Exercise and the metabolic syndrome with weight regain

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AMERICANS are experiencing an obesity epidemic, with US adults and children gaining weight at unprecedented rates, and the increased prevalence of lifestyle-related diseases such as Type 2 diabetes and cardiovascular disease (CVD) is accompanying this weight trend (9). Although obesity itself is a risk factor for chronic diseases, most of the increased risk of disease may be associated with the clustering of risk factors termed the metabolic syndrome (MetS). Epidemiological studies suggest increased prevalence of morbidity and mortality in individuals with the MetS (17), and estimates of the national medical expenditures attributed to the MetS have surpassed $80 million (28).

Weight loss, whether by energy restriction, increased energy expenditure, or a combination of the two strategies, is an effective way of improving metabolic health, as indicated by beneficial changes in insulin sensitivity (15), abdominal adiposity (11, 15), blood lipid profile (35), markers of inflammation (7), and blood pressure (5). The benefits of weight loss are clear in the scientific literature; what is less clear is the impact of exercise during cycles of weight loss and regain, which are common in overweight individuals (21). Recent data suggest that weight often is regained in a short period of time (14, 26, 31, 32), and even chronic exercisers may gain weight over time (34).

Results from numerous studies indicated that weight loss is not necessary to achieve the beneficial effects of exercise training on chronic disease risk parameters of insulin sensitivity (3), abdominal obesity (29), lipoprotein profile (27), C-reactive protein (CRP) (20), and blood pressure (5). Given that exercise is effective with or without weight loss, it follows that exercise may be beneficial even during periods of weight regain. In support of this concept, epidemiological studies suggest that fitness dramatically reduces the risk of death in overweight men (2, 22), and physical activity reduces the risk of adverse events in overweight women with coronary heart disease (CHD) (33). Collectively, these results suggest that exercise training may improve risk status regardless of weight.

Improved health profile in the face of weight gain has important implications to national health policies. In high-risk adults, the retention of beneficial metabolic effects may play an important role in preventing disease symptoms and events. Using a novel model of controlled weight regain in humans, the purpose of this study was to determine if aerobic exercise training effectively maintains improvements to MetS variables during partial weight regain. We hypothesized that exercise training would prevent deterioration of metabolic parameters during controlled weight regain.

METHODS

Study Participants

The primary criteria for participation were overweight to Class II obese (body mass index [BMI] 25–39.9 kg/m²) and sedentary, i.e., no more than one systematic exercise session over 30-min duration per week over the previous 4 mo. Subjects were weight stable for the previous 3 mo, as determined by questionnaire. All subjects had at least two characteristics and 60% had three to five characteristics of the MetS as defined by the third report of the National Cholesterol Education Program (8). Subject characteristics and incidence for individual MetS variables are presented in Table 1. There were no significant differences between groups on any baseline characteristic.
Table 1. Subject characteristics and incidence of metabolic syndrome

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>NoEX</th>
<th>EX</th>
<th>PWR</th>
<th>NoEX</th>
<th>EX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>40 ± 1</td>
<td>46 ± 1</td>
<td>49 ± 1</td>
<td>53 ± 1</td>
<td>45 ± 1</td>
<td>48 ± 1</td>
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<tr>
<td>Weight, kg</td>
<td>96.15 ± 1.91</td>
<td>96.15 ± 1.91</td>
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<tr>
<td>BMI, kg/m²</td>
<td>32.8 ± 0.5</td>
<td>32.8 ± 0.5</td>
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<tr>
<td>Body fat, %</td>
<td>34.8 ± 0.8</td>
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<tr>
<td>Waist-to-hip ratio</td>
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<td>0.94 ± 0.01</td>
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<tr>
<td>VO₂max, l/min</td>
<td>2.64 ± 0.09</td>
<td>2.64 ± 0.09</td>
<td>2.64 ± 0.09</td>
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<tr>
<td>VO₂max, ml·kg⁻¹·min⁻¹</td>
<td>27.5 ± 0.6</td>
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<tr>
<td>Resting HR, beats/min</td>
<td>75 ± 1</td>
<td>75 ± 1</td>
<td>75 ± 1</td>
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</tbody>
</table>

Values are means ± SE. BMI, body mass index; PWR, post-weight regain; EX, exercise training; NoEX, no exercise training; VO₂max, maximal oxygen consumption; HR, heart rate. *Percentage of subjects within group. aWaist circumference: men, >102 cm, women, >88 cm. bBlood pressure (BP) > 130/85 mmHg. cFasting blood glucose 100-125 mg/dl. dFasting triglycerides (TG) >150 mg/dl. eHigh-density lipoprotein-cholesterol (HDL-C): men, <40 mg/dl, women, <50 mg/dl.

