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Weight Regain is Related to Decreases in Physical Activity During Weight Loss

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Abstract

Purpose—To examine whether adaptations in physical activity energy expenditure (PAEE) and resting metabolic rate (RMR) during weight loss were associated with future weight regain in overweight/obese, older women.

Research Methods and Procedures—Thirty-four overweight/obese (BMI=25–40 kg/m^2), postmenopausal women underwent a 20-week weight loss intervention of hypocaloric diet with (low- or high-intensity) or without treadmill walking (weekly caloric deficit was ~11760 kJ), with a subsequent 12-month follow-up. RMR (via indirect calorimetry), PAEE (by RT3 accelerometer) and body composition (by DXA) were measured before and after intervention. Body weight and self-reported information on physical activity were collected after intervention, and at 6- and 12-months following intervention.

Results—The intervention resulted in decreases in body weight, lean mass, fat mass, percent body fat, RMR, and PAEE ($p < 0.001$ for all). Weight regain was 2.9 ± 3.3 kg (−3.1 to +9.2 kg) at 6-months and 5.2 ± 5.0 kg (−2.3 to +21.7 kg) at 12-months following intervention. The amount of weight regained after 6- and 12-months was inversely associated with decreases in PAEE during the weight loss intervention ($r = -0.521$, $p = 0.002$ and $r = -0.404$, $p = 0.018$, respectively), such that women with larger declines in PAEE during weight loss experienced greater weight regain during follow-up. Weight regain was not associated with changes in RMR during intervention or with self-reported physical activity during follow-up.

Conclusion—This study demonstrates that, while both RMR and PAEE decreased during weight loss in postmenopausal women, maintaining high levels of daily physical activity during weight loss may be important to mitigate weight regain after weight loss.

Keywords

energy expenditure; resting metabolic rate; weight loss intervention; hypocaloric diet

INTRODUCTION

Obesity is a major risk factor for several chronic diseases and health problems and the health benefits of weight reduction for obese/overweight persons are clear (15). Both behavioral and

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pharmacologic treatments for obesity are successful in eliciting weight loss in most individuals for short periods of time (7,8). However, nearly all overweight/obese people have difficulty maintaining weight loss. In most persons, one third to two thirds of their lost weight will be regained within the first year, and that the rate of regain does not diminish as time elapses, with an estimated 66% of lost weight regained within 2 years and 95% regained within 5 years (16,35).

Obesity is the result of a consistent surplus of energy intake over energy expenditure (EE), therefore, weight regain must result from a gradual excess of energy intake relative to energy expended. Daily EE is comprised of resting EE (or resting metabolic rate, RMR), thermic effect of feeding (EE associated with digestion, absorption, and storage of food), and physical activity EE (PAEE), which includes both purposeful exercise and non-exercise activity EE (2). PAEE is the most variable component among different individuals and, as such, can potentially play an important role in preventing weight gain, as well as in maintaining weight loss (4,[5],[30],37). Data from longitudinal cohort studies show that low levels of EE (both RMR and PAEE) are predictive of greater weight gain over time (3,[19],[22],[25],33). In addition, observational data from the National Weight Control Registry show that individuals who are successful at long-term weight loss have higher levels of self-reported physical activity than those who regain their weight after weight loss (34).

These available observational data suggest that low EE, and low PAEE in particular, is an important risk factor for subsequent weight gain, and, thus, may be important in predicting weight regain following weight loss. Importantly, both PAEE and RMR decrease during periods of negative energy balance, which is a potential undesirable consequence of weight loss treatments via hypocaloric dieting and/or exercise (11,[14],29). A few weight loss intervention studies show that increases in self-reported physical activity *after* the intervention are associated with less weight regain during follow-up (10,20). However, to our knowledge, no study to date has examined whether the magnitude of weight regain after weight loss is associated with decreases in PAEE *during* a weight loss intervention, and only one study examined whether weight regain is associated with decreases in RMR during a weight loss intervention (17). If weight regain is found to be associated with decreases in PAEE, this important information could be used to help design strategies to promote physical activity during weight loss to help mitigate future weight regain. Therefore, the purpose of this study was to examine whether adaptations in PAEE and RMR as a result of weight loss via a hypocaloric diet with or without exercise, are associated with future weight regain in overweight/obese, older women.

RESEARCH METHODS AND PROCEDURES

Participants

Participants in this study were women who volunteered to participate in a randomized clinical trial designed to determine the cellular mechanisms by which exercise intensity affects the loss of abdominal, compared to gluteal, adipose tissue under conditions of equal energy deficit in postmenopausal women with abdominal obesity. All women were recruited from the Piedmont Triad area of North Carolina and enrolled in the study based on the following inclusion/exclusion criteria: 1) middle-aged and older (age = 50–70 years, and at least one year without menses), 2) overweight or obese (BMI = 25–40 kg/m^2 and waist girth > 88 cm), 3) non-smoking, 4) not on hormone therapy, 5) sedentary (<15 min of exercise, 2 times/wk) in the past 6 months, and 6) weight-stable (< 5% weight change) for at least 6 months prior to enrollment. The study was approved by the Wake Forest University Institutional Review Board and all women signed an informed consent form to participate in the study according to the guidelines for human research.

Initial screening included a medical history review, physical examination, fasting blood profile (lipoprotein lipids and glucose) and 12-lead resting electrocardiogram. Participants with evidence of untreated hypertension (blood pressure >160/90 mmHg), hypertriglyceridemia (triglycerides > 400 mg/dl), insulin-dependent diabetes, active cancer, liver, renal or hematological disease, or other medical disorders were excluded. On a second screening visit, the participants underwent a graded exercise test to exclude those with an abnormal cardiovascular response to exercise. Additionally the maximal heart rate achieved during the graded exercise test was used in the determination of the appropriate exercise intensity.

