

Long-Term Effects of Energy-Restricted Diets Differing in Glycemic Load on Metabolic Adaptation and Body Composition*

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Abstract: A randomized controlled trial of high glycemic load (HG) and low glycemic load (LG) diets with food provided for 6 months and self-administered for 6 additional months at 30% caloric restriction (CR) was performed in 29 overweight adults (mean±SD, age 35±5y; BMI 27.5±1.5 kg/m²). Total energy expenditure (TEE), resting metabolic rate (RMR), fat and fat free mass (FFM), were measured at 3, 6 and 12 months. Changes in TEE, but not changes in RMR, were greater than accounted for by the loss of FFM and fat mass (P=0.001-0.013) suggesting an adaptive response to long-term CR. There was no significant effect of diet group on change in RMR or TEE. However, in subjects who lost >5% body weight (n=26), the LG diet group had a higher percentage of weight loss as fat than the HG group (p<0.05), a finding that may have implications for dietary recommendations during weight reduction.

Keywords: Glycemic load, caloric restriction, body weight, metabolic rate.

INTRODUCTION

The question of whether low glycemic index (GI) or low glycemic load (LG) diets facilitate greater weight loss and prevention of weight regain remains controversial, with some studies reporting benefits compared to high glycemic load (HG) diets [1-5] and other studies finding no such effect [5-10]. Further information on the effects of dietary GI and glycemic load (GL) on parameters related to long-term weight loss success is thus needed.

Information on the effects of HG and LG diets on metabolic adaptation and body composition may help determine whether one diet or the other is more beneficial for long-term weight control. Metabolic adaptation can be defined as a change in energy expenditure with weight gain or loss over and above that accounted for by the change in body fat free mass (FFM) and fat mass, and may potentially impact long-term weight loss success. Some studies have reported that metabolic adaptation occurs during weight loss and/or subsequently [11-18] while others have found no evidence for this phenomenon [19-25]. In part, the different results obtained may be due to different mathematical approaches to calculating metabolic adaptation, as well as the duration and severity of caloric restriction (CR) [26]. However, it is also possible that the macronutrient composition of the diets used may have influenced the results, as two recent short-term studies from the same group [15, 16] suggested greater

reductions in resting energy expenditure in subjects randomized to an energy-restricted HG diet compared to an LG diet.

Concerning the effects of GL on body composition, little information is currently available because most trials of dietary GL have reported only changes in body weight [1, 2, 4-6, 8]. One short-term study detected a non-significant trend toward a relative increase in nitrogen accretion in individuals consuming a LG diet compared to a HG diet [15], a finding consistent with a study in animals indicating relatively greater fat mass and lesser FFM after consumption of a HG diet compared [27] to a LG diet. However, another human study did not observe a significant difference in percent fat loss between individuals consuming HG and LG diets, [16] and thus further studies in this area are needed.

The objective of this study was to conduct further analyses on data from the first phase of the CALERIE (Comprehensive Assessment of the Long-term Effects of Restricting Intake of Energy) trial at Tufts University [10, 28], specifically to examine the effects of dietary GL on metabolic adaptation and the composition of weight loss during a 1 year CR intervention.

SUBJECTS AND METHODS

Study Population and Protocol

The subjects were 29 overweight but otherwise healthy men and women aged 24-42 years who completed the first phase of the CALERIE trial at Tufts University, having been randomized to the 30% CR arm of the protocol. CALERIE is a coordinated multi-center study of CR in human health and aging, and during this first phase, independent studies were conducted at the different sites. Details of the study eligibility criteria as well as the protocol are described elsewhere

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[10, 28]. Briefly, this year long intervention study included a 7-week baseline weight maintenance period (Phase 1), after which subjects were randomized to a HG load diet or a LG load diet and all food was provided at 70% of individual baseline weight maintenance energy requirements for 24-weeks (Phase 2). A second level of short term interventions during Phase 2 of the study tested common variations in dietary protocols, and involved serial short-term randomizations to: i) 6-week period of extra fiber (20 g/day from a high fiber breakfast cereal) or no extra fiber at 5-10 weeks of caloric restriction, and ii) a 6-week period at 15-20 weeks of caloric restriction when subjects were either offered or not offered the option of substituting 1000 kcal/week of food of their own choosing for 1000 kcal/week of study food. Both options were available to all participants after the randomization period. Neither of these secondary randomizations had significant effects on energy intake, body weight change or dietary satisfaction within the randomization period, and neither had a significant interaction in the analyses testing the effects of the primary randomization on body weight and other main outcomes at 6 or 12 months. Phase 3 occurred over the next consecutive 24 weeks, when subjects were given regular instruction in how to take over all responsibility for food preparation to continue their regimen at home. The study was conducted at the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University with approval by the Institutional Review Board of Tufts-New England Medical Center Hospital. All subjects gave written, informed consent prior to participating, and were provided with a stipend.

