Published in final edited form as:
Obesity (Silver Spring). 2011 June ; 19(6): 1177–1181. doi:10.1038/oby.2010.298.

Dietary Adherence During Weight Loss Predicts Weight Regain

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Abstract

This study examined the relationship between previous dietary adherence during a low-calorie diet weight loss intervention and subsequent weight change during a 2-year follow-up for weight maintenance. One hundred and sixteen healthy, recently weight reduced (lost ~12 kg, BMI 22–25 kg/m^2) premenopausal women were studied. Dietary adherence was assessed by doubly labeled water (DLW) and body composition change. Comparisons were made between the upper and lower tertiles for previous dietary adherence and subsequent weight change at 1- and 2-year follow-up. Percent weight regained was significantly lower (30.9 ± 6.7% vs. 66.7 ± 9.4%; $P < 0.05$) in the upper compared to the lower adherence tertile for previous weight loss dietary adherence (49.9 ± 8.8% vs. 96.8 ± 12.8% $P < 0.05$) at 1- and 2-year follow-up, respectively. This difference was partly explained by increases in daily activity-related energy expenditure (AEE) (+95 ± 45 kcal/day vs. −44 ± 42 kcal/day, $P < 0.05$) and lower daily energy intake (2,066 ± 71 kcal/day vs. 2,289 ± 62 kcal/day, $P < 0.05$) in the higher tertile for previous dietary adherence, compared to the lower. These findings suggest that higher adherence (i.e., higher tertile) to the previous low-calorie diet predicts lower weight regain over 2-year follow-up for weight maintenance, which is explained by lower energy intake and higher physical activity. Finally, how well an individual adheres to a low-calorie diet intervention during weight loss may be a useful tool for identifying individuals who are particularly vulnerable to subsequent weight regain.

INTRODUCTION

Over 60% of the adults in the United States are overweight. Decreased caloric intake and increased physical activity remain the first line of treatment for most weight management programs. Low-calorie diets typically require a significant commitment by the individual and adherence to these programs leads to a wide range of weight loss and the subsequent weight regain (1–4). Dansinger *et al*. (5) has shown a strong curvilinear association ($r = −0.60$) between self-reported dietary adherence and weight lost in overweight and obese patients. Recently, Del Corral *et al*. (6) quantified dietary adherence by coupling doubly labeled water (DLW) measurements of energy expenditure to body energy stores before and

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Disclosure
The authors declared no conflict of interest.

after a dietary intervention. The findings of that study indicated that good dietary adherence was associated with lower number of days to reach target BMI ($r = -0.69$), and with lower %caloric restriction ($r = -0.35$).

The prevention of weight regain depends on the individual's adherence to a target energy balance. Transitioning from caloric deficit to energy balance has proven difficult with many studies showing a wide range of weight regain (2,3). Most studies report group means and it is difficult to discern whether adherence to diet during weight loss is associated with subsequent dietary adherence during weight maintenance after the intervention has ended.

We examined the effect of prior dietary adherence during a low-calorie diet on subsequent weight regain during 2 years of follow-up in a group of premenopausal women who had recently undergone weight loss via a controlled intervention, and upon whom measures of dietary adherence were available (6). We hypothesized that good dietary adherence to a low-calorie diet would predict subsequent weight regain during a 2-year follow-up period of aiming at weight maintenance.

METHODS AND PROCEDURES

Subjects

The present study was conducted as part of an ongoing randomized clinical investigation designed to examine the metabolic factors that predispose premenopausal women to weight regain following weight loss. The subjects were healthy, weight reduced (BMI 20–25 kg/m^2) premenopausal women who had recently lost 12.2 ± 0.27 kg to bring their BMI <25 on a low-calorie diet (800 kcal/day) that generated a wide range (23–72%) of %caloric restriction (6). A subset of the women completed follow-up evaluations at 1 and 2 years. Data were collected at each time point at an in-patient visit at the Pittman General Clinical Research Center (GCRC) at the University of Alabama at Birmingham. This study was approved by the University of Alabama at Birmingham institutional review board for Human Use and subject consent was obtained before all testing.