A total of 41 eligible women (34% black, 66% white) were randomly assigned to participate in either a hypocaloric diet only (DIET; n=15), a diet plus low-intensity exercise (DIET+LO-EX; n=13), or a diet plus high-intensity exercise (DIET+HI-EX; n=13) intervention for a period of 20 weeks. Following the 20-week weight loss intervention, women returned for follow-up visits 6- and 12-month later. No intervention or contact with the participants was provided during the follow-up period. We report here data on PAEE, RMR and weight regain from a subset of 34 women (DIET, n=11; DIET+LO-EX, n=12; DIET+HI-EX, n=11) who completed the 20-week weight loss intervention and both follow-up visits at 6- and 12-months following intervention. Among those who did not finish follow-up visits, 2 were ill, 1 moved out of the area, 2 had schedule conflicts, and 2 had no specific reason.

Study intervention

Upon entry into the study, all women completed a 4-day food record, which was used as an initial measure of dietary habits. Individual energy needs were calculated from RMR directly measured via indirect calorimetry, and applying an activity factor based on each woman's description of her daily activities (typically 1.3 for sedentary women). The calorie deficits of all women were adjusted to ~11760 kJ/week (~1680 kJ/day). The deficits for the diet only group resulted totally from reduction in dietary intake, whereas deficits for the diet plus exercise groups resulted from both reductions in dietary intake (~10080 kJ/week) and exercise energy expenditure (~1680 kJ/week).

All women were given food for their lunch and dinner, which was prepared and provided by the Wake Forest University General Clinical Research Center metabolic kitchen. These meals were prepared individually after women chose from a hypocaloric menu designed by the registered dietitian to provide a balanced, healthy diet. Calorie make-up of the diet was approximately 25% from fat, 15% from protein, and 60% from carbohydrate. In consultation with the dietitian, women purchased and prepared their breakfast meal from the same menu. They were asked to eat only the food that was given to them or that was approved from the breakfast menu. They were allowed two free days per month, where they were given guidelines for diet intake and asked to report their intake on those days. They were allowed to consume non-caloric, non-caffeinated beverages ad libitum. All women picked up their food twice a week and were asked to keep a log of everything they ate or drank. They were also provided with a daily calcium supplement to insure adequate calcium intake (1000 mg/day). The records were monitored weekly by the dietitian to verify compliance to the diet. The average daily calorie intake recorded by participants was 100.1±0.4% of the provided calorie level.

The exercise prescription involved center-based treadmill walking three days/week at a target heart rate calculated from the Karvonen equation [(HRR × (intensity))+resting heart rate] (9), where heart rate reserve (HRR) is maximal heart rate, obtained from each subject's graded exercise test, minus resting heart rate. The duration and intensity of the exercise prescription progressed from 15–20 min at 45–50% of HRR during the first week to 55 min at 45–50% HRR for the low-intensity exercise group or 30 min at 70–75% HRR for the high-intensity exercise group within eight weeks. Participants attended an average of 85.0% of the exercise sessions.

Measurements

Body composition—Height and weight were measured with shoes and jackets or outer garments removed before and after the 20-week intervention, and at 6- and 12-month follow-up visits. Lean body mass, fat mass, and percent body fat were measured by dual energy X-ray absorptiometry (Hologic Delphi QDR, Bedford, MA) before and after the 20-week intervention.

Resting metabolic rate—RMR was measured before and after the 20-week intervention using indirect calorimetry following 10 or more hours of fasting. Participants were instructed not to participate in heavy physical activity 24 hours prior to the measurement. They were allowed to breathe freely through a face mask, while expired air was collected through a one-way valve and analyzed using a MedGraphics CCM/D metabolic cart (MedGraphics Inc., Minneapolis, MN). Participants rested quietly for 15–30 minutes before the collection of data and for an additional 30 minutes during which data were collected. During the measurement, steady state is defined as ± 5% in oxygen consumed and rate of exchange ratio. One participant was not able to achieve a steady state during their post-intervention resting metabolic rate test, so her RMR data were removed from analyses. For those in groups with exercise intervention, RMR was measured at least 48 hours after the previous exercise session.

PAEE—The average daily PAEE of each woman was measured prior to the start of and during the final week of the 20-week intervention using a RT3 (StayHealty, Inc., Monrovia, CA) triaxial accelerometer. It is the size of a pager and is worn by clipping onto the waist. Participants were instructed to maintain their regular level of physical activity and to wear the monitor at all times for 5 to 7 days including weekends and weekdays except while bathing and sleeping. They wore the monitor for 6.5 ± 0.7 days at baseline and 5.6 ± 1.0 days at the end of the intervention. The RT3 was not used at the 6- or 12-month follow-up visits. Data were downloaded and average daily calories expended, PAEE, were calculated using the manufacturer's software.

Women in the exercise intervention groups wore the RT3 monitors during the 20th week of intervention which included 3 prescribed exercise sessions each week. The energy expended during these structured exercise sessions were recorded for each woman from readings provided by treadmills and was subtracted from each woman's individual RT3-recorded PAEE for that week. Thus, the PAEE reported here only includes calories expended outside of the exercise program.

Self-reported physical activity—Self-reported physical activity during the follow-up was assessed using the Physical Activity Scale for the Elderly (PASE) (28,28). Data were collected post-intervention and at both follow-up visits. The scale measures the level of physical activity in older individuals, comprising self-reported occupational, household, and leisure activities during a one-week period. Data on reliability and validity have been reported (23,[26],[26–28], 28). Higher scores indicate higher levels of physical activity.

