

Dieting is more effective in reducing weight but exercise is more effective in reducing fat during the early phase of a weight-reducing program in healthy humans

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Abstract

This study compared the relative effectiveness of two means of energy deficit, food restriction (FR) and increased physical activity (EX), on body weight, body composition and concentrations of serum leptin, insulin, glucose, and lipids in female subjects. Thirteen adult female volunteers participated in a two-phase crossover-treatment study. Each phase involved a 9-day energy deficit period and a 5-day follow up energy repletion period. A 25% energy deficit was achieved by either FR or EX. Baseline values were established prior to phase one. Results showed that FR had greater body weight loss, but less body fat loss compared to EX. FR and EX both reduced serum leptin, insulin, total triacylglycerol, LDL-C and VLDL-C concentrations. However, only EX elevated HDL-C. These effects were reversed during follow up energy repletion. Results suggest that under iso-caloric energy deficit conditions FR is more effective in reducing body weight but EX is more effective in reducing body fat and maintaining lean body mass. EX can lead to a more desirable blood lipid profile than can FR. Thus, it is desirable to include exercise in a weight reduction program. © 2003 Elsevier Inc. All rights reserved.

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1. Introduction

The prevalence of overweight (based on BMI >25.0) and obesity (BMI >30.0) in the US adult population has increased from 47% in 1976 to 56% in 1991 and to 61% in 1999. For the entire US population, the prevalence of overweight (BMI 25.0 to 29.9) increased from 32% in 1976 to 34% between 1976 and 1999. However, the prevalence of obesity increased from 15% to 27% in the same time span, indicating that the greatest increases are in severe overweight conditions [1,2]. A major factor contributing to this increase is physical inactivity [3]. Obesity is linked with an increase in a number of health risks including coronary heart disease, hypertension, diabetes, gall bladder disease and certain types of cancer. Weight reduction and weight maintenance have become increasingly important public health issues. Food restriction (dieting, FR) and increased physical activity (EX) are the two most recommended methods in weight reduction.

Energy deficit, as a result of dieting and/or exercise, when performed properly, not only can result in weight loss but also reduce the risk of heart disease by improving ones plasma lipid profile. Because of the variations in study conditions and research designs, effects of FR and EX on weight loss, body fatness and blood lipid profiles are rather variable. Some studies have suggested that FR is more effective than EX in reducing body weight while exercise is more effective than FR in reducing body fat, maintaining body protein, improving blood lipid profile, reducing abdominal fat and reducing insulin resistance [4–6].

The physiological regulation of body weight is very complex and not yet well understood. However, significant progress has been made in recent years. Leptin, a peptide hormone produced by the adipose tissue, has been suggested to play a role in regulating body fatness and body energy balance. The concentration of leptin in the circulation has been shown to be correlated with measures of adiposity including body mass index (BMI), adipose tissue mass, percentage of body fat, the sum of skin-fold thickness and serum insulin concentration [7,8]. Leptin is also known to play a role in regulating energy balance and food intake

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Table 1
Characteristics of subjects

Parameters	Mean \pm range ¹
Age (y)	29.08 \pm 9.63 (22–55)
Height (cm)	164.3 \pm 7.84 (153.5–177.7)
Body weight (kg)	61.3 \pm 20.3 (46.2–76.4)
BMI (kg/m ²)	22.5 \pm 5.8 (17.4–40.3)
Body fat ² (%)	27.8 \pm 9.6 (12.8–52.5)

¹ Mean \pm (range) for 13 female subjects at the beginning (baseline) of the study.

² Body fat (%) was calculated on basis of BIA values.

[9–12]. However, its influence on food intake behavior in humans is not yet well understood.

Energy repletion is a common phenomenon in weight reducing individuals. It generally occurs when one reaches his/her desired weight or when one encounters difficulty in continuing the energy-deficit program due to health conditions or otherwise. Energy repletion has been shown to quickly reverse the preceding energy-deficit effects. There is a rapid regain in body weight & body fat and tissue lipogenic activity is high during the early phase of energy repletion [13–17].

Although numerous studies have investigated the relative effects of dieting vs. exercise, there are many unanswered questions regarding the relative effects, health benefits and quality of weight loss during the weight reduction phase or during the follow up energy repletion period. We conducted a study to compare the effect and the quality of weight loss in a group of mainly female graduate students under closely monitored but free-living conditions.