Study Diets

Details of the study diets have been described elsewhere [10, 28]. The diets differed in macronutrients and glycemic load (HG: 60% carbohydrate, 20% fat, 20% protein with a glycemic load of 118.3 ± 4.1 g/1000 kcal vs LG: 40% carbohydrate, 30% fat, 30% protein with a glycemic load of 45.4 ± 4.6 g/1000 kcal) and the carbohydrate sources in the LG diet were lower in GI based on published GIs of different foods [29]. Also as described previously [10], the diets contained equivalent amounts of fiber and had similar energy density. Since the largest difference between the diets is in GL, the diets are described as HG and LG diets. **Daily Glycemic Load** = daily GI x total available carbohydrate (g for day)/1000 kcal (and available carbohydrate for each food = total grams carbohydrate – total dietary fiber). Please note that although technically it would have been possible to change GL between the diets by changing just carbohydrate and fat (and leaving protein constant), in that approach it would have been hard to control other factors between the diets including palatability and energy density. Using the chosen approach, it was possible to match the diets for dietary variety, and palatability (assessed using a visual analog scale, VAS, during pilot testing of the diets). All subjects were also provided with one half of a multivitamin supplement and 500 mg/day of calcium.

All food was provided at the 30% reduced CR prescription to subjects during the first 6 months of the CR intervention. Subjects were asked to consume only the provided food and were requested to bring back their leftover foods from the provided foods and these were weighed and the amounts were recorded on the data recording sheets. Allowances were

made on days such as Thanksgiving and Christmas (or other infrequent special requests) and subjects were given non-perishable foods and menu suggestions when traveling. Intake was self-recorded during these times. Subjects or their designated representative came to the research center twice a week to pick up meals.

During the second 6 months, subjects were instructed to self-select and prepare their own food at home to maintain their randomization. To prepare for this phase, subjects worked with the study dietitian to develop an individualized plan which included menus, recipes, portion sizes and food lists that were consistent with their randomized diets, prescribed calorie levels, and food preferences. Food scales were provided to help with appropriate portioning and subjects participated in a preparatory grocery store tour and cooking class.

Body Weight and Height

Body weight was measured at weekly intervals to ± 0.01 kg (DETECTO-Cardinal Scale Manufacturing Co. Model CN-20, Webb City, MO). Height was measured during baseline using a wall-mounted stadiometer.

Body Composition

Body composition was measured in duplicate at baseline and at 3, 6 and 12 months using air displacement plethysmography (BOD POD[®], Life Measurement, Inc, Concord, CA). The details of this method and the underlying principles were described previously [30, 31]. Briefly, measurements were conducted with the subject in a Lycra-style swim cap and minimal skin-tight shorts or underwear while subjects were dry and in the resting state according to the manufacturer's instructions. Body weight was measured to the nearest 1 g on the instrument's electronic scale that was calibrated daily. After the standard calibration of the plethysmograph's chamber, subjects entered the chamber for measurements of raw body volume and thoracic gas volume (V_{TG}). V_{TG} measurements were repeated until a figure of merit value less than 1.0 (signifying compliance) was obtained for all subjects. The obtained V_{TG} and the average of two raw body volume measurements that agreed within 0.2 % was used in subsequent calculations. Body density was calculated as body weight/body volume, where body volume was corrected for V_{TG} and a surface area artifact as described previously [31]. Body weight and the corrected body volume were used to calculate body density, and body fat percent was derived using the two-compartment Siri formula [32]. Calculations were performed by the BOD POD's software (version 2.14). Percentage of weight lost as fat and FFM was calculated using the body composition variables derived from this method. The test-retest coefficient of variation for percent body fat measured by BOD POD in human adults is $1.7\% \pm 1.1\%$ [30].

Resting Metabolic Rate (RMR)

RMR was measured on two mornings at baseline and at 6 months and 12 months of CR, after the subject slept overnight in the research center and fasted for 12 hours according to our usual procedures [10]. Measurements were obtained with subjects resting supine in comfortable thermo neutral conditions by indirect calorimetry (Deltatrac portable metabolic cart, Sensor Medics Corp., Yorba Linda, CA) and sub-

jects were instructed to relax and avoid hyperventilation, fidgeting or sleeping during measurements. Measurements of oxygen consumed (VO_2) and carbon dioxide produced (VCO_2) were obtained for 40 minutes, and the last 30 minutes of the data were used to calculate RMR using de Weir's equation [33]. The calorimeter was assessed periodically with an alcohol burn test to ensure that the accuracy of the measurements was within $\pm 1\%$.