Statistics

Statistical analyses were performed using SAS software, version 9.1 (SAS Institute, Cary, NC). Descriptive statistics were calculated and values are reported as means ± SDs. Analysis of variance including the treatment group × time interaction was used to compare means at the end of the weight loss intervention to means at baseline, and to compare means at the 6-month and 12-month visits to means at the end of intervention across the three groups. Pearson's correlations (or Spearman correlations for non-normally distributed data) between changes in body weight during follow-up and changes in PAEE and RMR during intervention, as well as changes in self-reported physical activity (PASE score) during follow-up were examined. In addition, multiple linear regression analyses were used to determine the correlations after individual adjustment for the amount of weight loss and treatment group. An alpha level of 0.05 was selected to denote statistical significance.

RESULTS

Changes in body weight/composition, maximum oxygen consumption, RMR and PAEE during weight loss

The average age of the 34 women was 58.6 ± 5.2 years. Body composition, relative and absolute maximum oxygen consumption (VO_2max), and energy expenditure data at baseline and at the end of the 20-week weight loss intervention are shown in Table 1 by intervention group. No baseline differences were found among groups. Decreases in body weight, lean body mass, fat mass, and percent body fat were similar across all 3 groups (p>0.05 for group × time interactions). Although increases in relative VO_2max were not statistically different among the 3 groups (p>0.05 for group × time interaction), the percent increases were highest in the DIET+HI-EX group and lowest in the DIET group. Absolute VO_2max did not change after the intervention (p>0.05).

The interventions resulted in overall declines in both RMR and PAEE (p<0.0001) with no significant group differences (Table 1; p>0.05 for group × time interactions). Overall, changes in RMR ranged from −1445 to +752 kJ/day, with 27 of the 33 women having decreased values, and changes in PAEE ranged from −2310 to +487 kJ/day, with 31 of the 34 women having decreased values. However, RMR relative to lean mass remained unchanged (104.6 ± 14.2 and 104.4 ± 15.5 kJ/kg·day before and after intervention, respectively; p=0.960), and RMR relative to fat mass increased (140.6 ± 31.2 kJ/kg·day and 167.0 ± 51.6 kJ/kg·day before and after intervention, respectively; p< 0.001). In contrast, PAEE relative to lean mass decreased (45.5 ± 14.1 and 35.1 ± 11.3 kJ/kg·day before and after intervention, respectively; p<0.0001), and PAEE relative to body weight decreased (26.4 ± 8.3 and 22.0 ± 7.5 kJ/kg·day before and after intervention, respectively; p=0.0003).

Changes in body weight and self-reported physical activity during follow-up

Table 2 shows the body weight changes at 6- and 12-months following completion of the weight loss interventions by treatment group. There were no group differences in the amount of weight regained at either 6- or 12-months (p>0.05 for group × time interactions). Overall, the average weight regain at 6 months was 2.9 ± 3.3 kg, ranging from −3.1 to +9.2 kg, with 26 of the 34 women regaining some (>0 kg) weight. A total of 31.5 ± 41.6% of the weight lost during intervention was regained by 6 months. At 12-months, the average weight regain was 5.2 ± 5.0 kg, ranging from −2.3 to +21.7 kg, with 28 of the 34 women regaining some (>0 kg) weight. A total of 51.4 ± 59.2% of the lost weight was regained by 12 months. The amount of weight regained at 6- and 12-months was not related to the amount of weight lost (r=0.267, p=0.128; and r=0.107, p=0.545, respectively).

Self-reported physical activity did not change during the 6 months of follow-up (PASE score: 156.0 ± 77.6 to 178.8 ± 95.5, p=0.132) or during the 12 months of follow-up (PASE score: 156.0 ± 77.6 to 181.9 ± 114.5, p=0.104).

Relationship of weight regain to changes in RMR and PAEE during weight loss, and self-reported physical activity during follow-up

Since there were no treatment group differences in changes in RMR, PAEE, or weight regain, we combined all groups to examine whether changes in PAEE and RMR during weight loss were associated with future weight regain. We found that weight changes from the end of intervention to 6- and 12-month follow-up visits were inversely correlated with changes in

PAEE during intervention (r= −0.521, p=0.002, Figure 1a; and r= −0.404, p=0.018, Figure 1b, respectively), such that women with larger declines in PAEE during weight loss experienced greater weight regain during follow-up. The correlations between weight regain and PAEE changes were not different among groups (p>0.05 for group interactions after 6- and 12-month follow-up), and adjusting for treatment group did not significantly affect these relationships (6- month: r= −0.474, p=0.002; 12-month: r= −0.332, p=0.020). When we examined the correlations between weight regain and PAEE changes during weight loss in each group separately, a significant correlation was found in DIET+HI-EX group only (6-month: Spearman ρ= −0.83, p=0.002; 12-month: Spearman ρ= −0.94, p< 0.001). Additionally, the amount of weight regained at 6- and 12-month was still associated with changes in PAEE after adjusting for the amount of weight lost during intervention (6-month: r= −0.588, p=0.0004; 12-month: r= −0.370, p=0.014). Similarly, weight regain was associated with changes in PAEE relative to lean mass (6-month: r= −0.549, p=0.0008; 12-month: r= −0.398, p=0.020) or body weight (6-month: r = −0.614, p=0.0001; 12-month: r= −0.453, p=0.007).

Changes in body weight during follow-up were not related to absolute changes in RMR during intervention (Figures 2a and 2b), indicating that decreases in RMR were not associated with subsequent weight regain. Weight regain during follow-up was also not associated with changes in RMR per kg lean mass (r=0.010, 0.059 for 6- and 12-months, respectively) or RMR per kg fat mass (r= −0.123, −0.130 for 6- and 12-months, respectively).

The amount of weight regained at the 6-month follow-up was not related to individual changes in self-reported physical activity during the 6-month follow-up (r=0.106, p=0.563). Similarly, weight regained at 12-months was not related to individual changes in self-reported physical activity during the 12-month follow-up (r= −0.198, p=0.293).