Exclusion criteria included diagnosed cardiovascular disease or diabetes or disease symptom according to the American College of Sports Medicine (1), smoking, menopause, or medications or supplements (e.g., fbrates, statins, metformin, thiazolidinediones, antihypertensives, fish oil) that could affect weight loss or variables of the MetS. One-hundred two subjects (37 men, 65 women) started the study, and 67 subjects (27 men and 40 women) completed both phases. All participants provided written informed consent as approved by the Health Sciences Institutional Review Board at the University of Missouri. The study was registered in ClinicalTrials.gov [identifier: NCT00543985 (http://www.clinicaltrials.gov/ct2/show/NCT00543985?term=metabolic+syndrome&state1=NA%3AUS%3AMO&rank=6)].

Interventions

Weight loss treatment protocols. All subjects were assigned individual exercise and diet programs designed to induce a loss of 10% body weight titrated over a 4- to 6-mo period (Fig. 1), which for most participants was a rate of loss of 0.2–0.4 kg/wk. The average daily energy deficit required for an individual to achieve this amount of weight loss over the 6-mo period was estimated from the initial body weight and an energy deficit of 7,700 kcal for 1 kg of weight loss. A combination of increased energy expenditure and decreased energy intake was used to achieve the target daily energy deficit.

The exercise program for weight loss consisted of supervised walking or jogging exercise in a fitness center within the Exercise Physiology Lab complex at the University of Missouri. To prevent lower extremity injury or discomfort in this previously sedentary population, a ramping protocol was used to attain the desired level of training. Week 1 consisted of treadmill exercise at ~50% of aerobic capacity (VO₂max) or 75% of maximal heart rate (HRmax) for 20 min/day, 5 days/wk. Weeks 2 and 3 consisted of treadmill exercise at ~50% of VO₂max for 30 and 45 min/day, respectively, 5 days/wk. By week 4, subjects were training at the desired intensity of 60% of VO₂max for 45 min/day, 5 days/wk (~200–2,500 kcal/wk), where they remained for the duration of the study. The exercise intensity was monitored daily by the personal trainer assigned to the subject. In addition, stationary cycling and elliptical exercise were used for recovery/rehabilitation when muscle or joint injuries occurred. This quantity of exercise paralleled that recommended by the Institute of Medicine (4). The weight loss was monitored one to two times weekly, and adjustments to the exercise and diet prescription were made as necessary. The average kilocalorie deficit targets were ~450 kcal/day for exercise (measured VO₂) and 600 kcal/day for diet.

At the beginning of the study, a nutritionist met with the subjects to discuss overall dietary health (e.g., food pyramid, importance of fruits and vegetables, dairy, etc.), present simple strategies to reduce energy intake, and teach subjects how to read and interpret food labels. The nutritionist met with each subject to evaluate habitual diet and develop an individualized plan to reduce energy intake. Subjects kept a daily food intake record throughout the study, and a study nutritionist utilized the records each week to provide each participant with specific suggestions on how to modify the diet to achieve the prescribed energy deficit. Total energy and macronutrient composition of the diet were estimated at baseline, post-weight loss (PWL), and post-weight regain (PWR) from the written daily food records using the Food Processor software, version SQL (ESHA, Salem, OR).

Weight regain treatment protocols. The second phase of the study was 4- to 6-mo duration and was the primary focus of the research. After completing the weight loss phase of the study, subjects were randomly assigned to two groups: partial weight regain with partial weight regain with exercise...
training (EX) (Fig. 1). For randomization, subjects were divided into pairs based on sex and the time scheduled to finish the weight loss phase. The first participant in the pair to complete the weight loss phase was assigned to the EX or NoEX group based on a coin flip, and the second participant of that pair was then assigned to the other group.

Subjects who were randomized to the NoEX group discontinued exercise training and were provided an energy intake prescription designed to cause regain of 50% of the lost body weight over 4–6 mo, with focus on the addition of healthy dietary energy. In addition, each subject in the NoEX group was required to report to the lab a minimum of 1–2 days/wk for weigh-in, diet diary analysis, and counseling. Utilizing the daily food records, modifications to the diet prescriptions were made as needed.

