ/d (16.73 ± 3.21 kcal/d) for a total energy loss of 1892.77 ± 149.09 kJ/d (452.22 ± 35.62 kcal/d). The DEF (total energy loss/energy deficit) for the MER group for the 6-mo study period was 0.80 ± 0.06. The SER group had a mean energy deficit for the 6 mo of 5176.00 ± 165.68 kJ/d (1236.65 ± 39.56 kcal/d). Mean energy lost as fat was 2550.77 ± 242.30 kJ/d (609.43 ± 57.89 kcal/d) and as FFM was 96.18 ± 11.55 kJ/d (22.89 ± 2.76 kcal/d) for a total energy loss of 2646.58 ± 250.21 kJ/d (632.32 ± 59.78 kcal/d). The DEF for this period was 0.52 ± 0.05. This suggests that those subjects in the SER group had greater energy conservation than those in the MER group. In other words, moderate restriction appears to be more effective in terms of the amount of energy deficit necessary to produce a significant weight loss.

Those who performed aerobic exercise showed a smaller decline in DEF than both the sedentary and CWT groups between the 0- to 3-mo and 3- to 6-mo periods. The DEF in the aerobic group (0.56 ± 0.13) was significantly greater than the sedentary (0.35 ± 0.06) and CWT (0.20 ± 0.05) groups ($P \leq 0.05$) for the 3- to 6-mo period. The DEF was greater for the aerobic group overall (0.75 ± 0.10 vs 0.66 ± 0.08 and 0.54 ± 0.08 for the sedentary and CWT groups, respectively) but this was not statistically significant.

Discussion

One intention of this experiment was to determine whether MER offered any additional benefits over SER in the treatment of obesity. These results show that moderate restriction may indeed offer a more desirable treatment for obese patients for a number of reasons.

First, MER definitely appears to be a more cost efficient means of losing weight as demonstrated by a higher DEF. The DEF is analogous but opposite to the food-efficiency factor frequently referred to in the literature when weight (or energy) gained is divided by energy intake. The DEF is measured as weight (or energy) lost divided by the energy deficit created. Diets that lead to energy preservation will produce a smaller loss in energy (low DEF) than diets which promote greater relative energy loss (high DEF). This greater deficit-to-loss ratio seen with MER indicates that moderate restriction does not cause the body to produce as great an adaptive response as severe restriction; ie, it does not cause the body to conserve energy to as great a degree. This may allow obese patients to continue to lose weight over a longer period of time without reaching a plateau and also to allow for a relatively easier long-term maintenance of the reduced body weight. The fact that the DEF was > 1 in the MER groups implies that the actual energy deficit may be slightly greater than the calculated deficit. This error most likely occurs during the estimation of maintenance energy and as such is likely to affect all subjects in the same manner. The difference between groups should, therefore, remain unaffected.

Second, moderate restriction also allows for a greater preservation of FFM than severe restriction, though this effect was only significant during the first 3 mo. Preservation of FFM, the most metabolically active component of body weight, may be an important consideration in successful weight maintenance. Nitrogen loss was significantly lower in the MER group as manifested by a consistently greater nitrogen balance.

Third, a less drastic reduction in food intake may assist the patients in body-weight reduction attempts. The only disadvantage to moderate restriction appears to be a smaller loss of body weight and body fat over the 6-mo period of energy restriction. The actual difference between groups, however, is relatively small. There was only a 4-kg difference between the MER and SER groups in body weight loss over the 6-mo period. It is also important to note that the rate of weight loss declined in all subjects during the second 3 mo, and the amount of body weight lost was no longer significantly different between diet groups. This suggests that the longer the duration of energy restriction, the less pronounced the difference is in terms of weight loss between the levels of energy restriction. Therefore, the advantages of MER appear to outweigh the advantages of SER, especially considering the fact that dietary compliance and the ability to maintain a balanced nutrient intake may be easier with a more moderate degree of restriction.

Few other studies in human subjects have systematically compared effects of degree of energy restriction on body energetics. Foster et al (5) reported results similar to those reported here. They compared 24-wk weight loss on a very low-energy diet (beginning at 2093 kJ/d) with a moderate energy-restriction diet (5023 kJ/d) in obese women. They found that although total weight loss was greater on the very low-energy diet, the composition of weight loss did not differ between groups. However, in contrast to the findings in the present study, they found that the ratio of resting energy expenditure to FFM declined more in the more severely restricted group than in the moderately restricted group, suggesting that the moderate-energy diet could provide a long-term benefit in maintaining weight loss.

Davies et al (6) compared women given a 1381-kJ/d diet with others given a 3265-kJ/d diet. Total weight loss and loss of FFM was greater in subjects given 1381 kJ/d than in those given 3265 kJ/d, but loss of body fat was similar between groups. Although this suggests that degree of energy restriction may influence composition of weight loss, both diets in this study were substantially lower in energy than the moderate-energy diet used in the present study.

We found that exercise condition had minimal effects on loss of body weight or body fat. Neither aerobic exercise nor aerobic exercise plus CWT increased total weight loss or total loss of body fat as compared with sedentary subjects. It is important to realize, however, that exercising subjects were given a greater amount of food to compensate for the cost of the exercise itself. This allowed us to assess the effects of the exercise itself and not the energy deficit produced by the exercise. These results suggest that the effects of exercise on body weight and body composition found by other investigators (7, 9, 28, 29) could have occurred because of a greater total energy deficit produced by the added cost of exercise.