In addition, we also calculated PAEE using the same calendar days (PAEE2) before and after the intervention during which RT3 monitors were worn. All women wore the monitors for at least 4 same calendar days: PAEE2 = 2371.5 ± 748.0 kJ/day (2377.4 ± 802.9, 2305.3 ± 645.2, and 2431.9 ± 849.0 kJ/day for DIET, DIET+LO-EX, and DIET+HI-EX groups, respectively) at baseline and 1711.13 ± 543.5 kJ/day (1660.0 ± 576.8, 1584.8 ± 468.1, and 1888.6 ± 581.7 kJ/day for each group, respectively) at the end of intervention. The correlations between weight regain after 6- and 12-month follow-up and PAEE2 changes during intervention were −0.513 (p=0.002) and −0.393 (p=0.024). These results were very similar to calculating PAEE using all days recorded by RT3 monitors, as described above.

DISCUSSION

In this weight loss intervention study, we found that the amount of weight regained during follow-up was associated with the magnitude of change in objectively measured PAEE during weight loss. Specifically, the greater the decrease in PAEE during the 5-months of energy deficit, the greater the weight regain during follow-up. The amount of weight regained was related to the decrease in PAEE even after adjustment for the amount of weight loss during intervention. Conversely, weight regain was not associated with decreases in RMR during the weight loss intervention.

Although it has been suggested that physical activity inversely affects body weight, to our knowledge, no previous study has examined whether a decline in PAEE (either measured objectively or by self-report) during periods of energy deficit is a factor predictive of future weight regain. However, a few studies have examined the effect of changes in self-reported physical activity *after* a weight loss intervention on weight regain. One study found that increases in physical activity measured by a questionnaire during a 2-year period after a weight loss program was a protective factor, and was among a group of variables related to the amount

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of weight regain (10). Another study found less exercise time (sports and other activities) and more television/computer time accompanied weight regain during the 2-year follow-up after a 9-month weight loss intervention in adolescents (20). Other studies have also shown high levels of self-reported physical activity after weight loss are associated with less weight regain (12,18). Also, integration of walking into a weight maintenance program decreased the amount of weight regain 2 years after weight loss compared to controls (6). These studies point to the importance of physical activity in reduced-weight individuals trying to maintain their weight loss. Our data, however, showed the magnitude of weight regain during follow-up was associated with decreases in an objective measure of physical activity during a period of energy deficit. Interestingly, weight regain was not related to self-reported physical activity during follow-up, possibly due to inconsistencies of self-reported data and the scale's inadequate sensitivity to change over a period of time for this sample of women. Thus, whatever the mediating factor, these results do suggest that maintaining a higher level of physical activity during a weight loss treatment is important for prevention of weight regain.

There are conflicting data regarding whether differences in baseline RMR or changes in RMR with weight loss are predictive of weight change. Ravussin et al. found that Pima Indians with a lower RMR gained more weight over a 4-year period (19). However, data from the Baltimore Longitudinal Study on Aging showed weight change during a 10-year follow-up was not related to individual RMR (24). Weinsier et al. also found lower RMR after weight loss was not predictive of greater weight regain after 4 years (32). Pasman et al. examined the association between changes in RMR induced during a 2-month low energy diet and weight regain during 14 months of follow-up in obese, premenopausal women (17). They found that the amount of weight regained was greater in women with a greater decrease in RMR. In contrast, in our study, weight regain was not associated with weight loss-induced changes in absolute RMR, or RMR relative to lean mass or fat mass. The study by Pasman et al. and ours induced a similar amount of weight loss, however, in our study, the weight loss intervention was longer, the decrease in RMR appeared less, and our participants were older.

Our study showed that most of the women experienced a decrease in PAEE and absolute RMR during weight loss, with an average decline on the order of 26% and 7%, respectively. Other studies that have directly measured PAEE or derived non-resting EE from a measure of total EE, have also found that these components of EE decline during negative energy balance induced by exercise training (14) or a hypocaloric diet (1,[11],29). In our study, PAEE decreased in all groups, even when calories expended during exercise sessions were included in total PAEE (changes in PAEE: −444.0 ± 635.6 kJ/day for DIET+EX-LO, −357.2 ± 620.9 kJ/day for DIET+EX-HI, and −498.3 ± 551.9 kJ/day three groups combined). The amount of weight regain after 6- and 12-month follow-up was also related to changes in total PAEE ($r = -0.518$, $p = 0.002$; and $r = -0.429$, $p = 0.011$, respectively). Therefore, it appears that PAEE outside of the exercise program (i.e. spontaneous physical activity), decreased to a greater level than the increased EE resulting from purposeful exercise as part of the intervention. PAEE relative to lean mass or body weight also decreased, suggesting that the decrease in EE due to daily physical activity was not solely accounted for by a reduced body mass. Furthermore, it is the decrease in PAEE itself, beyond variation in weight loss, that predicts future weight regain, as evidenced by the fact that the amount of weight loss did not affect the relationship between PAEE decrease and weight regain. Additionally, the fact that the DIET+HI-EX group showed a strong association between PAEE decrease and weight regain, suggests that exercise intensity during weight loss intervention may affect the rate of weight regain by altering PAEE.

Likewise, our RMR results confirm other studies that show a decrease in RMR with dietary-induced weight loss (1,[11],32). However, our data showed that, when adjusted for lean mass, there was no change in RMR, suggesting that the decrease in RMR was accounted for by the loss of lean mass. This is consistent with some studies showing the decrease in RMR after weight loss was not beyond the expected reduction for the amount of lean mass lost (31,36).