Subjects in the EX group continued to exercise at 60% \( V_{O2\text{max}} \), reassessed by a second maximal stress test for 5 days/wk as in the weight loss phase. During the regain phase, at least three exercise sessions per week were performed under supervision in the fitness center. The 1–2 days/wk unsupervised sessions were monitored using pedometers, heart rate (HR) monitors, and activity logs. Others have shown that unsupervised exercise sessions can be monitored accurately using pedometers or accelerometers (13, 30).

Thus, in the EX group, the target positive energy balance was achieved only by increasing energy intake. The dietary energy intake was increased from the weight loss phase based on the new body weight and the exercise kilocalorie deficit. The dietary intake was adjusted weekly by the study nutritionist or assistant as necessary with the goal to regain steadily over the 4- to 6-mo period. Healthy snacks (e.g., protein bars, dried fruits, and nuts) were provided during the regain period to help participants meet energy intake goals.

Outcome variables. Measurements on outcome variables were performed at baseline, PWL, and PWR. For a given subject, a single technician made all measurements at the three time points. Weight was measured using a Toledo scale sensitive to 100 g and height measured using a wall tape calibrated to 0.1 cm. Waist circumference was measured to the nearest 0.1 cm with a spring-loaded metal tape. Body composition was estimated using QDR-4500A dual X-ray absorptiometry (Hologic, Shelby Township, MI).

After the subject sat quietly in a padded chair for 15 min, systolic (SBP) and diastolic blood pressures (DBP) were measured using a standard aneroid sphygmomanometer. Each subject underwent a cardiologist-supervised treadmill stress test to volitional exhaustion using the Bruce protocol to assess \( V_{O2\text{max}} \) using a True One 2400 (Parvo, Sandy, UT) metabolic cart.

Computed tomography (CT) on a Siemens Somatom Sensation 4 (Forchheim, Germany) was used for determination of cross-sectional abdominal adipose tissue at the level of the L4–L5 vertebral disc space as described by Kelley et al. (12, 16). Using a blinded, single technician strategy, total abdominal adipose tissue (TAT) was divided into visceral (VAT) and total subcutaneous (TSAT) by manual tracing along the borders of the abdominal wall musculature. TSAT was further subdivided into superficial (SSAT) and deep (DSAT) compartments by a manual tracing along the subcutaneous fascia.

To standardize food intake before each testing session for measuring blood parameters, each subject used a self-selected 48-h diet with 12-h fast before baseline blood collection and then repeated this “personalized” 48 h diet before each blood sampling day. An attempt was made to have all subjects’ weight stable for 2 wk before and during the posttesting periods.

Following a 48-h dietary control with 12-h fast, blood samples were collected, separated in a refrigerated centrifuge for plasma and serum, and stored at −80°C until analyzed. All samples (baseline, PWL, PWR) from a given subject were analyzed in a single run. We previously observed that plasma volume corrections were not necessary due to the similar timing in association with exercise (48 h post-training session) for each testing time period (unpublished data).

A given female subject had blood collected at the same phase of the menstrual cycle (follicular or luteal) during each testing period.

Glucose, triglyceride (TG), and cholesterol concentrations were measured with colorimetric kits (Thermo, Atlanta, TX). Plasma high-density lipoprotein (HDL)-cholesterol (C) and subfractions, less dense HDL\(_2\) and denser HDL\(_3\), were determined using a modified heparin-MnCl\(_2\)-dextran sulfate method (6), and low-density lipoprotein (LDL)-C was calculated according to the Friedewald equation (10). Insulin and C-reactive protein (CRP) were measured with an immunoassay system (Immulette 1000, Siemens, New York). Oxidized LDL (oxLDL) concentration was analyzed with a commercially available enzyme-linked immunosorbent assay (ELISA) (Merckodia, Uppsala, Sweden). TNF-α and its soluble receptor two (TNFRII) were assessed using ELISA kits (R&D Systems, Minneapolis, MN).

Exercise and weight regain (Fig. 2). The 1–2 days/wk unsupervised sessions were monitored using pedometers, heart rate (HR) monitors, and activity logs. Others have shown that unsupervised exercise sessions can be monitored accurately using pedometers or accelerometers (13, 30).