Total Energy Expenditure (TEE)

TEE of the subjects was measured in duplicate over successive 14-day periods at baseline and additional 14-day measurements were made at 3, 6 and 12 months of CR. This standard, non-radioactive isotopic method has been extensively validated and is described elsewhere [34, 35]. Briefly, at the start of each TEE measurement, subjects fasted overnight and were given an oral dose of doubly labeled water ($^2\text{H}_2^{18}\text{O}$) containing 0.22 g $\text{H}_2^{18}\text{O}/\text{kg}$ total body water and 0.115 g of $^2\text{H}_2\text{O}/\text{kg}$ total body water following collection of 2 independent baseline urine specimens. Subjects were then required to remain fairly sedentary and not to consume any food or water while urine samples were collected from complete voids made at 3, 4.5 and 6 hours after dose administration. After completion of urine collections, subjects were discharged from the unit and carried out their usual daily activities for 14 days, with supervised urine specimen collection on days 7 and 14. All samples were aliquoted in duplicates into airtight storage tubes (Sarstedt – No 62.547.004) immediately after collection, and stored at -20°C .

Abundances of H_2^{18}O and $^2\text{H}_2\text{O}$ in dilutions of the isotope doses and in urine specimens were measured in duplicate using isotope ratio mass spectrometry [36] and deuterium was prepared for analysis using an automated chromium reduction system [37]. The urine samples were analyzed at the Pennington Biomedical Research Center (Baton Rouge, LA). Isotope elimination rates (k_i and k_o) were calculated using linear regression of logged values, and CO_2 production was calculated using the equations of Schoeller *et al.* [38], with the modifications by Racette *et al.* [39]. TEE was then calculated based on an assumed respiratory quotient (RQ) of 0.86. Please note that quite large errors in RQ have a small effect on the error of calculations of TEE [40].

Measurements of TEE obtained at 3, 6 and 12 months during the CR intervention were used to calculate the actual energy intake of the subjects at these time periods. Since energy intake is equal to TEE plus change in energy balance (when a subject is not in neutral energy balance), TEE data can be used to calculate a value for energy intake unbiased by subject reporting, by correcting for the estimated change in body energy stores during the same period based on weight change [41]. Individual values for weight change during the DLW period were calculated from the regression of daily measurements of body weight made for up to 7 days before and 7 days after the period of TEE measurements (for maximum of 28 days). The energy content of weight change was calculated assuming a energy content of weight loss of 7.4 kcal/g [26].

Statistics

Statistical analyses were performed using SAS for Windows (version 9.1, SAS Institute, Cary, NC). Values are expressed as mean \pm SD unless otherwise specified. Two dif-

ferent mathematical approaches were used to examine metabolic adaptation because different approaches can give different results and there is no consensus about which, if any, procedure is more valid. The first approach used paired t tests to compare measured and predicted values for RMR and TEE for each individual at 3, 6 and 12 months of CR. Predicted RMR values were determined from regression equations developed using i) baseline FFM alone, and ii) using both baseline FFM and fat mass, as independent variables. Predicted TEE values were determined from regression equations developed using i) baseline body weight, and ii) using both baseline FFM and fat mass, as independent variables. The second approach to examining metabolic adaptation in RMR was to compute changes in RMR from baseline to 3, 6 and 12 months of CR adjusted for changes in FFM and fat mass using mixed model regression analyses. Mixed models were also used to examine differences between diet groups in percent changes from baseline in RMR, TEE, RQ and PAL. Independent sample t-tests were used to examine the differences in percent of weight lost as fat mass and as FFM. For this analysis we used data for all subjects with complete data (N = 29; 15 HG, 14 LG) as well as a subset of subjects (N = 26; 13 HG, 13 LG), with weight loss $>5\%$ at 6 months. The justification for analyzing the subset was: i) individuals with $<5\%$ weight loss were non-adherent to the dietary regimens and thus their inclusion would include individuals who were non-compliant and eating other foods of unknown composition as well as the provided diet; ii) there are inherent methodological errors in body composition assessment that are substantial for small amounts of weight loss. All P values were two-sided and a P value of 0.05 or less was considered to indicate statistical significance.