2. Subjects and method

2.1. Subjects

Thirteen female subjects, 22 to 55 years old, with BMI ranging from 17.4 to 40.3, voluntarily participated in a weight-reduction study. Subjects were students and the instructor of a nutrition class. Before the study, they were pre-screened with a questionnaire to assess their general health conditions, current medication, and physical information. All were found to be in apparent good health. All subjects gave their informed consent. The study protocol was approved by the Institutional Review Board of the University of Michigan.

The physical characteristics of subjects are shown in Table 1. Among the thirteen subjects, one was obese (BMI 40.3, body fat 52.5%). All others had BMI ranging from 17.4 to 26.4 (body fat 12.8 to 37.3%) at the beginning of the study. Two were over 40 y of age. The age range of the remaining subjects was from 23 to 30 y.

2.2. Experimental design and procedure

The study was a crossover-treatment design. The treatments were iso-energy deficit created by either food restriction or increased physical activity. The study consisted of two phases. Each included a 9-day energy deficit period with a follow-up 5-day food-repletion period. There was also a 14-day washout period in-between the two phases. Prior to the initiation of the study there was a 4-day baseline period. During this period, each subject completed a four-day food intake and daily activity record for computing the baseline food intake and physical activity according to Food Processor (Version 7.0, ESHA Research, Salem, OR, USA). These baseline data were then used as the basis for computing the amount of foods allowed or extra physical activity to be performed to reach a 25% energy deficit during the treatment periods. The study was initiated by randomly assigning subjects to one of the two treatment groups of 6 and 7 each. During the 9-day trial period, each subject underwent a 25% energy deficit program according to the assigned treatment. Each subject followed a pre-planned diet or activity schedule during the period. Those who were assigned to dieting would each consume a diet that provided 75% of her average baseline energy intake and maintained a steady baseline level of physical activity. Those who were assigned to exercise would achieve the same level of energy deficit by performing extra daily physical activity while maintaining the baseline energy intake. Subjects could choose activities such as walking, jogging, swimming, and bicycling as their means of exercise on an individual but consistent basis. They were instructed to perform the same type of activity each day during the 9-day exercise period. Following the 9-day treatment period, there was a 5-day monitored energy repletion period. During this period subjects were asked to eat to satisfy their appetite and to maintain baseline physical activity. However, their food consumption and physical activity were recorded. There was a two-week washout period before the beginning of the second phase. The entire process was repeated in phase 2, but each subject's treatment was crossed. The 28-day study cycle was designed to minimize the possible influence of menstrual cycle on body water retention. The study was conducted under free-living conditions. Subjects had the liberty of attending classes or performing their daily routines but otherwise followed pre-planned schedules. All thirteen subjects completed the study under a uniform schedule.

2.3. Body weight and body composition measurements

Body weight of each subject was measured in the morning between 07:30 and 09:00 AM on days 1, 10 and 15 of each phase under overnight-fasting conditions. Subjects wore the same specific indoor exercise clothing for all weighing. Body weight measurements were done with a calibrated platform scale with digital displays (Health 0

Meter, Electronic Doctor's Scale). Following body weight measurement, each subject's body composition was assessed with a RJL body composition analyzer (Model RJL Quantum 101Q, RJL Systems, Clinton, MI) measuring the bioelectrical impedance. The BIA measurements were used to calculate body composition including body fat and body water content.