Study design

The overall study time line is as follows and is illustrated in Figure 1.

Before the baseline assessment, which took place immediately after the women completed weight loss, all women completed 4 weeks of supervised weight maintenance.

During the first 2 weeks, subjects consumed their own foods and during the final 2 weeks, the GCRC provided a macronutrient-controlled diet (20–23% of energy from fat, 20–23% from protein, and 56–59% from carbohydrate) with energy content appropriately adjusted by a dietitian to ensure a stable body weight (subjects were weighed three to five times weekly). Also, during the last 2 weeks, DLW was used to estimate energy requirements. The 4-week weight maintenance phase ended with a 4-day in-patient stay at the GCRC where comprehensive metabolic studies were completed, including resting metabolic rate (RMR), fitness testing, and a packet of questionnaires to assess dieting history and socioeconomic status (SES). Dieting history was measured with a brief questionnaire specific to this study, as previously described (7). We also assessed SES of women enrolled in the study with the Hollingshead 4-factor index of social class (8), with higher scores reflecting greater SES. Following the in-patient visit, participants underwent diet education. Subjects were asked to return at 1 and 2 years after weight loss for evaluation to repeat the 4 weeks of supervised weight maintenance described above. During the 1st year of follow-up, study participants participated in bimonthly dietary education class aim at weight maintenance (energy needs,

food portions, nutrition labels, healthy food choices, and behavioral strategies) for the first 6 months, then it became monthly for months 6th to 12th.

Body composition

Body composition was assessed under the weight reduced state and at 1- and 2-year follow-up visits by dual-energy X-ray absorptiometry (GE-Lunar-Prodigy, Madison, WI), all measurements were performed during the last 2 weeks of the supervised weight maintenance. Scans were analyzed for total fat and total lean mass using the software (Encore 2002, Version 6.10.029).

Energy expenditure studies

The DLW technique was used to measure total energy expenditure (TEE) before and after the weight loss intervention, and at 1-year follow- up, as previously described (9). In brief, a baseline urine sample (10 ml) was collected followed by a mixed oral dose (≈0.10 g/kg ^{18}O and 0.08 g ^{2}H/kg body mass) administration of DLW. The average initial isotope enrichments of two urine samples was obtained morning after dosing and on the 14th day, two additional final samples were obtained and results averaged. All urine samples were analyzed in triplicate for ^{2}H and ^{18}O by isotope ratio mass spectrometry at the Metabolism Core Laboratory of the Clinical Research Nutrition Center and the GCRC at our institution. Activity-related energy expenditure (AEE) was quantified as the level of energy expenditure above RMR. It was estimated by subtracting RMR from TEE. This was calculated after adjusting (10%) TEE for the thermic response to meals. The RMR assessment was performed as previously described (10). Briefly, three consecutive mornings after an overnight stay in the GCRC and 12-h fast, RMR was measured immediately after awakening between 6 and 7 AM. The RMR was measured for 30 min with a computerized, open-circuit, indirect calorimetry system with a ventilated canopy (Delta Trac II; Sensor Medics, Yorba Linda, CA). We report the average RMR for the three consecutive mornings. The RMR, TEE, and AEE during weight loss and 1-year follow-up represent averages obtained under energy balance before and after.

Adherence to diet and dietary intake

The method for determining adherence to diet during the weight loss phase has been previously reported (6). In brief, a series of calculations was used to develop an estimate of dietary adherence based on DLW-derived TEE and body energy store change determined by DXA, both determined before and after the weight loss intervention. The resulting dietary (800 kcal/day) adherence during weight loss was dichotomized to examine its effect on subsequent weight regain. Women in the lower tertile for dietary adherence had a metabolized energy intake (MEI) of 1,573 ± 33 kcal/day referred as low adherence (Lo-Ad) were compared to those in the higher tertile (MEI 644 ± 74 kcal/day), referred as high-adherence (Hi-Ad). For the weight maintenance phase, DLW and body energy stores were quantified as previously described (6), under the weight reduced state and at ~1 year of weight maintenance. Body energy stores in fat mass and fat-free mass were converted to energy by using energy coefficients of 12 and 1.8 kcal/g, respectively. If subjects lost fat and/or fat-free mass, an energy coefficient of 9.3 and 1.1 kcal/g were used, respectively (11,12). MEI during 1st year follow-up was calculated as the average TEE (i.e., under energy balance, before and after the 1-year follow-up, in kcal/day) + ΔEnergy stores (kcal/day).