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A priori power analyses were conducted to calculate the samples sizes needed to detect the effect sizes of interventions at PWL vs. PWR. All participants were treated as one group in the weight loss phase and treated as two groups in the weight regain phase (Fig. 1). We calculated that an n of 34 participants per group would detect a medium effect of \( d = 0.50 \) at power = 0.80, \( \alpha = 0.05 \).

Values are presented as means and SE, and \( \alpha \) level was set at 0.05 for all comparisons. To verify changes in the metabolic parameters with weight loss, data from the phase 1 weight loss, the single group was analyzed using a one-factor (time) ANOVA with repeated measures (baseline vs. PWL) (Fig. 1). For phase 2 weight regain, data were analyzed using a group (NoEX and EX) by time (baseline, PWL, and PWR) ANOVA with repeated measures on time. Bonferroni adjustment was applied when there were multiple comparisons for a variable.

RESULTS

Of the 102 subjects who began the study, 67 subjects, ages 21–52 yr, completed both phases of the study and were included in the statistical analysis and are characterized in Table 1. The dropout rate at the end of weight loss was 27% and after both phases was 31%. Subjects completed 96% of all assigned exercise sessions during both phases (%compliance = no. of sessions attended/total no. of sessions required \( \times 100\)). The average exercise performance during the study was 4.8 sessions/wk and 2,000 kcal/wk. The incidence of MetS characteristics at baseline and PWR is listed in Table 1.

Dietary analysis of each time point is summarized in Table 2. Although groups were not formed at baseline, the group means are presented to assess retrospectively changes between baseline and PWR. Dietary intake of each macronutrient was reduced during the weight loss phase and then tended to go back toward baseline values during the regain period. Carbohydrate and calcium in the EX group and energy, carbohydrate, and fiber in the NoEX group were significantly different between baseline and PWR.

As prescribed, subjects lost 9.7% of body weight during the weight loss phase and regained back 54.4% of the lost weight in the regain phase (Fig. 2). BMI paralleled body weight changes (Fig. 2) as did percent fat, in which the total group exhibited a significant loss of 3% fat during weight loss and each group a significant increase of 1.3% fat during regain. \( V_{O2\text{max}} \) was significantly increased by 11% during the weight loss phase and then was maintained during the regain period in the EX group but decreased significantly by 7% during regain in the
NoEX group (Fig. 2). In addition, significant reductions in DBP and SBP were maintained in the EX group, while the NoEX group exhibited a significant increase in SBP during weight regain (Fig. 2).

All measured markers of glucose homeostasis were significantly improved during weight loss. Insulin, HOMA, and QUICKI were significantly improved after weight loss although HDL-C was a trend only (Fig. 4). Cholesterol and TG concentrations generally deteriorated following the regain phase in both groups. HDL-C continued to increase and was significantly different from baseline in both groups during regain. HDL2-C also remained significantly higher than baseline in both groups during regain (data not shown).

Fig. 2. Body weight, body mass index (BMI), maximal oxygen consumption (VO2max), and blood pressure (BP). Data points are means ± SE. *Significantly different, PWL vs. baseline. †Significantly different, PWR vs. baseline within group. ‡Significantly different, PWR vs. baseline within group. ††Significantly different, EX vs. No EX. Note: although groups were not formed at baseline, the group means are presented in order to assess retrospectively changes between baseline and PWR.

LDL-C was maintained in the EX group but not in the NoEX group after regain (Fig. 4).

Waist circumference and abdominal adipose tissue compartments were significantly reduced with weight loss and then increased significantly in both groups with weight regain (Fig. 5). However, the PWR mean remained lower than baseline in both groups for all variables. SSAT and DSAT (data not shown) results each paralleled those of TSAT.

OxLDL concentrations were decreased following weight loss, and the reduction was maintained during weight regain in the EX group (Fig. 6). Inflammatory marker changes were small, but TNFRII was significantly reduced with weight loss, and CRP and TNF-α concentrations were significantly lower than baseline after regain in the EX group only (Fig. 6). The CRP result may have been due in part to the nonsignificantly
higher baseline value in the EX group (0.62 ± 0.12) vs. the NoEX group (0.39 ± 0.12).