2.4. Blood sampling and laboratory analyses

Two tubes of blood samples were drawn on the morning of those days that subjects had their body weight and body composition measured. One tube (5 mL) contained anticoagulant, oxalate, and sodium fluoride to prevent glycolysis. The plasma separated from it was for blood glucose analysis. The other (10 mL) contained no anticoagulant and its serum was used for all other biochemical measurements. After sampling blood tubes were immersed in ice water for up to 60 min before being centrifuged at 1,500 rpm for 30 min. Serum and plasma were then transferred and partitioned into tubes and kept frozen until the completion of both study phases. Laboratory analysis were then performed. Serum leptin was measured by radioimmunoassay [18] with an assay kit obtained from Linco Research (St Charles, MO). According to the manufacturer, the antibody used in the assay did not cross-react with human insulin, proinsulin, glucagon, pancreatic polypeptide or somatostatin. The range of the standards in the assay was 0.5 to 100 η g/mL and the intra-assay and inter-assay CVs were <5%. Serum insulin concentration was measured by standard procedure at the Diabetes Research and Teaching Center of the University of Michigan [19,20]. Plasma glucose was measured enzymatically [21] with commercial kits (#352 purchased from Sigma Biochemicals, St Louis, MO). Concentrations of serum total triacylglycerol, total cholesterol and HDL-Cholesterol were measured enzymatically [22–24] (using kit #352 for cholesterol, & kit #337 for triacylglycerol, Sigma Diagnostics). HDL-C was assayed after phosphotungstate-MgCl₂ precipitation (kit #352 to 4, Sigma Diagnostics). Concentrations of serum LDL-C were calculated using the formula (LDL-C = Total Cholesterol- HDL Cholesterol- Triacylglycerol/5) validated by Friedewald et al. [25]. The concentration of VLDL-C was calculated by subtracting the concentration of HDL-C and LDL-C from total C.

2.4. Statistical analysis

Data are expressed as means \pm standard deviation. Statistical analyses were performed using the Statistical Analysis System (SAS) [26]. Student's paired *t*-test was applied to determine the significance of the changes within treatment and the significance of the changes between treatments. Pearson's correlation analysis was applied to determine the significance of correlation between two variables.

A probability level of 0.05 was designated as the level of statistical significance.

3. Results

3.1. Effect on body weight and body fat

The characteristics of subjects at the baseline are summarized in Table 1. Changes in body weight, BMI, body fat, body water, and circulating leptin, insulin, glucose, total cholesterol, LDL-C, VLDL-C, HDL-C, and total TAG concentrations as a result of FR or EX are summarized in Table 2. Daily 25% FR for 9 days decreased body weight by 1.75 kg/subject ($P < 0.001$) and BMI by 0.63 ($P < 0.001$) while the same level of energy deficit by EX reduced body weight by 0.85 kg/subject ($P < 0.001$) and BMI by 0.25 ($P < 0.001$) (Fig. 1). FR resulted in significantly ($P < 0.01$) greater reductions in body weight and BMI than did EX. Conversely, a 5-day energy repletion resulted in greater gains in body weight (0.44 vs. 0.15 kg) and BMI (0.18 vs. 0.0) following food restriction than following exercise (Fig. 1). Both means of energy deficit significantly reduced body fat. Food repletion significantly increased body fat following discontinuation of EX (+ 0.89%) but not following FR (–0.01%). FR significantly ($P < 0.05$) increased % body water, while EX did not. Energy repletion following dieting did not change % body water, but it reduced % body water (0.65%) following exercise ($P < 0.05$).

3.2. Effect on serum leptin, insulin and glucose

Blood leptin concentration was reduced by 27.02% ($P < 0.01$) and 32.27% ($P < 0.01$) after 9 days of food restriction or increased physical activity, respectively. These reductions were not significantly different from each other ($P > 0.05$). A 5-day energy repletion increased the serum leptin concentration by 44.51% after FR ($P < 0.01$) and 45.59% after EX ($P < 0.01$) from the day-10 values. Blood insulin concentration was reduced by 4.49 μ U/mL (or –36%, $P < 0.05$) by FR, and by 3.91 μ U/mL (or –31.3%, $P = 0.07$) by EX (Fig. 2). These reductions were not significantly different from each other. Energy repletion reversed these changes. Energy repletion increased serum insulin concentration by 3.34 μ U/mL (or +42%, $P < 0.01$) following FR and 1.82 μ U/mL (or +21.2%, $P < 0.05$) following EX (Fig. 2). These two increases were significantly different from each other. Plasma glucose concentration was not significantly influenced by either food restriction or exercise. However, discontinuation of dieting and exercise both resulted in small but statistically significant ($P < 0.05$) increases in circulating glucose concentrations.