Statistics

The differences in age, anthropometric (BMI, body weight), and metabolic (TEE, AEE, RMR, MEI) parameters between the Hi-Ad and Lo-Ad groups was assessed by independent

sample *t*-test. Between group differences for TEE, AEE, RMR data were also analyzed after adjusting for fat mass and fat-free mass by analysis of covariance. A repeated measures ANOVA was used to examine differences in %weight regain between dichotomized groups. Pearson correlations were used to examine associations between %weight regain and dietary adherence during previous weight loss, rates of weight loss, MEI during weight loss, attendance to dietary education, and MEI during 1-year follow-up. All analyses were conducted using SPSS statistical package (version 16.0). Results are expressed as means ± s.e.

RESULTS

A total of 141 subjects started the weight maintenance phase. Of these 116 had DLW evaluated and were ranked by tertile for dietary adherence (lower tertile = 39, middle tertile = 38; upper tertile = 39). No differences in BMI or %fat were observed between the 116 women that complete data was obtained and the 25 women that did not have complete data. Of these, 95/116 (lower tertile = 29/39, middle tertile = 30/38; upper tertile = 36/39) and 59/116 (lower tertile = 19/39, middle tertile = 20/38; upper tertile = 19/39) completed the 1- and 2-year follow-up, respectively. Most dropouts were due to loss of interest (48/58); other reasons included moved from the area (three), marriage (two), unknown/could not be reached (five). Dropouts had higher SES (55.9 ± 2.8 vs. 46.7 ± 1.2; $P = 0.003$), adhered less to the diet (i.e., ate more: 1,366 ± 74 kcal/day vs. 1,128 ± 43 kcal·kg·day^{-1}; $P = 0.018$) and were more calorically restricted (a larger % difference between expenditure and intake during weight loss, 61.1 ± 0.9% vs. 58.5 ± 0.6%, $P = 0.033$) during the weight loss phase of the study, compared to study completers. The results of this study are based on study participants who completed at least 1 year of follow-up measurements and are dichotomized by their prior dietary adherence during the weight loss intervention.

Table 1 shows there were no differences in the means for age, height, body mass, dietary attempts, SES, or parity between adherence groups at the weight reduced state. However, the number of days to reach target weight was lower (112 ± 7 day vs. 216 ± 11 day; $P < 0.001$) and the rates of weight loss were higher (126.5 ± 7.7 g/day vs. 56.9 ± 2.7 g/day; $P < 0.001$) in the Hi-Ad group, compared to the Lo-Ad. The Hi-Ad group regained less weight at 1 ($P < 0.001$) and 2 ($P < 0.01$) years of follow-up, compared to the Lo-Ad group; virtually all the weight gained was accounted by fat gain. During the 1st year of follow-up, attendance to dietary education tended to be higher in the Hi-Ad group (Table 1). Figure 2 shows lower %weight regain (31.0 ± 5.0% vs. 68.7 ± 6.4% $P < 0.001$ at 1-year follow-up and 51.6 ± 9.5% vs. 99.0 ± 12.3% $P < 0.01$ at 2-year follow-up) in the Hi-Ad group compared to the Lo-Ad group.