DISCUSSION

The results of the weight loss phase confirm the positive impact of exercise training and weight loss on the MetS variables and extend our understanding of the comprehensiveness of these effects. The primary hypothesis tested was that the two groups would respond differently to the weight regain. Using a novel controlled weight regain model, these results show for the first time in humans that exercise can maintain most aspects of metabolic health during partial weight regain. The EX group exhibited maintenance of VO₂max, resting DBP and SBP, glucose homeostasis, LDL-C, HDL-C, and oxLDL. The results for insulin sensitivity (QUICKI) and resistance (HOMA) (Fig. 3) follow other data, which indicated that acute or chronic exercise has a marked impact on glucose homeostasis regardless of weight loss (3). Our results extend this finding and further suggest that exercise has a beneficial impact on insulin sensitivity and other metabolic parameters even in the

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Fig. 3. Glucose homeostasis. Data points are means ± SE. HOMA, homeostasis model assessment; QUICKI, quantitative insulin sensitivity check. *Significantly different, PWL vs. baseline. †Significantly different, PWR vs. baseline within group. ‡Significantly different, PWL vs. PWR within group. §Significantly different, EX vs. NoEX.

Fig. 4. Lipids and lipoproteins. Data points are means ± SE. HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol. *Significantly different, PWL vs. baseline. †Significantly different, PWR vs. baseline within group. ‡Significantly different, PWL vs. PWR within group.
face of weight gain. Although HOMA and QUICKI have limitations as markers of glucose homeostasis, intravenous glucose tolerance tests performed on a cohort of subjects in this study confirmed the results of the QUICKI analysis (24). The ability of exercise to maintain the improvements in these metabolic variables despite the weight regain highlights the potential of this treatment strategy in the prevention of Type 2 diabetes and associated health care costs.

Lipid and lipoprotein parameters were beneficially affected by the weight loss, but the impact of the regain on lipids was variable (Fig. 4). While others have reported improved lipoprotein profile induced by exercise training with weight loss (35) or without (27), maintenance of HDL-C, LDL-C, and oxLDL during weight regain is a novel finding and suggests a powerful impact of exercise on these important CVD risk factors despite weight regain. Others have reported negative effects on lipoproteins during follow up to a weight loss program, presumably caused by the weight regain (18). The reason for the significant increase in HDL-C in the NoEX group during regain is unclear. This result could indicate a delayed response to the exercise accumulated during the weight loss period. Slentz et al. (27) reported on the stability of HDL-C for 14 days

Fig. 5. Abdominal fat. Data points are means ± SE. TAT, total abdominal adipose tissue; TSAT, total subcutaneous adipose tissue; VAT, visceral adipose tissue. *Significantly different, PWL vs. baseline. aSignificantly different, PWR vs. baseline within group. bSignificantly different, PWL vs. PWR within group.

Fig. 6. Inflammation markers. Data points are means ± SE. OxLDL, oxidized low-density lipoprotein; CRP, C-reactive protein; TNFRII, tumor necrosis factor receptor II. *Significantly different, PWL vs. baseline. aSignificantly different, PWR vs. baseline within group. bSignificantly different, PWL vs. PWR within group.
after a training program comparable to ours. On the other hand, the increased HDL-C also could result from the increased total cholesterol concentration observed during the regain period.

In contrast to most outcome variables, exercise did not maintain the improvements in abdominal fat, cholesterol, or TG concentrations. The lack of maintenance in TG and cholesterol concentrations in the EX group was most likely due to the increased intake of cholesterol, saturated fat, and trans fat, PWL vs. PWR (Table 2). Aerobic exercise has been shown to have a potent impact on reducing abdominal fat (15, 25). However, exercise training had virtually no impact on maintaining the reductions in abdominal adiposity during the weight regain period (Fig. 5). This unexpected finding could be due to differences in the weight changes among studies. In previous studies there was an extended period of energy balance (29) or energy deficit (15), whereas participants in the present study were in a state of positive energy balance during the weight regain phase. These results suggest that the ingestion of excess energy can result in adipose fat accumulation in the abdomen despite concomitant exercise training.

Reductions in abdominal adiposity have been linked to improvements in other metabolic variables, most notably insulin sensitivity (11, 15), suggesting that changes in insulin sensitivity and abdominal adiposity would occur in parallel during weight regain. However, these two variables did not change equally during the weight regain period in the EX group. This result suggests that other factors related to exercise training, such as improved cardiovascular fitness (VO2max) or reduced systemic inflammation (oxLDL, TNF-α), may be driving the maintained improvement in insulin sensitivity during weight regain. Regardless, the results of the present study suggest that it is necessary to maintain reduced body weight to stabilize reduced abdominal fat stores.