Mayer and coworkers hypothesized that, in sedentary persons, there is a threshold of physical activity below which leads to obesity (13). Schoeller et al. further examined this threshold hypothesis in women. They found that previously obese women whose physical activity was great enough to increase total EE to RMR ratio (TEE:RMR, or physical activity level) above 1.75 were less likely to regain weight than those less active women (TEE:RMR <1.75) (21, 22). They subsequently provided a structured exercise program to a subset of these less active women to increase TEE:RMR to 1.75, and their weight gain was stopped for the duration of the program. In a study by Weinsier et al., women who were successful at maintaining lost body weight had a TEE:RMR of around 1.7 before and after weight loss intervention, while those gaining weight had a value of 1.55 and 1.60, before and after the intervention (30). We calculated TEE:RMR (considering thermic effect of food is approximately 15% of TEE, TEE = [RMR + total PAEE]/85%) at the end of weight loss intervention. The mean TEE:RMR was 1.58 (± 0.12), with 6 of the 33 women having levels greater than 1.70, and only 2 of them greater than 1.75. Since most women regained weight during follow-up, our results appeared to support this threshold hypothesis.

In summary, our study found the magnitude of weight regain during follow-up was associated with decreases in PAEE during weight loss in women, thereby suggesting the importance of maintaining a high level of daily physical activity to mitigate weight regain after weight loss. Given the mean PAEE decreased even when calories expended during prescribed exercise were included, physical activity outside of structured exercise programs may be a more important factor in prevention of weight regain. Therefore, behavioral strategies to minimize this decrease should be integrated into weight loss interventions to help with maintenance of weight loss.

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REFERENCES

1. de Groot LC, van Es AJ, van Raaij JM, Vogt JE, Hautvast JG. Energy metabolism of overweight women 1 mo and 1 y after an 8-wk slimming period. Am J Clin.Nutr 1990 Apr;51(4):578–583. [PubMed: 2321566]
2. Donahoo WT, Levine JA, Melanson EL. Variability in energy expenditure and its components. Curr Opin Clin Nutr Metab Care 2004 Nov;7(6):599–605. [PubMed: 15534426]
3. Elfhag K, Rossner S. Who succeeds in maintaining weight loss? A conceptual review of factors associated with weight loss maintenance and weight regain. Obes Rev 2005 Feb;6(1):67–85. [PubMed: 15655039]
4. Esparza J, Fox C, Harper IT, Bennett PH, Schulz LO, Valencia ME, Ravussin E. Daily energy expenditure in Mexican and USA Pima indians: low physical activity as a possible cause of obesity. Int J Obes Relat Metab Disord 2000 Jan;24(1):55–59. [PubMed: 10702751]
5. Filozof C, Gonzalez C. Predictors of weight gain: the biological-behavioural debate. Obes Rev 2000 May;1(1):21–26. [PubMed: 12119641]
6. Fogelholm M, Kukkonen-Harjula K, Nenonen A, Pasanen M. Effects of walking training on weight maintenance after a very-low-energy diet in premenopausal obese women: a randomized controlled trial. Arch Intern Med 2000 Jul 24;160(14):2177–2184. [PubMed: 10904461]

7. Hill JO, Thompson H, Wyatt H. Weight maintenance: what's missing? J Am Diet Assoc 2005 May; 105(5):S63–S66. [PubMed: 15867898]
8. Jakicic JM, Clark K, Coleman E, Donnelly JE, Foreyt J, Melanson E, Volek J, Volpe SL. American College of Sports Medicine position stand. Appropriate intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 2001 Dec;33(12):2145–2156. [PubMed: 11740312]
9. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate; a longitudinal study. Ann Med Exp Biol Fenn 1957;35(3):307–315. [PubMed: 13470504]
10. Lavery MA, Loewy JW. Identifying predictive variables for long-term weight change after participation in a weight loss program. J Am Diet Assoc 1993 Sep;93(9):1017–1024. [PubMed: 8360406]
11. Leibel RL, Rosenbaum M, Hirsch J. Changes in Energy Expenditure Resulting from Altered Body Weight. N Engl J Med 1995 Mar 9;332(10):621–628. [PubMed: 7632212]
12. Leser MS, Yanovski SZ, Yanovski JA. A low-fat intake and greater activity level are associated with lower weight regain 3 years after completing a very-low-calorie diet. J Am Diet Assoc 2002 Sep;102 (9):1252–1256. [PubMed: 12792622]
13. Mayer J, Roy P, Mitra KP. Relation between caloric intake, body weight, and physical work: studies in an industrial male population in West Bengal. Am J Clin Nutr 1956 Mar;4(2):169–175. [PubMed: 13302165]
14. Morio B, Montaurier C, Pickering G, Ritz P, Fellmann N, Coudert J, Beaufrere B, Vermorel M. Effects of 14 weeks of progressive endurance training on energy expenditure in elderly people. Br J Nutr 1998 Dec;80(6):511–519. [PubMed: 10211049]
15. National Institutes of Health. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report; Obes Res. 1998 Sep. p. 51S-209S.
16. NIH Technology Assessment Conference Panel. Methods for voluntary weight loss and control. Ann Intern Med; Consensus Development Conference; 30 March to 1 April 1992; 1993 Oct 1. p. 764-770.
17. Pasman WJ, Saris WH, Westerterp-Plantenga MS. Predictors of weight maintenance. Obes Res 1999 Jan;7(1):43–50. [PubMed: 10023729]
18. Phelan S, Wyatt HR, Hill JO, Wing RR. Are the eating and exercise habits of successful weight losers changing? Obesity (Silver.Spring) 2006 Apr;14(4):710–716. [PubMed: 16741274]
19. Ravussin E, Lillioja S, Knowler WC, Christin L, Freymond D, Abbott WG, Boyce V, Howard BV, Bogardus C. Reduced rate of energy expenditure as a risk factor for body-weight gain. N Engl J Med 1988 Feb 25;318(8):467–472. [PubMed: 3340128]
20. Rolland-Cachera MF, Thibault H, Souberbielle JC, Soulie D, Carbonel P, Deheeger M, Roinsol D, Longueville E, Bellisle F, Serog P. Massive obesity in adolescents: dietary interventions and behaviours associated with weight regain at 2 y follow-up. Int J Obes Relat Metab Disord 2004 Apr; 28(4):514–519. [PubMed: 14968129]
21. Schoeller DA. Balancing energy expenditure and body weight. Am J Clin Nutr 1998 Oct;68(4):956S–961S. [PubMed: 9771879]
22. Schoeller DA, Shay K, Kushner RF. How much physical activity is needed to minimize weight gain in previously obese women? Am J Clin Nutr 1997 Sep;66(3):551–556. [PubMed: 9280172]
23. Schuit AJ, Schouten EG, Westerterp KR, Saris WH. Validity of the Physical Activity Scale for the Elderly (PASE): according to energy expenditure assessed by the doubly labeled water method. J Clin Epidemiol 1997 May;50(5):541–546. [PubMed: 9180646]
24. Seidell JC, Muller DC, Sorkin JD, Andres R. Fasting respiratory exchange ratio and resting metabolic rate as predictors of weight gain: the Baltimore Longitudinal Study on Aging. Int J Obes Relat Metab Disord 1992 Sep;16(9):667–674. [PubMed: 1328091]
25. Sherwood NE, Jeffery RW, French SA, Hannan PJ, Murray DM. Predictors of weight gain in the Pound of Prevention study. Int J Obes Relat Metab Disord 2000 Apr;24(4):395–403. [PubMed: 10805494]
26. Washburn RA, Ficker JL. Physical Activity Scale for the Elderly (PASE): the relationship with activity measured by a portable accelerometer. J Sports Med Phys Fitness 1999 Dec;39(4):336–340. [PubMed: 10726435]