Table 2 shows the RMR, TEE, AEE, and MEI in Lo-Ad ($n = 28/29$) and Hi-Ad ($n = 23/36$) with complete data for all time points. During the initial weight loss phase, there were significant differences in TEE and AEE between groups, which did not extend during 1st year of follow-up. No differences were noticed in RMR at baseline or 1-year follow-up. During the transition from weight reduced to the 1st year of follow-up, the Hi-Ad group had a higher Δ-TEE (64 ± 47 kcal/day vs. −69 ± 48 kcal/day, $P = 0.05$) and Δ-AEE (by 95 ± 45 kcal/day vs. −44 ± 42 kcal/day, $P < 0.05$), compared to the Lo-Ad, respectively. These differences were enhanced when the Δ-TEE and Δ-AEE were adjusted for changes in fat mass and fat-free mass. The daily kcal gained from energy stores calculated from fat and fat-free tissue were significantly lower (135 ± 21 kcal/day vs. 266 ± 25 kcal/day, $P < 0.001$) for the Hi-Ad compared to the Lo-Ad group. During the 1st year of follow-up, the MEI was significantly lower (2,066 ± 71 kcal/day vs. 2,289 ± 62 kcal/day, $P < 0.05$) for the Hi-Ad compared to the Lo-Ad group. Additionally, Table 2 also shows RMR, TEE, AEE, and MEI variables adjusted for fat mass and fat-free mass. Figure 3 illustrates differences in MEI

pattern during the previous weight loss and 1st year follow-up (in the same subset of subjects as in Table 2), indicating lower values for the Hi-Ad group across time, compared to the Lo-Ad.

The %weight regain at 1 and 2 years of follow-up were significantly correlated to dietary adherence during prior weight loss ($r = -0.405$, $P = 0.001$; $r = -0.310$, $P < 0.05$), prior rates of weight loss ($r = -0.435$, $P < 0.001$; $r = -0.276$, $P < 0.05$), attendance to dietary education during 1 year of follow-up ($r = -0.24$, $P < 0.05$; $r = -0.158$, P = NS), MEI during prior weight loss ($r = 0.373$, $P < 0.001$; $r = 0.300$, $P < 0.05$), and MEI during 1-year follow-up ($r = 0.462$, $P < 0.0001$; $r = 0381$, $P < 0.01$), respectively.

DISCUSSION

The primary finding for this study is that those individuals who did a better job of adhering to a low-calorie diet that induced 12 kg weight loss regained less weight the 1st and 2nd year following the weight loss. The differences were quite dramatic with the Hi-Ad group regaining only 6.30 kg (50%) and the Lo-Ad group regaining 11.46 kg (99%) of their weight lost over the course of 2 years. In addition, the difference in MEI between the low- and high-adherence groups was ~200 kcal/day. This finding indicates that prior adherence to a low-calorie diet intervention may be a useful tool for identifying individuals who are at particular risk for subsequent weight regain for at least 2 years.

We examined the components of energy balance to explore the differences in tissue accrued over the 1-year weight maintenance period. During the weight loss phase, the Lo-Ad group actually had slightly higher AEE and TEE than the Hi-Ad group. In contrast, during the weight maintenance phase, AEE and TEE did not differ between groups. Further analysis indicated that in transitioning from weight loss to weight maintenance, subjects in the Hi-Ad group increased their TEE (primarily through increased AEE), whereas those in the Lo-Ad group decreased AEE and TEE, findings became more robust when we adjusted for changes in fat mass and fat-free mass. Neither group was able to increase physical activity to the required level to match dietary intake, preventing weight regain. In any event, although it is impossible to determine from our results whether the increase in AEE was intentional, it can be suggested that Δ-AEE was an important strategy for slowing weight regain in the Hi-Ad group. Several studies, including one by us, have shown that AEE is lower in individuals who gain weight over 1 year than in individuals who maintain weight (13,14). The significant different change in AEE between the Hi-Ad and the Lo-Ad during follow-up suggests that the Hi-Ad in this study may have used physical activity as a tool for assisting in weight management.

As illustrated in Figure 3, our results indicated that dietary adherence played a major role in successful weight loss and attenuated weight regain more effectively in the Hi-Ad compared to the Lo-Ad group. Few studies have attempted to quantify dietary adherence. Dansinger *et al*. (5) have shown a strong curvilinear association ($r = -0.60$) between self-reported dietary adherence and weight lost in overweight and obese patients. Others have suggested that programs using regular face-to-face contact enhance adherence to diet during weight maintenance (15) and that keeping dietary records via internet is inversely associated with weight regain (16). In keeping with these findings, weight regain at 1-year follow-up was inversely associated ($r = -0.24$, $P < 0.05$) to dietary education attendance. Recently, our laboratory (6) quantified dietary adherence, showing a robust association between dietary adherence and number of days to weight loss goal ($r = -0.69$) and %caloric restriction ($r = -0.349$). In this follow-up study, we show that the women who adhered the most during the weight loss phase regained a lower fraction of body weight for at least 2 years. Taken together, the above has important practical implications because the degree of dietary