RESULTS

There were no statistically significant differences between the diet groups for any of the baseline variables as shown in Table 1.

Table 1. Baseline Subject Characteristics^a

	HG Diet	LG Diet
Age (y)	35 \pm 5	35 \pm 6
Gender		
<i>Males</i>	3	3
<i>Females</i>	12	11
Height (cm)	168.7 \pm 11.0	168.2 \pm 10.6
Weight (kg)	78.5 \pm 12.3	78.0 \pm 9.4
BMI (kg/m^2)	27.4 \pm 1.7	27.5 \pm 1.3
% Body Fat	35.0 \pm 7.1	35.2 \pm 8.7
Fat free mass (kg)	51.2 \pm 11.3	50.7 \pm 10.5
RMR (MJ/day)	6.62 \pm 1.1	6.72 \pm 0.8
Resting RQ	0.85 \pm 0.02	0.84 \pm 0.04
TEE (MJ/day)	12.10 \pm 2.3	11.71 \pm 1.5

^aValues are means \pm SD. HG - high glycemic load diet (N=15), LG - low glycemic load diet (N=14), RQ - respiratory quotient. Using independent sample t-tests, no statistically significant differences were observed between the diet groups for the baseline variables.

Metabolic Adaptation in Relation to Weight Change and Diet Randomization

Fig. (1) shows data for the measured and predicted RMR at 3, 6 and 12 months of CR, with predicted values calculated as described in the statistics section above. At baseline, both FFM and fat mass significantly and positively predicted RMR ($R^2 = 0.81$, $P < 0.001$). At all time points during the intervention, the correlation between predicted and measured RMR was higher when the regression equation included both FFM and fat mass as independent variables versus when only FFM was used. When only FFM was used in the regression equation, predicted RMR was significantly higher than measured RMR ($P < 0.0001$ at 3 months; $P = 0.003$ at 6 months and $P = 0.001$ at 12 months) but when both FFM and fat mass were used there was no significant difference between meas-

ured and predicted RMR at any time point ($P = 0.36$ at 3 months; $P = 0.22$ at 6 months and $P = 0.25$ at 12 months). There was also no significant effect of diet group on the difference between measured RMR and RMR predicted from FFM alone or from FFM and fat mass at any time point ($P = 0.19-0.95$).

Fig. (2) shows measured versus predicted TEE, with predicted values calculated as described in Statistics. At all time points during CR, measured TEE was significantly lower than TEE predicted from fat and FFM ($P \leq 0.01$) but not significantly different from TEE predicted from body weight ($P = 0.40-0.44$). With regards to diet groups effects on TEE, the difference between measured TEE and TEE predicted from FFM and fat mass was significantly higher ($P = 0.02$) in the LG group only at 3 months, and this difference was not