3.3. Effect on blood lipids

Both forms of energy deficit, FR and EX, significantly reduced serum total TAG concentrations (–21.8 and

Table 2

Baseline values and changes in body weight, BMI, body fat, body water, and concentrations of serum leptin, insulin, plasma glucose, plasma total TAG, LDL-C, VLDL-C, HDL-C, and total cholesterol in healthy subjects after a 10-day 25% caloric deficit and a 5-day follow-up caloric repletion^{1,2}

	Food restriction					Exercise				
	Food restriction		Repletion	Changes		Exercise		Repletion	Changes	
	Day 0	Day 10	Day 15	Day 10-day 0	Day 15-day 10	Day 0	Day 10	Day 15	Day 10-day 0	Day 15-day 10
Body Wt. (kg)	61.22 ± 20.32	59.48 ± 19.33 ^{cd}	59.92 ± 19.09 ^a	-1.75 ± 1.45	+0.44 ± 0.63	60.57 ± 18.73	59.72 ± 18.42 ^c	59.88 ± 18.17	-0.85 ± 0.70 ^e	+0.15 ± 0.76 ^d
Percent change ³ (%)				-2.76 ± 1.74	-4.35 ± 3.05				-1.40 ± 1.07	+0.33 ± 1.30
BMI (kg BW/m ² Ht)	22.45 ± 5.84	21.82 ± 5.55 ^c	22.0 ± 5.45 ^b	-0.63 ± 0.50	+0.18 ± 0.21	22.22 ± 5.30	21.97 ± 5.22 ^c	21.97 ± 5.12	-0.25 ± 0.23 ^e	+0.00 ± 0.19 ^e
Body fat (%)	27.63 ± 9.97	26.58 ± 10.12 ^c	26.58 ± 9.81	-1.05 ± 0.73	-0.01 ± 1.23	27.13 ± 9.34	25.93 ± 9.03 ^c	26.82 ± 9.42 ^a	-1.2 ± 0.70	+0.89 ± 1.37
Percent change (%)				-4.35 ± 3.05	+0.49 ± 4.84				-4.26 ± 2.95	+2.91 ± 7.61
Body water (%)	54.15 ± 6.07	54.83 ± 6.06 ^a	54.97 ± 6.03	+0.68 ± 0.93	+0.14 ± 1.05	55.2 ± 6.63	55.48 ± 5.38	54.82 ± 5.79 ^a	+0.27 ± 2.00	-0.65 ± 1.0 ^d
Leptin (ng/ml)	13.47 ± 8.54	9.26 ± 5.89 ^b	12.19 ± 6.19 ^b	-4.21 ± 4.88	+2.93 ± 2.70	13.13 ± 8.00	8.34 ± 5.48 ^b	10.73 ± 5.00 ^b	-4.79 ± 4.43	+2.40 ± 2.78
Percent change (%)				-27.02 ± 29.93	+44.51 ± 32.04				-32.27 ± 25.07	+45.59 ± 52.29
Insulin (μU/ml)	12.45 ± 10.54	7.95 ± 4.01 ^a	11.29 ± 6.29 ^b	-4.49 ± 7.62	+3.34 ± 3.11	12.48 ± 12.40	8.58 ± 4.52	10.4 ± 4.92 ^a	-3.91 ± 9.08	+1.82 ± 2.66 ^d
Glucose (mmol/L)	4.30 ± 0.31	4.30 ± 0.27	4.48 ± 0.34 ^a	+0.01 ± 0.32	+0.17 ± 0.24	4.30 ± 0.48	4.28 ± 0.41	4.44 ± 0.36 ^a	-0.02 ± 0.45	+0.16 ± 0.31
Total TAG (mmol/L)	0.87 ± 0.42	0.68 ± 0.25 ^a	1.03 ± 0.40 ^c	-0.19 ± 0.34	+0.35 ± 0.25	0.94 ± 0.37	0.77 ± 0.30 ^b	0.95 ± 0.28 ^b	-0.17 ± 0.22	+0.18 ± 0.20 ^d
Tot Chol (mmol/L)	4.84 ± 0.49	4.39 ± 0.59 ^b	4.43 ± 0.62	-0.45 ± 0.53	+0.04 ± 0.52	4.58 ± 0.62	4.32 ± 0.68 ^a	4.52 ± 0.66 ^b	-0.26 ± 0.51	+0.20 ± 0.24
LDL-C (mmol/L)	2.93 ± 0.47	2.55 ± 0.44 ^b	2.52 ± 0.54	-0.39 ± 0.39	-0.02 ± 0.37	2.72 ± 0.58	2.50 ± 0.52 ^a	2.62 ± 0.50 ^a	-0.23 ± 0.39	+0.12 ± 0.24
VLDL-C (mmol/L)	0.40 ± 0.19	0.31 ± 0.11 ^a	0.47 ± 0.18 ^c	-0.09 ± 0.15	+0.16 ± 0.12	0.43 ± 0.17	0.35 ± 0.14 ^b	0.43 ± 0.12 ^b	-0.08 ± 0.10	+0.08 ± 0.09 ^d
HDL-C (mmol/L)	1.50 ± 0.35	1.42 ± 0.36 ^a	1.43 ± 0.35	-0.08 ± 0.15	+0.01 ± 0.16	1.42 ± 0.33	1.53 ± 0.49	1.47 ± 0.42	+0.10 ± 0.26 ^d	-0.06 ± 0.25