adherence during weight maintenance will determine the required amount of moderate physical activity required (i.e., 30–120 min·day^{-1}) to prevent weight regain. To the best of our knowledge, there is no prior study that quantified dietary adherence and %caloric restriction during weight loss and linked it to long-term weight regain.

Attrition in this study was 50% across the 2 years using healthy premenopausal women who were compensated for their time. Most dropouts were due to loss of interest. Dropouts had higher SES, and during the weight loss phase were more calorically restricted (larger difference between energy expenditure and energy intake, 61% vs. 59%) and overate more ~240 kcal/day (i.e., 1,366 vs. 1,128 ± 43 kcal·kg·day^{-1}), compared to study completers. It is plausible that the rigorous weight loss intervention that our participants went through induced psychological fatigue in susceptible individuals (17). It is critical to develop tools to identify potential dropouts early on and follow them closely. Future studies should also examine strategies that might attenuate attrition and enhance dietary adherence.

In summary, this study presents a key finding; the greater the dietary adherence to a low-calorie diet during weight loss, the lower the %weight regain during 2 years of follow-up. Our results suggest that milder overeating and increased physical activity seem to be strategies used by the Hi-Ad group to temper weight regain, compared to the Lo-Ad group, which had greater overeating and lower physical activity. The knowledge of how well individuals adhere to low-calorie diets during weight loss may be a useful tool for identifying individuals who are particularly vulnerable to subsequent weight regain. For instance, health-care providers may use the rate of weight loss as a proxy measure of dietary adherence. Finally, the translation of our findings will require substantial assistance from behaviorists to encourage adherence to weight maintenance diets, this in turn will modulate the amount of physical activity required to prevent weight regain.

Acknowledgments

We thank our sources of support: NIH grants R01 DK 49779 and R01 DK51684, General Clinical Research Center grant M01-RR00032, Clinical Nutrition Research Unit grant P30-DK56336, and UAB University-Wide Clinical Nutrition Research Center grant. The NIH grants R01 DK 49779 and R01 DK51684. The Nestlé Food Co. (Solon, OH) provided the Stouffer's Lean Cuisine entrées. We appreciate LuAnn Johnson for assistance with statistical analysis.

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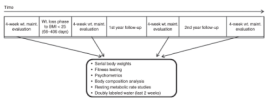

Figure 1.
Study timeline.

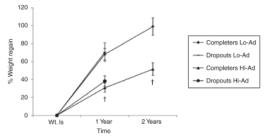

Figure 2.

Percent weight regain at 1 and 2 years, dichotomized by dietary adherence during the initial weight loss phase. Lo-Ad (low-dietary adherence) and Hi-Ad (high-dietary adherence) during weight loss. $^{\dagger}P < 0.05$, significantly difference between Lo-Ad and Hi-Ad. Wt. ls, weight loss.

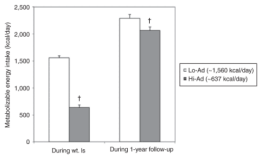

Figure 3.

Metabolizable energy intake during the weight loss phase and 1st year follow-up, dichotomized by dietary adherence during the initial weight loss phase. Lo-Ad (low-dietary adherence, $n = 28$) and Hi-Ad (high-dietary adherence, $n = 23$) during weight loss, †Statistical significance ($P < 0.05$) between Hi-Ad and Lo-Ad group. Wt. ls, weight loss.