27. Washburn RA, Goldfield SR, Smith KW, McKinlay JB. The validity of self-reported exercise-induced sweating as a measure of physical activity. Am J Epidemiol 1990 Jul;132(1):107–113. [PubMed: 2192545]
28. Washburn RA, Smith KW, Jette AM, Janney CA. The Physical Activity Scale for the Elderly (PASE): development and evaluation. J Clin Epidemiol 1993 Feb;46(2):153–162. [PubMed: 8437031]
29. Weigle DS, Sande KJ, Iverius PH, Monsen ER, Brunzell JD. Weight loss leads to a marked decrease in nonresting energy expenditure in ambulatory human subjects. Metabolism 1988 Oct;37(10):930–936. [PubMed: 3173112]
30. Weinsier RL, Hunter GR, Desmond RA, Byrne NM, Zuckerman PA, Darnell BE. Free-living activity energy expenditure in women successful and unsuccessful at maintaining a normal body weight. Am J Clin Nutr 2002 Mar;75(3):499–504. [PubMed: 11864855]
31. Weinsier RL, Hunter GR, Zuckerman PA, Redden DT, Darnell BE, Larson DE, Newcomer BR, Goran MI. Energy expenditure and free-living physical activity in black and white women: comparison before and after weight loss. Am J Clin Nutr 2000 May;71(5):1138–1146. [PubMed: 10799376]
32. Weinsier RL, Nagy TR, Hunter GR, Darnell BE, Hensrud DD, Weiss HL. Do adaptive changes in metabolic rate favor weight regain in weight-reduced individuals? An examination of the set-point theory. Am J Clin Nutr 2000 Nov;72(5):1088–1094. [PubMed: 11063433]
33. Williamson DF, Madans J, Anda RF, Kleinman JC, Kahn HS, Byers T. Recreational physical activity and ten-year weight change in a US national cohort. Int J Obes Relat Metab Disord 1993 May;17(5):279–286. [PubMed: 8389337]
34. Wing RR, Hill JO. Successful weight loss maintenance. Annu Rev Nutr 2001;21:323–341. [PubMed: 11375440]
35. Wing RR, Phelan S. Long-term weight loss maintenance. Am J Clin Nutr 2005 Jul;82(1 Suppl):222S–225S. [PubMed: 16002825]
36. Wyatt HR, Grunwald GK, Seagle HM, Klem ML, McGuire MT, Wing RR, Hill JO. Resting energy expenditure in reduced-obese subjects in the National Weight Control Registry. Am J Clin Nutr 1999 Jun;69(6):1189–1193. [PubMed: 10357738]
37. Zurlo F, Ferraro RT, Fontvielle AM, Rising R, Bogardus C, Ravussin E. Spontaneous physical activity and obesity: cross-sectional and longitudinal studies in Pima Indians. Am J Physiol 1992 Aug;263 (2 Pt 1):E296–E300. [PubMed: 1514610]