Footnote:

¹ Caloric deficit was created by food restriction or by performing extra physical activities during the 9-day study period, respectively. All subjects returned to ad libitum food intake and routine activity conditions during the repletion period (day 10-14).

² All values are mean ± 1 SD for 13 subjects

³ Percent change at the end of the caloric deficit period (day 10) from the baseline (day 0) or end of the repletion period (day 15) from the day 10, respectively.

⁴ a,b,c designating significant changes of the day-10 values from the baseline values or the day-15 values from the day-10 values at P < 0.05, P < 0.01 and P < 0.001, respectively; d,e designating significant differences between the changes resulted from the two treatments, FR and EX, at P < 0.05 and P < 0.01, respectively.

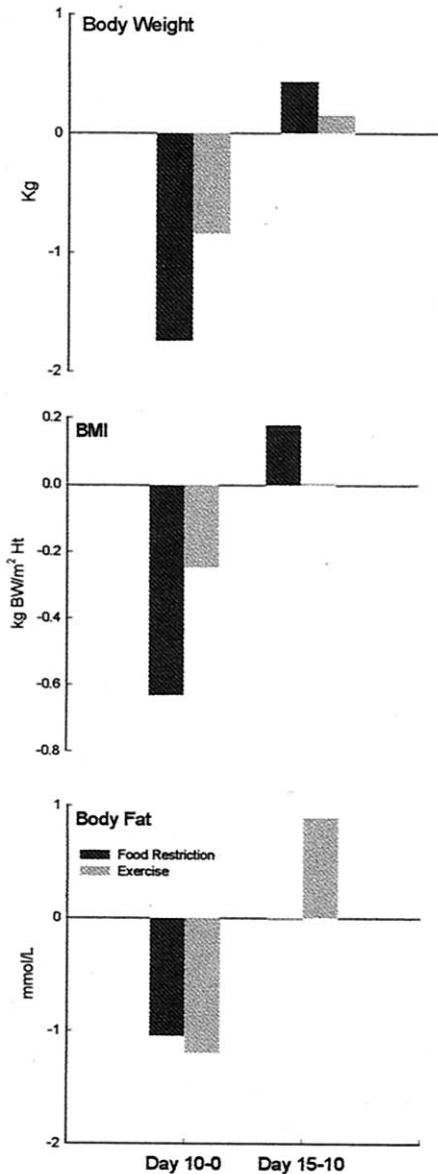


Fig. 1. The changes in body weight, BMI, and body fat after a 10-day 25% dieting or exercise-induced energy deficit and a 5-day follow-up energy repletion in health subjects.

–18.1%, respectively). Energy repletion reversed these decreases and the effect was significantly greater following FR (+51.5%) than following EX (+23.4%). Both forms of energy deficit significantly reduced serum total cholesterol concentrations (–9.3% for FR vs. –5.7% EX) (Fig. 3). These two values were not significantly different from each other. Discontinuation of exercise reversed the effect (+4.4%, $P < 0.01$) but energy repletion following discontinuation of dieting had no effect (+0.9%). The effect of dieting and exercise on LDL-C was similar to that of total serum cholesterol (–13.3% for FR vs. –8.5% for EX). Both forms of energy deficit reduced serum VLDL-C concentrations. Again, these effects were reversed by food