Table 1

Subject characteristics in the weight reduced state, after 1 and 2 years after weight loss; dichotomized by dietary adherence during previous weight loss

	Low adherence	High adherence	Group effect *P* value
Age (years)	35.0 ± 1.1	33.4 ± 1.1	*P* = 0.322
Height (m)	1.66 ± 0.01	1.65 ± 0.01	*P* = 0.924
Parity	0.96 ± 0.20	1.1 ± 0.17	*P* = 0.583
Socioeconomic status	48.0 ± 1.5	45.9 ± 1.6	*P* = 0.370
Number of diet attempts	4.5 ± 0.8	4.1 ± 0.6	*P* = 0.690
Body mass at weight loss (kg)	66.8 ± 1.1	64.5 ± 1.1	*P* = 0.160
Weight loss (kg)	11.69 ± 0.48	12.63 ± 0.45	*P* = 0.163
Days to goal (day)	216 ± 11	112 ± 7[a]	*P* < 0.001
Rate of weight loss (g/day)	56.9 ± 2.7	126.5 ± 7.7[a]	*P* < 0.001
1-Year attendance to dietary education (%)	47.1 ± 6.0	61.4 ± 4.9	*P* = 0.067
1-Year weight gained (kg)	7.93 ± 0.85	3.91 ± 0.50[a]	*P* < 0.001
1-Year fat gain (kg)	7.62 ± 0.70	3.85 ± 0.58[a]	*P* < 0.001
2-Year weight gained (kg)	11.46 ± 1.32	6.30 ± 1.06[a]	*P* < 0.01
2-Year fat gained (kg)	11.10 ± 1.23	5.25 ± 1.03[a]	*P* < 0.01

Days to goal was defined as the number of days to reach target weight loss during the previous weight loss phase of the study (6).

[a] Significantly difference between low adherence and high adherence.

Table 2

Energy balance characteristics during weight loss and 1 year after weight loss, dichotomized by dietary adherence during a previous weight loss intervention (ref. 6)

	Low adherence (n = 28)	High adherence (n = 23)	P value
RMR during weight loss	1,353 ± 22	1,297 ± 29	$P = 0.12$
Adjusted[a]	1,334 ± 19	1,319 ± 21	$P = 0.62$
TEE during weight loss	2,092 ± 50	1,866 ± 60[b]	$P < 0.01$
Adjusted[a]	2,069 ± 51	1,895 ± 57[b]	$P < 0.05$
AEE during weight loss	530 ± 44	377 ± 49[b]	$P < 0.05$
Adjusted[a]	527 ± 46	380 ± 51[b]	$P < 0.05$
RMR following weight loss	1,335 ± 26	1,264 ± 29	$P = 0.08$
Adjusted[a]	1,311 ± 21	1,293 ± 23	$P = 0.60$
TEE following weight loss	2,023 ± 53	1,931 ± 66	$P = 0.28$
Adjusted[a]	2,004 ± 58	1,953 ± 64	$P = 0.58$
AEE following weight loss	485 ± 45	473 ± 55	$P = 0.85$
Adjusted[a]	492 ± 49	465 ± 55	$P = 0.72$
Δ-RMR	−18 ± 11	−32 ± 8	$P = 0.30$
Adjusted[a]	−17 ± 10	−33 ± 11	$P = 0.35$
Δ-TEE	−69 ± 48	64 ± 47[b]	$P = 0.05$
Adjusted[a]	−113 ± 45	117 ± 51[b]	$P < 0.01$
Δ-AEE	−44 ± 42	95 ± 45[b]	$P < 0.05$
Adjusted[a]	−84 ± 42	143 ± 47[b]	$P < 0.01$
Total kcal gained	98,764 ± 8,531	51,148 ± 7,987[b]	$P < 0.001$
kcal gained/day	266 ± 25	135 ± 21[b]	$P < 0.001$
MEI during weight loss	1,560 ± 35	637 ± 49	$P < 0.001$
MEI following weight loss	2,289 ± 62	2,066 ± 71[b]	$P < 0.05$
Δ-MEI	728 ± 53	1,429 ± 90[b]	$P < 0.001$

Activity-related energy expenditure (AEE), metabolized energy intake (MEI), resting metabolic rate (RMR), and total energy expenditure (TEE) are all expressed in kcal/day.

[a] Adjusted: variables were adjusted for fat mass and fat free mass.

[b] Significant difference between low and high adherence.