The danger of weight regain without exercise is highlighted in the present study. In the NoEX group, the weight loss-induced benefits to metabolic parameters were rapidly lost. That is, in the absence of exercise, even partial weight regain produced significant detriment in health status within a 6-mo period. It may be noteworthy that several markers were back to near pre-study values, i.e., the PWR value was not significantly different from baseline (e.g., SBP and DBP, HOMA, and oxLDL) even though only half the weight was regained. In another study, 12 women who participated in 16 wk of aerobic training and then detrained for 6 wk regained all the lost body weight (4.9% body weight) and exhibited complete return of the lipoprotein profile to baseline values (18). In addition, recent work on rodents demonstrated that weight regain was caused in part by weight loss-induced metabolic aberrations that were normalized in a group undergoing exercise training (19). The possibility also exists that the negative health changes in outcome measures during weight regain in NoEX could have been due to the cessation of exercise training, not necessarily solely due to weight regain. In support of the “detraining” concept, results from a recent report demonstrated that reduced activity had a negative impact on metabolic health even without weight gain (23).

Although the results point to the ability of exercise to maintain the metabolic effects of weight loss, the magnitude of the effect is debatable. In most cases, the NoEX group exhibited deterioration in metabolic markers, while the EX group maintained these parameters during regain. However, except for DBP and insulin concentration, the NoEX and EX groups were not significantly different from each other on any other parameter at the end of the regain period. It could be argued that to be more confident of the exercise impact, the two groups should be significantly different at the end of regain period on most variables. This was not the case. Thus the interpretation of a positive impact of exercise is based on less definitive comparisons between the PWL and PWR time points within each group. On the other hand, the EX group exhibited lower incidence of achieving threshold on three of the five MetS variables than the NoEX group following regain (Table 1). When only those subjects with ≥3 MetS variables at baseline were analyzed, results were similar to those for all subjects; that is, only HOMA was significantly different between groups after regain. The data indicate that the groups were separating on most variables during the regain period, and an extended time period (e.g., 1 yr) may produce more conclusive results. It is also possible that a different exercise regimen may better counter the effects of weight regain than the moderate aerobic prescription. For example, a higher intensity exercise with shorter duration could be used or a different mode such as resistance training. However, it may be difficult for overweight subjects to tolerate higher intensity exercise.

Prescribing weight regain in human research carries an ethical dilemma. Support for this approach can be rationalized given the overwhelming number of individuals who regain weight and thus the potential importance of the findings gained from this design. Dietary markers suggested that the healthiness of the participants’ diets was not compromised during regain vs. baseline, as only the reduction in fiber in the in NoEX might be considered detrimental. This lack of overshoot in the regain diet is noteworthy considering that the EX group had to compensate with extra energy from diet for the increased energy expenditure during exercise (Table 2). On the other hand, the carefully controlled diet during the regain period may have partially accounted for the protection provided by exercise. However, the deterioration of the metabolic variables in the NoEX group, who also were using “healthy” overeating to gain weight, suggests that diet was not a part of the protection during the regain period. In addition, in the regain diet only CHO and calcium were different during regain vs. baseline and the energy intake was similar baseline vs. regain in the EX group, suggesting that exercise at least has the ability to protect if a person returns to the pre-weight loss diet. However, the study design does not allow conclusions on whether exercise could counter a less healthy or more excessive diet during a regain period.

Most individuals who participate in exercise and diet programs are successful at losing weight. However, it is also common for many of these individuals to relapse and regain the weight. To our knowledge this is the first human study to examine the role of exercise in countering the potential detrimental effects of this weight regain on MetS variables and overall health status. This model offers unique potential for studying weight regain in humans. In conjunction with a relatively standard aerobic exercise prescription, we were able to titrate caloric intake using daily food records and weekly dietary counseling to achieve an individualized controlled weight regain program.

In conclusion, the results of this study suggest that exercise may counter the detrimental effects of partial weight gain on many markers of metabolic health and disease risk. In contrast,
weight regain without exercise produces generally detrimental effects on these markers.

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GRANTS

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DISCLOSURES

No conflicts of interest (financial or otherwise) are declared by the authors.

REFERENCES