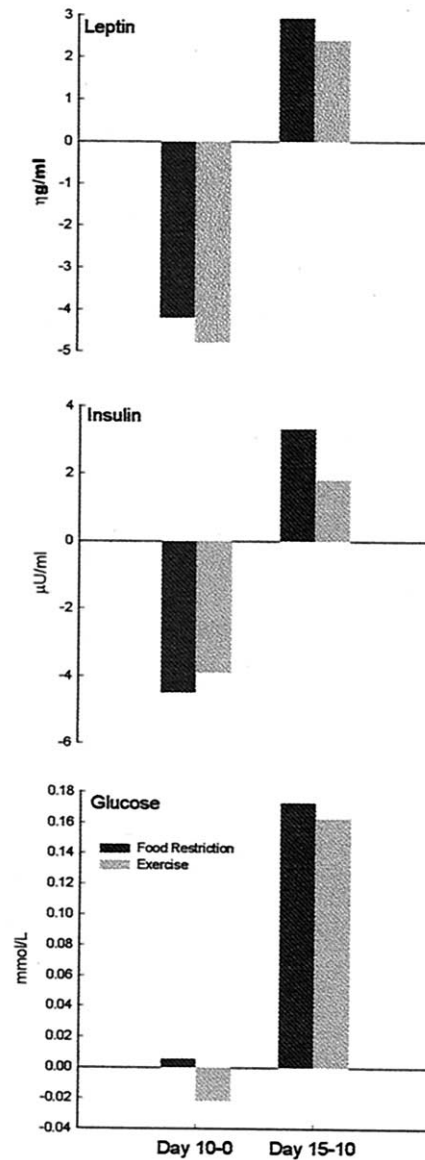


Fig. 2. The changes in serum concentrations of leptin, insulin, and glucose after a 10-day 25% dieting- or exercise-induced energy-deficit and a 5-day follow-up energy repletion in health subjects.

repletion. The reversal effect was significantly greater following discontinuation of FR than following EX. Serum HDL-C concentration was reduced by FR (–5.3%, $P < 0.05$), but was increased by EX (+7.0%, $P < 0.05$) (Fig. 3). A 5-day energy repletion did not significantly reverse these effects.

3.4. Correlation of body weight with other parameters

The correlational relationships of body weight and other parameters under baseline conditions are shown in Table 3. There were significant correlations between body weight and BMI, % body fat, % body water, and

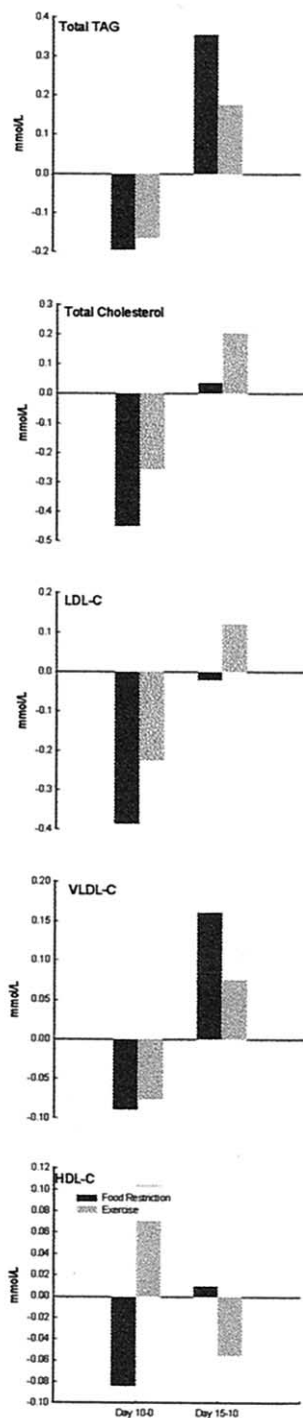


Fig. 3. The changes in serum total triacylglycerol, total cholesterol, HDL-LDL-, and VLDL-cholesterol after a 10-day 25% dieting or exercise-induced energy deficit and a 5-day follow-up energy repletion in health subjects.

concentrations of circulating leptin and insulin. Blood glucose level was correlated with circulating insulin concentration ($r = 0.638$) but not with other parameters measured. The concentration of TAG was not correlated with any other parameters.