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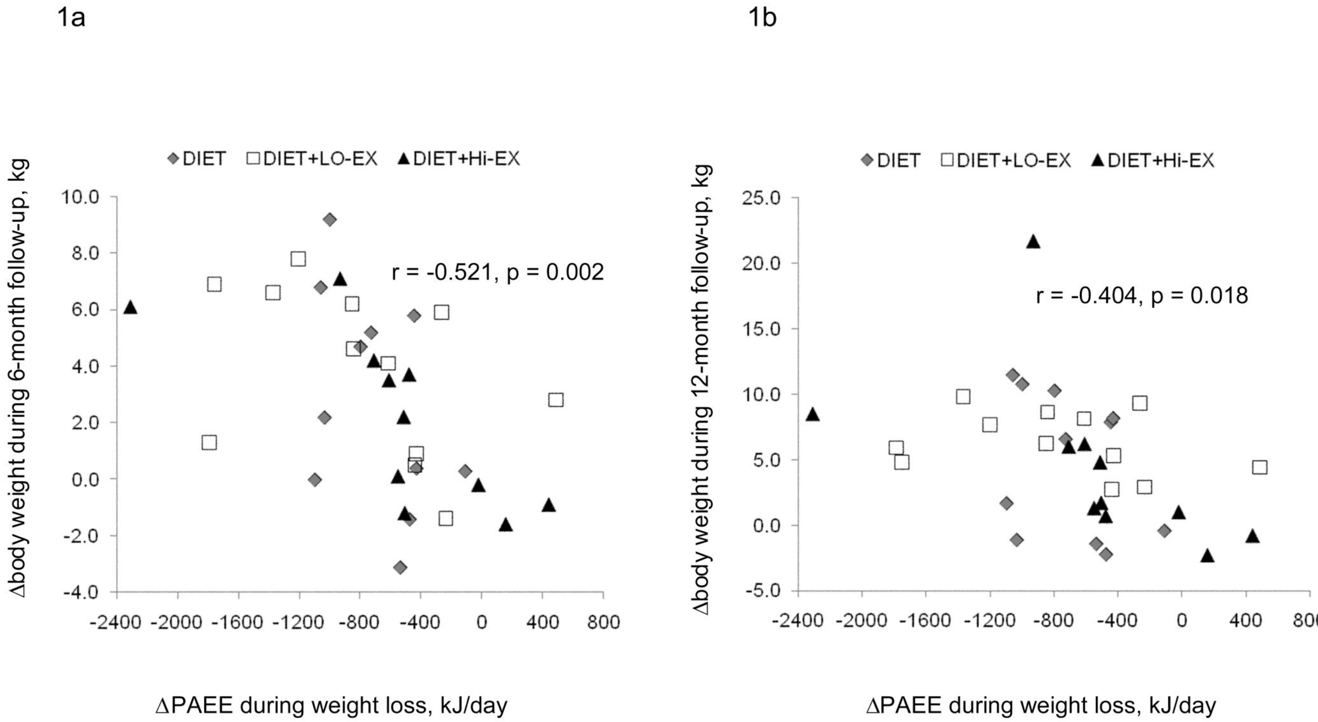

Figure 1.

a. Relationship between changes in body weight during 6-month follow-up and changes in physical activity energy expenditure (PAEE) during weight loss. For the entire sample, r= −0.521, p= 0.002. For DIET and DIET+LO-EX groups, r= −0.44, −0.42, respectively, p> 0.05 for both. For DIET+HI-EX group, Spearman ρ= −0.83, p= 0.002.

b. Relationship between changes in body weight during 12-month follow-up and changes in physical activity energy expenditure (PAEE) during weight loss. For the entire sample, r= −0.404, p= 0.018. For DIET and DIET+LO-EX groups, Spearman ρ= −0.27, −0.32, respectively, p> 0.05 for both. For DIET+HI-EX group, Spearman ρ= −0.94, p< 0.001.

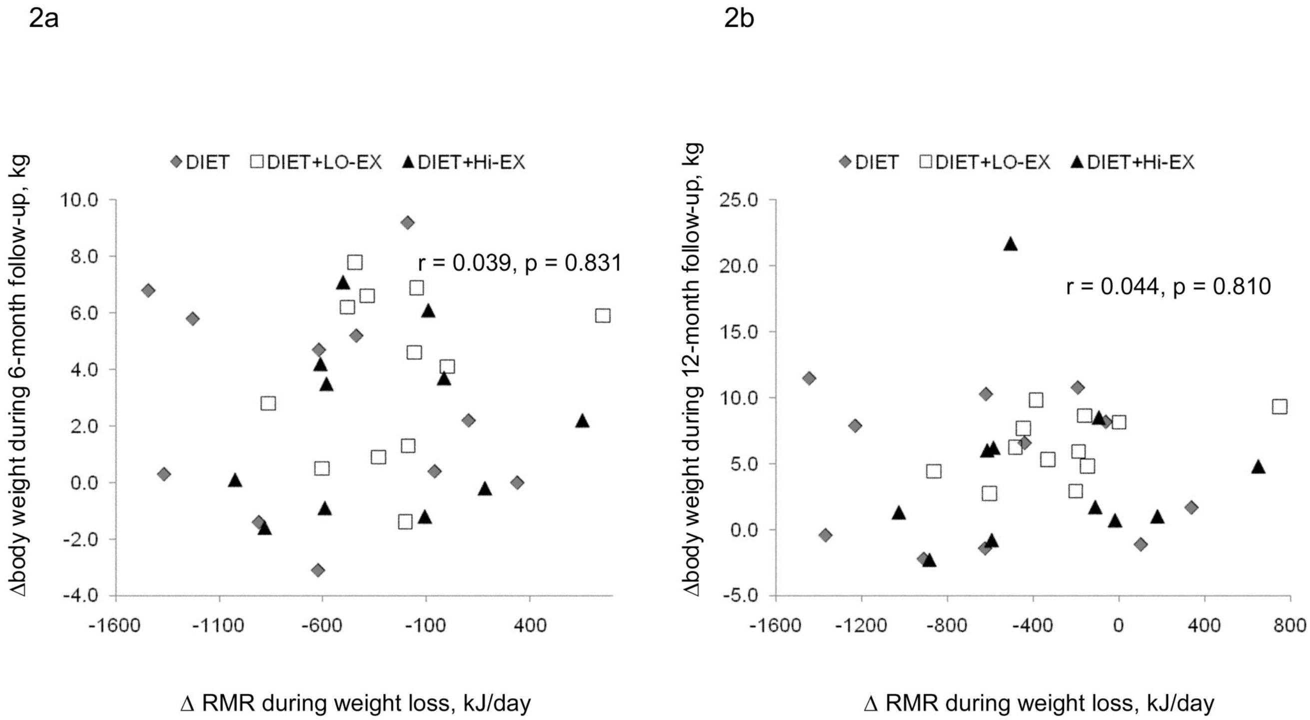

Figure 2.