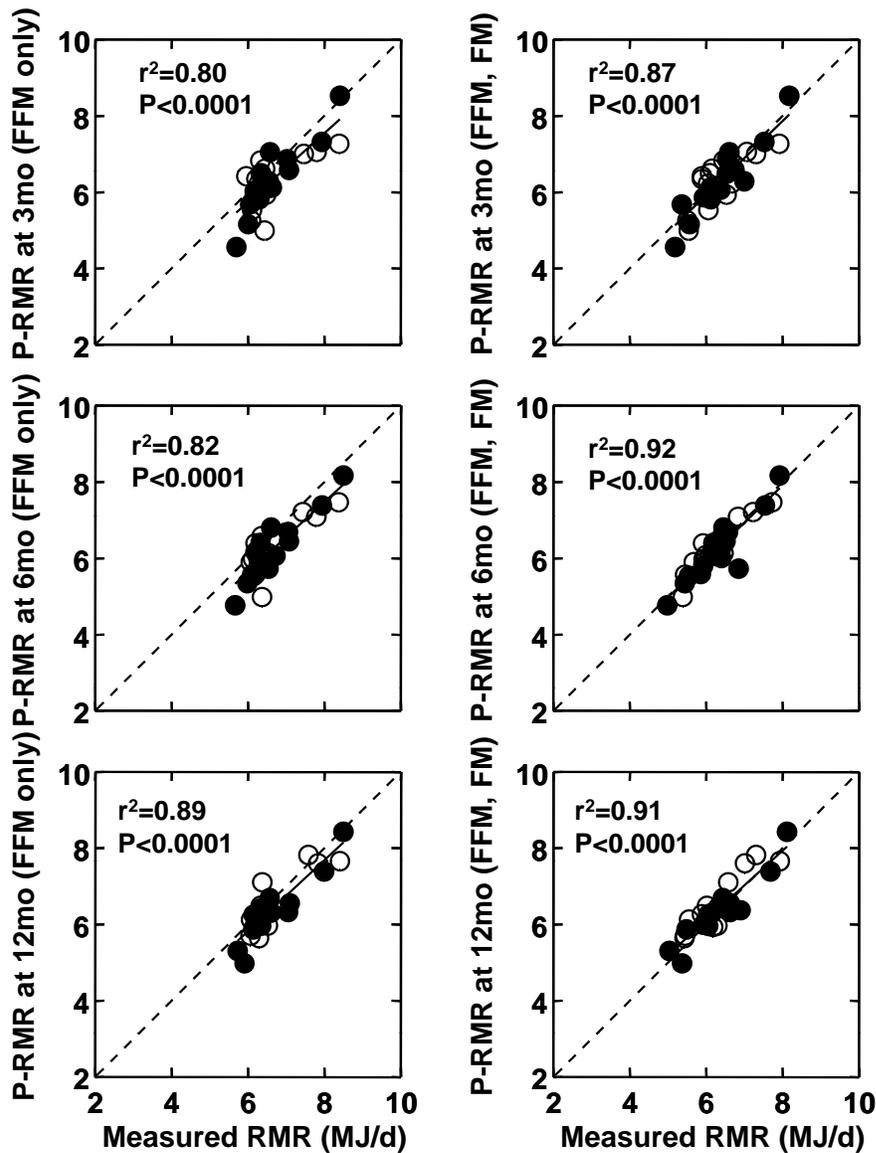


Fig. (1). Correlation between measured resting metabolic rate (RMR) and RMR predicted using fat free mass (FFM) alone or both FFM and fat mass at 3, 6 and 12 months of caloric restriction. Predicted RMR, (P-RMR) was determined using equations developed with baseline FFM only or FFM and fat mass.

RMR predicted from FFM alone was significantly higher than measured RMR at all time points ($P < 0.0001$ at 3 months; $P = 0.003$ at 6 months and $P = 0.001$ at 12 months) but RMR predicted from FFM and fat mass was not significantly different from measured RMR at all time points ($P = 0.36$ at 3 months; $P = 0.22$ at 6 months and $P = 0.25$ at 12 months).