4. Discussion

4.1. Effect on body weight, body fat and BMI

The study compared the effect of two means of energy deficit, i.e., food restriction (reducing energy intake while maintaining the baseline level of physical activity) and exercise (increasing energy expenditure while maintaining the baseline level of energy intake), on body weight, body fat mass, BMI, and circulating leptin, insulin, glucose and lipids concentrations in healthy human subjects under free-living conditions. Subjects were the instructor and students of a nutrition assessment class. All subjects fully understood the objectives and procedures of the study and were enthusiastic about accomplishing the objectives of the study. To the best of our knowledge, all subjects tried their best to adhere to the study protocol. They consumed the pre-calculated amounts of foods and performed the predetermined duration and level of physical activities each day during the study periods. The study was a crossover-treatment design in which every subject served as her own control. Results of this study showed that during a 9-day period a 25% daily energy deficit by FR was twice as effective ($P < 0.01$) in reducing body weight as the same level of caloric deficit by elevated physical activities. However, it should be noted that although weight loss by food restriction doubled that of exercise, subjects lost a greater proportion of body fat by exercise than by food restriction. As a result, subjects lost less non-fat body mass by exercise than by food restriction. These results suggest that energy deficit by increased exercise can better preserve fat-free (lean) body mass than can energy deficit by dieting. These results support the study of Stefanick et al. [4] who observed significant weight loss by dieting, but not by exercise. Ross et al. [6], observed weight loss induced by increased daily physical activity, without caloric restriction, substantially reduced obesity. They observed that although total fat decreased in both weight loss groups (exercise vs. diet), the average reduction was greater in the exercise-induced weight loss group than in the diet-induced weight loss group. Our observation also supports the finding of some earlier studies that exercise training can moderately decrease body fat and preserve or increase body fat-free mass [27–30]. The present study affirmed earlier findings [28–30] that relative to FR, exercise-induced energy deficit can better preserve body non-fat mass, presumably by better preserving tissue glycogen and proteins.

Results of this study also showed that energy repletion following FR or EX led to different responses in weight and body fat gains. Energy repletion (ad libitum feeding for a period of 5 days) following FR led to a rapid regain ($P < 0.05$) in body weight (+ 0.44 kg) with nearly no gain in body fat (−0.01%). On the other hand, the same repletion process following the termination of exercise led to a rapid gain ($P < 0.05$) in % body fat (+ 0.89%) with nearly no gain in body weight (+ 0.15 kg). Thus, there were significant differences in the quality of body mass gain by energy

Table 3

Pearson's correlation (r) among serum body weight, BMI, body fat, body water, leptin, serum insulin, plasma glucose and TAG at baseline (N = 13)

	Body wt.	BMI	%Body Fat	%Body water	Leptin	Insulin	Glucose	TAG
BMI	0.966* ¹	1						
%Body fat	0.858*	0.942*	1					
%Body water	-0.723*	-0.852*	-0.966*	1				
Leptin	0.629*	0.706*	0.783*	-0.763*	1			
Insulin	0.916*	0.920*	0.828*	-0.727*	0.716*	1		
Glucose	0.450	0.411	0.287	-0.229	0.368	0.638*	1	
TAG	0.415	0.433	0.315	-0.215	0.229	0.383	0.233	1

¹ Significant correlation at $P < 0.05$.

repletion following each of the two means of energy deficit. It is clear that different forms of energy deficit deplete different forms of stored nutrient in the body; energy repletion reversed these effects.

In humans and in experimental animals, food restriction or increased physical activities are known to result in weight loss. Conversely, energy repletion by refeeding or discontinuation of exercise has been observed to result in rapid regain of body weight and body fat. In humans, there is a well-known “yo-yo” phenomenon of weight reduction and regain. Tsai et al. [14,15] showed that discontinuation of exercise led to a fast gain of body fat and body weight. Similar effects were observed in experimental animals such as rats and hamsters [31]. In hamsters, there was a rapid regain of weight and fat during refeeding following food restriction or exercise [32].