We did find some transient effects of CWT on body composition. During the first 3 mo, this form of exercise seemed to minimize loss of FFM. This finding agrees with that of Ballor et al (10) who reported that weight training combined with a moderate energy-restriction diet preserved LBM in obese women during an 8-wk period. However, in the present study, the effects of CWT on preservation of FFM were present after 12 wk but disappeared by the end of the 6-mo study. It is impossible to determine conclusively whether this was due to a decline in compliance with the diet, a declining level of enthusiasm and effort with the CWT program, or to metabolic adaptations to the exercise.

On the basis of changes in body weight and body composition alone, aerobic exercise does not seem more advantageous in obesity treatment. However, we did find that subjects in this exercise condition lost a greater proportion of their weight as predicted by their dietary deficit than subjects in the other exercise conditions. Furthermore, aerobic exercise appeared to enhance the effects of energy restriction by causing a greater loss of body weight during the second 3-mo period. Thus, there may be some advantage to adding aerobic exercise to a weight-reduction program, and this advantage may become more evident as weight loss continues over the long term. Finally, aerobic exercise also caused a greater reduction in the waist-to-hip ratio than either weight training or sedentary conditions. Lowering this ratio may decrease the risk for illnesses such as coronary artery disease, diabetes, and hypertension.

Our finding that exercise added to food restriction did not affect amount or composition of body weight loss is in agreement with results of several other studies (13–16). However, other investigators have reported that exercise can affect the amount or composition of weight lost during a program of food restriction. For example, in another study (9), we found that exercise when added to an 3348-kJ/d diet did not affect total weight loss but led to more loss of body fat and less loss of FFM. In a second study, exercise added to a 5023-kJ/d diet led to greater total weight and body fat loss and less loss of FFM as compared with sedentary subjects (30).

The reasons for the discrepant results regarding effects of exercise on amount and composition of weight loss are unclear. Results of a study by Ballor et al (31) in rats suggested the effects of exercise on preservation of FFM may be dependent on the degree of food restriction. Exercise preserved FFM when combined with moderate energy restriction but not when combined with severe food restriction. Although the question has not been systematically evaluated in humans, Phinney et al (16) reported no effects of exercise combined with very low-energy diet on FFM as compared with very low-energy diet alone. However, we found no indication in the present study that the degree of energy restriction influenced whether or not exercise was effective as a treatment for obesity.

In the present study, the decline in RMR was proportional to the decline in FFM, and was not affected by the degree of energy restriction or the exercise condition of the subject. The question of whether the decline in energy expenditure seen during food restriction is completely explained by the loss of FFM is controversial, with some finding such a result (32, 33) and others finding that RMR often declines to a greater extent than would be expected from the decline in FFM (34). SER did not result in a greater reduction in RMR (expressed per kg FFM) than did MER. Some have suggested that exercise could be effective in preventing the decline in RMR that accompanies food restriction (11, 12). However, we found no evidence of such an effect of exercise. This may also be related to the moderate nature of the exercise regimens.

The efficiency with which weight is lost could be an important determinant of long-term success in maintaining weight reduction. We believe our DEF can be a useful method of quantifying effectiveness of a weight-loss regimen. However, it must be emphasized that these are static measures of a dynamic process. The actual energy deficit will vary on a day-to-day basis as energy requirements change. Certainly, the importance of efficiency of the weight-loss intervention remains to be determined. The DEF provides a tool for a systematic assessment of the efficiency of weight loss by various therapeutic modalities. MER and aerobic exercise seem to be the methods of choice for weight reduction if one's goal is to produce the greatest loss for a specific energy deficit.

There are some limitations in the present study. Because the majority of the study was done on an outpatient basis, the problem of dietary noncompliance cannot be totally eliminated. We sought to minimize noncompliance through weekly weight monitoring, group meetings, and the use of detailed daily diet diaries. Also, this study is relatively short term. Finally, 30 subjects is a relatively small sample. Our failure to find significant effects of exercise and degree of restriction on body composition and RMR may be attributable to the limited number of subjects studied. Further investigations are needed to address the effects of long-term energy restriction, exercise, and weight maintenance on these parameters.

In summary, MER appears to be a more cost-effective method of treatment in obese subjects, causing a greater loss of body energy storage for a given energy deficit than SER. This is demonstrated by the fact that MER produced a consistently greater DEF throughout the study when compared with SER. MER also led to a smaller loss of FFM and more positive nitrogen balance than SER. Because FFM is more metabolically active than fat mass and, therefore, contributes more to overall energy requirements, this fact may be clinically significant. The difference in loss of total body weight between SER and MER, though statistically significant, is relatively small, ≈4 kg over the 6-mo period. More importantly, this difference declines as the duration of restriction continues beyond 3 mo. Therefore, these advantages, coupled with the fact that patients' long-term compliance with diet and their ability to maintain a balanced nutrient intake in a nonmedically supervised, outpatient setting may be easier with MER, leads us to conclude that MER may be a more ideal treatment than SER. Even though aerobic exercise or aerobic exercise plus CWT had no direct effect on the amount of weight loss, aerobic exercise produced a greater DEF, suggesting that it may prevent the body from adapting to the effects of energy restriction. Furthermore, aerobic exercise has many other proven benefits such as increased aerobic fitness, decreased resting and exercise blood pressure and heart rate, and improved sense of well-being. Neither the degree of energy restriction nor exercise condition had major influence on the composition of weight loss or the changes in RMR (per kg FFM). On the basis of these results, we conclude that MER combined with aerobic exercise may offer an advantage over SER because it produces a greater energy loss relative to energy deficit.

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