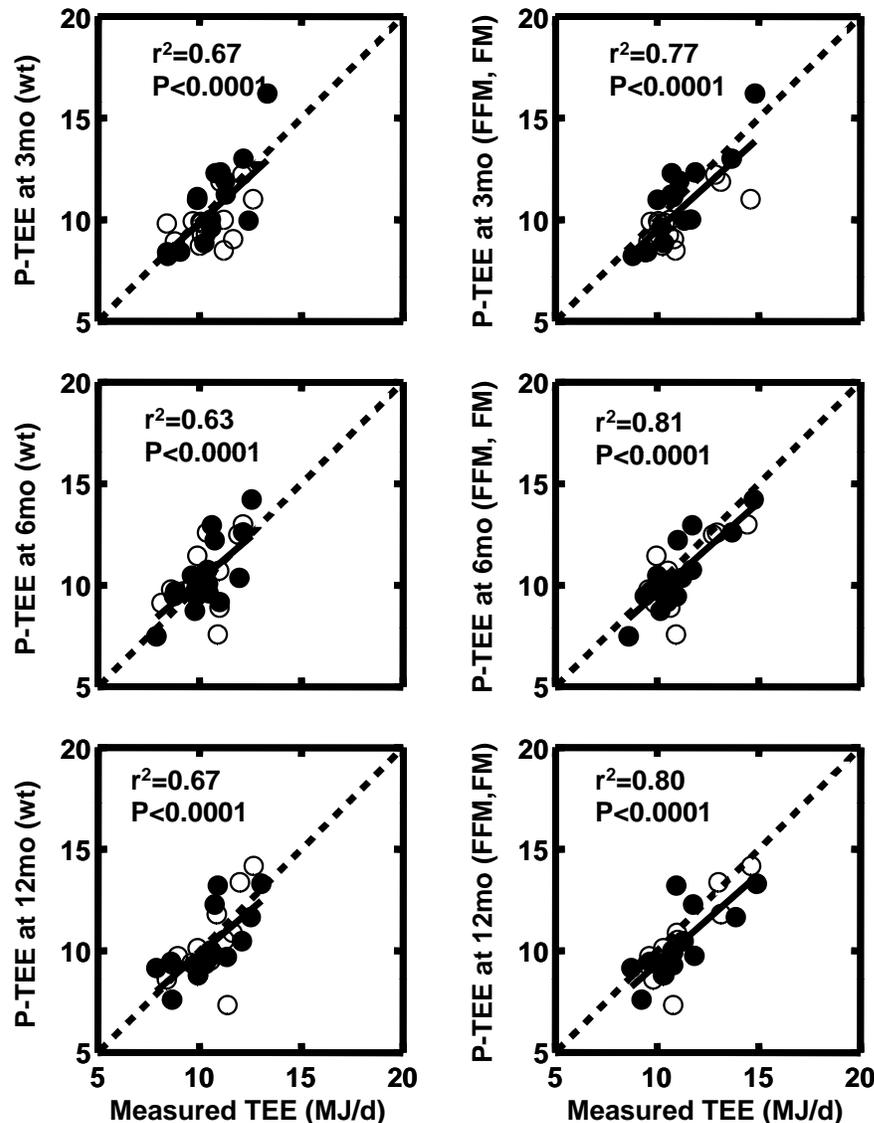


Fig. (2). Correlation between measured total energy expenditure (TEE) and TEE predicted using body weight or using fat free mass (FFM) and fat mass at 3, 6 and 12 months of caloric restriction. Predicted TEE, (P-TEE) was determined using equations developed with baseline body weight or FFM and fat mass. TEE predicted from body weight alone was not significantly higher than measured TEE at all time points ($P=0.44$ at 3 months; $P=0.42$ at 6 months and $P=0.40$ at 12 months) but TEE predicted from FFM and fat mass was significantly different from measured TEE at all time points ($P=0.007$ at 3 months; $P=0.013$ at 6 months and $P=0.001$ at 12 months).

statistically significant long-term at the 6 month ($P=0.84-0.96$) and 12 month ($P=0.84-0.96$) time points.

The results of the second approach to examining metabolic adaptation are shown for RMR in Table 2. The RMR results were very similar to those obtained in the first exploration of metabolic adaptation. The decrease in RMR at 3 and 6 months was significant after accounting for the change in FFM alone but not significant after the change in fat mass was also accounted for. At month 12 of CR, the decrease in RMR was not significant after adjusting for either the change in FFM only or the combined changes in FFM and fat mass. There was no significant effect of diet randomization on change in RMR with CR. With regards to diet group effects on TEE using this approach, there was no significant effect of diet randomization on change in TEE both in the short term i.e., at 3 months and also at the 6 and 12 month time points ($P=0.20-0.70$, data not shown).

Fig. (3) shows the percent change in RMR, TEE, RQ and PAL for the two diets. No statistically significant differences between the diet groups were seen for any variable at any time point (P values for diet*time interaction: $P=0.40$ for RMR, $P=0.10$ for TEE, $P=0.95$ RQ and $P=0.18$ for PAL). Mean PAL was 1.79 ± 0.18 at baseline and 1.68 ± 0.16 and 1.60 ± 0.17 at 6 and 12 months of CR, respectively, in all subjects combined.

Composition of Weight Loss in Relation to Weight Loss and Diet Randomization

Percentage of weight lost as fat and FFM was calculated from baseline to 6 months, when all food was provided and adherence was highest [10]. There was no significant difference in the mean percent weight loss between the groups at 6 or 12 months of CR (-9.6 ± 3.8 for HG vs -10.9 ± 4.2 for LG at 12 months) [10]. When the subset of subjects with weight

Table 2. Regression Models Predicting Change in Resting Metabolic Rate from the Change in Body Composition

	Coefficient \pm SEE	p value	p value (overall change)
<u>Δ RMR (FFM as the only body composition variable)</u>			
3months			0.011
Intercept	-0.356 \pm 0.13	0.010	
Diet Group	0.138 \pm 0.17	0.428	
Δ FFM	0.101 \pm 0.08	0.190	
6months			0.000
Intercept	-0.401 \pm 0.10	0.000	
Diet Group	0.125 \pm 0.14	0.386	
Δ FFM	0.159 \pm 0.06	0.016	
12 months			0.079
Intercept	-0.161 \pm 0.13	0.245	
Diet Group	-0.032 \pm 0.19	0.867	
Δ FFM	0.100 \pm 0.07	0.172	
<u>Δ RMR (FFM and fat mass as body composition variables)</u>			
3months			0.406
Intercept	-0.262 \pm 0.27	0.338	
Diet Group	0.121 \pm 0.18	0.506	
Δ FFM	0.089 \pm 0.08	0.285	
Δ Fat	0.020 \pm 0.05	0.694	
6months			0.243
Intercept	-0.246 \pm 0.20	0.224	
Diet Group	0.088 \pm 0.15	0.557	
Δ FFM	0.136 \pm 0.07	0.054	
Δ Fat	0.021 \pm 0.02	0.369	
12months			0.593
Intercept	-0.086 \pm 0.22	0.698	
Diet Group	-0.036 \pm 0.19	0.852	
Δ FFM	0.095 \pm 0.07	0.209	
Δ Fat	0.012 \pm 0.03	0.667	