Results of the present study indicate that under the conditions of this experiment, food restriction is more effective in reducing body weight, but relatively less effective in reducing body fat compared to a similar level of energy deficit created by increasing physical activity. The differences in the effect might be related to the fact that physical exercise stimulates the release of epinephrine while fasting or food restriction stimulates mainly the release of glucagon and glucocorticoids. Epinephrine is a potent lipolytic hormone that stimulates hormone-sensitive lipase, an enzyme catalyzing the release of free fatty acids from triacylglycerol in adipose tissue. On the other hand, glucagon is glycogenolytic in the liver, and glucocorticoids are catabolic in peripheral tissues enhancing tissue protein degradation. Thus, energy deficit by food restriction favors energy mobilization from the non-fat body mass while exercise favors the release of stored body fat. Due to the differences in energy density of the type of nutrients stored in tissues, a change in body glycogen and protein will result in a much greater change in body weight relative to an isocaloric change of body fat.

4.2. Effect on serum leptin, insulin and glucose

Both forms of energy deficit resulted in similar degrees of decrease in serum leptin concentrations. It should be

noted that a relatively small reduction in body weight (2.76% by dieting and 1.40% by exercise) or body fat (4.35% by dieting and 4.26% by exercise) can lead to a rather drastic decreases (27.02% and 32.27%, respectively) in circulating leptin concentrations. Circulating leptin is known to reflect body fatness [7,8,33,34]. Recent studies have shown that short-term changes in dietary intake such as increased caloric intake or fasting can affect leptin secretion. In humans, fasting for longer than 12 h is associated with a decline in circulating leptin and the leptin returns rapidly to baseline values during refeeding with an isocaloric balanced diet [35]. Qian et al. [36] and Friedman and Halaas [37] have illustrated that body weight is associated with leptin secretion and the regulation of leptin expression in adipose tissue. Recently, it has been suggested that it may also reflect the status of energy balance [35,38]. Results of this study seem to support these suggestions. Energy deficit, created by either FR or increased EX, reduced circulating leptin (10–13,35). On the other hand, energy repletion, created by either discontinuation of FR or reducing EX activity, resulted in significant increases in circulating leptin levels, even in the absence of significant body fat changes. These observations suggest that blood leptin concentration may reflect energy balance on a short-term basis and body fatness on a long-term basis. Caloric restriction also resulted in a significant decrease in serum insulin levels. However, energy deficit by exercise appeared to have a lesser effect ($P = 0.07$). Energy repletion reversed these effects

4.3. Effect on serum lipids

In general, both forms of energy deficit, FR and EX, have similar effects in reducing serum total cholesterol, LDL-C, VLDL-C, and total TAG concentrations. Energy repletion reversed these changes. Our results also confirmed the observation that exercise can elevate HDL-C concentrations ($P = 0.08$). Isocaloric energy deficit by means of FR decreased the HDL-C concentrations ($P = 0.05$). Energy repletion for a period for 5 days did not significantly change these effects, suggesting that the reversal effect on HDL-C changes occurs much more slowly than did the reversal effects on VLDL-C or LDL-C levels. Thus, exercise but not

food restriction can lead to a relatively long-term beneficial effect on HDL-C. These findings are in agreement with published studies [39] that weight reduction accomplished by increased aerobic exercise usually results in decreases in total cholesterol, plasma TAG and LDL cholesterol and an increase in HDL cholesterol. Similar findings were also observed by Lewis et al. [28] who studied the effects of physical activity in obese middle-aged women. It was observed that HDL-C concentrations were elevated and LDL-C concentrations were decreased, thus leading to an increased HDL-C/LDL-C ratio.

4.4. Correlation of body weight with other parameters

In this study we also observed that under the baseline conditions there were significant correlations among body weight, % body fat, and concentrations of circulating leptin and insulin (Table 3). These findings are consistent with previous observations that body fatness is positively correlated with circulating leptin and insulin concentrations [7,33]. Ostlund et al. [34] showed that plasma leptin concentration was highly correlated with percent body fat and was 3 times higher in women than in men. Thus, Ostlund et al. [34] concluded that circulating leptin rises continuously with increasing adiposity and that gender, age, and short-term caloric restriction may be important as secondary regulators of plasma leptin. It was also observed that blood glucose level was correlated with circulating insulin concentration but not with other parameters measured.

Taken together, under the conditions of this study, our results suggest that even though increased physical activity may not lower weight as quickly as food restriction during the early phase of a weight-reduction program, it does lead to a better quality of weight loss. Physical activity results in a greater loss in fat and conserves more non-fat tissues (body proteins). Exercise also elevates HDL-cholesterol concentrations, an effect not seen under the condition of food restriction.

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