a. Relationship between changes in body weight during 6-month follow-up and changes in resting metabolic rate (RMR) during weight loss. For the entire sample, r= 0.039, p= 0.831. For DIET, DIET+LO-EX, and DIET+HI-EX groups, r= −0.14, Spearman ρ= 0.13, 0.14, respectively, p> 0.05 for all.

b. Relationship between changes in body weight during 12-month follow-up and changes in resting metabolic rate (RMR) during weight loss. For the entire sample, r= 0.044, p= 0.810. For DIET, DIET+LO-EX, and DIET+HI-EX groups, Spearman ρ= −0.08, 0.36, 0.18, respectively, p> 0.05 for all.

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Table 1

Body composition, maximum oxygen consumption (VO_2max), energy expenditure at baseline and end of intervention, and percent changes, by intervention groups.

Variables	DIET Mean ± SD	DIET+LO-EX Mean ± SD	DIET+HI-EX Mean ± SD	Overall Mean ± SD
Weight, kg				
Baseline	92.3±10.3	88.2±9.1	90.1±11.6	90.1±10.2
End of intervention	79.5±11.3*	75.1±8.5*	79.3±9.8*	77.9±9.8*
% change	−14.0±4.6	−14.8±4.4	−11.9±3.7	−13.6±4.3
Lean mass, kg				
Baseline	53.0±3.1	51.5±6.0	51.9±4.4	52.1±4.6
End of intervention	48.8±3.4*	47.6±5.6*	48.7±4.0*	48.3±4.4*
% change	−8.0±3.8	−7.5±2.9	−6.1±3.6	−7.2±3.4
Fat mass, kg				
Baseline	40.7±8.0	37.9±5.8	39.8±8.0	39.4±7.2
End of intervention	32.5±8.5*	29.6±5.8*	32.6±6.6*	31.5±6.9*
% change	−20.9±8.1	−22.0±9.0	−18.0±5.2	−20.4±7.6
Body fat, %				
Baseline	43.0±4.0	42.3±3.8	43.1±3.4	42.8±3.6
End of intervention	39.3±5.2*	38.2±5.0*	39.8±3.6*	39.1±4.6*
% change	−3.7±1.9	−4.1±2.7	−3.3±1.1	−3.7±2.0
VO_2max, ml/min·kg				
Baseline	20.9±3.2	21.0±2.7	18.2±3.4	20.0±3.3
End of intervention	22.5±5.1†	23.7±2.4†	22.2±2.0†	22.8±3.3*
% change	7.7±11.6	14.7±9.8	26.0±27.6	16.4±19.3
VO_2max, ml/min				
Baseline	*1669.6±260.4*	*1786.0±310.8*	*1811.7±263.3*	*1758.4±277.5*
End of intervention	*1649.5±197.3*	*1749.4±319.0*	*1796.8±152.3*	*1734.5±235.4*
% change	*0.5±17.0*	*−1.3±11.9*	*0.5±11.6*	*−0.1±13.2*
Resting metabolic rate, kJ/day				
Baseline	5371.4±628.5	5367.3±1003.1	5572.6±745.0	5435.1±795.4
End of intervention	4783.8±601.3†	4924.7±746.4‡	5246.6±804.2‡	4985.0±726.6*
% change	−10.5±10.6	−4.7±9.6	−5.7±8.7	−6.9±9.7
Physical activity energy expenditure, kJ/day				
Baseline	2300.4±610.5	2336.1±722.2	2434.8±828.3	2356.5±705.6
End of intervention	1601.9±487.6*	1561.2±453.7†	1888.6±581.7‡	1680.3±514.7*
% change	−30.2±12.8	−29.6±25.8	−17.9±23.5	−26.0±21.7

DIET, diet only; DIET+EX-LO, diet plus low-intensity exercise; DIET+EX-HI, diet plus high-intensity exercise. No between group differences were found for all variables at baseline, or changes during intervention.

* $p < 0.001$ comparing with baseline

† $p < 0.01$ comparing with baseline

‡ $p < 0.05$ comparing with baseline

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Table 2

Body weight and changes in weight at 6- and 12-month following completion of weight loss interventions by intervention group.

Variables	DIET	DIET+LO-EX	DIET+HI-EX	overall
End of intervention				
Weight, kg	79.5±11.3	75.1±8.5	79.3±9.8	77.9±9.8
6-month following intervention				
Weight, kg	82.3±13.7	79.0±9.5	81.4±11.7	80.8±11.4
Δ from end of intervention, kg	2.7±3.8[†]	3.9±3.0[*]	2.1±3.0[†]	2.9±3.3[*]
% change	3.2±4.5	5.1±4.2	2.5±3.6	3.6±4.1
12-month following intervention				
Weight, kg	84.2±14.4	81.4±9.6	83.7±14.2	83.1±12.5
Δ from end of intervention, kg	4.7±5.4[†]	6.3±2.4[*]	4.4±6.6[†]	5.2±5.0[*]
% change	5.7±6.6	8.4±3.1	5.3±7.3	6.5±5.9

DIET, diet only; DIET+EX-LO, diet plus low-intensity exercise; DIET+EX-HI, diet plus high-intensity exercise. No between group differences in weight regained during follow-up.

[*] $p < 0.001$ comparing with end of intervention

[†] $p < 0.05$ comparing with end of intervention