RMR, resting metabolic rate (MJ/d), FFM, fat free mass (kg), Diet group - high glycemic load, low glycemic load diets. Using mixed model analysis of regression changes in RMR were examined at 3, 6 and 12 month time points after accounting for changes in FFM and fat mass.

loss >5% were compared (justified in Statistics, above; also we only lost 3 subjects for this subset analysis N = 26: 13 HG, 13 LG), the LG group had a significantly higher percentage of weight loss as fat (98.5 vs 87.4) and a significantly lower percentage of weight loss as FFM (1.50 vs 12.6; P= 0.047; 95 %CI = 0.14-22.15) (Fig. 4). This difference in percentage of weight loss as fat approached significance (P=0.063) at 6 months when all subjects were included in the analysis. At 12 months when subjects were on self-selected foods and adherence to the prescription was lower, the dif-

ference in percent of weight loss as fat and FFM was not significant in the whole sample (P=0.16) and no longer significant in the subset (P=0.44).

DISCUSSION

The role of dietary carbohydrate in successful weight loss and prevention of weight regain remains very controversial. Both total carbohydrate and carbohydrate type (as quantified by the GL and GI, respectively) have been studied for their effects on hunger and satiety [42-45], and weight loss and

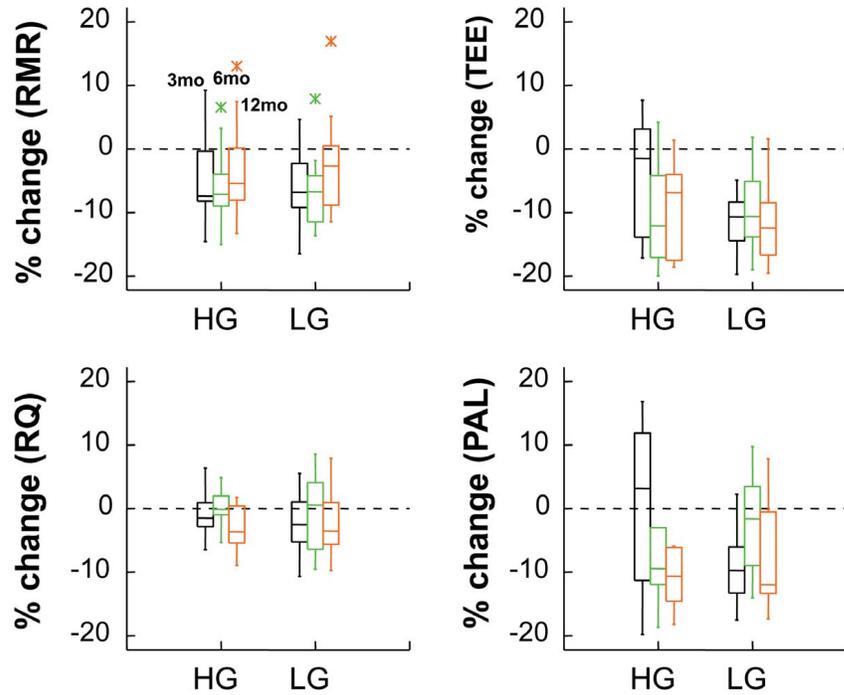


Fig. (3). Mean and variability in percent changes in resting metabolic rate (RMR), total energy expenditure (TEE), respiratory quotient (RQ) and physical activity level (PAL) at 3, 6 and 12 months of caloric restriction in subjects randomized to the high glycaemic (HG) and low glycaemic (LG) diets. There was no significant difference in the percent change over time from baseline in any parameter (P values for diet*time interaction: P=0.40 for RMR, P=0.10 for TEE, P=0.95 RQ and P=0.18 for PAL).

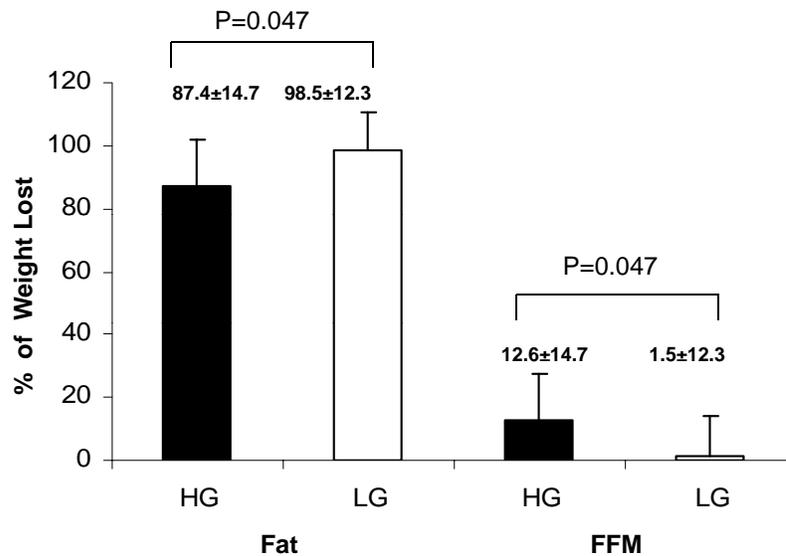


Fig. (4). Percent of weight lost as fat and fat free mass (FFM) on the high glycaemic (HG) ■ and low glycaemic (LG) □ diets at 6 months of caloric restriction. N= 13 HG, 13 LG; analysis excludes 3 subjects with weight loss < 5% of initial weight as measured at 6 months.

prevention of weight gain [5-7, 10, 46]. Single-meal and other short-term studies generally document beneficial effects of low carbohydrate diets and low GI diets on hunger and satiety [43, 44], but most longer-term studies have reported no significant difference in weight loss or weight regain [5-7, 10]. Given the ongoing lack of consensus in this area, we evaluated the effects of HG and LG diets on metabolic adaptation and body composition change, reasoning that a finding of differences in these parameters could contribute to the ongoing debate about optimal carbohydrate

intake for long-term weight control. The results of our study indicate no effect of LG versus HG diets on metabolic adaptation to CR, but tentatively suggest significantly greater fat content of weight loss in individuals consuming LG diets.

Some strengths and weaknesses of this study should be noted. First, most previous studies of dietary carbohydrate and energy regulation have either been very short-term studies providing food [15, 47-49] or long-term studies in which subjects were counseled on regimens for self-administration [1, 50, 51]. Dietary intake in the present study was uniquely

controlled because all food was provided to volunteers for 6 months and documented adherence to the regimen was high when food was provided [10], thus allowing us to relate metabolic adaptation and body composition change to more reliable dietary intake information than is usually possible. On the other hand, since the primary focus was on the GL we tested diets with different macronutrient balances and the results cannot be attributed with certainty to one particular nutrient. Also the population studied was relatively small and our sample size was further reduced for the body composition analyses and therefore further studies are needed in larger populations.

The first finding in the study was that there was no difference in long-term metabolic adaptation to weight loss between individuals randomized to HG and LG regimens. On theoretical grounds, the dietary GL has the potential to influence energy expenditure and, hence, metabolic adaptation. HG diets have been demonstrated to cause greater fluctuations in circulating metabolic fuels [52], and metabolic fuel availability is a known contributor to variability in metabolic rate [53, 54]. To our knowledge, only two studies have been conducted on dietary GL and energy expenditure, both by the same group [15, 16]. Results in both studies suggested that LG diets were associated with smaller reductions in resting energy expenditure, indicating reduced metabolic adaptation, and therefore potentially greater weight loss. The reason for the difference between our study and the previous ones is not known. Our results were obtained using two different mathematical approaches and at 3 different time points, suggesting that the results are not an artifact of the method of calculation or time of assessment. We speculate that one explanation might be the lack of differences in hunger between our study diets, in view of recent speculations that metabolic adaptation and hunger may be closely linked [55]. Both of our diets were relatively high in fiber and low in energy density, factors which have been linked to reduced hunger and adequate satiety [56, 57].

With regard to metabolic adaptation in response to weight loss more generally, we did not find a greater than anticipated reduction in the RMR component at any time point when changes in both FFM and fat mass were taken into account. Previous studies have reported both metabolic adaptation to weight loss [14-17] and no metabolic adaptation [19-23], and factors such as ongoing weight loss and lack of accounting for body fat change as well as FFM change may help explain the variability in results [26]. However, in our study, TEE was lower than expected based on the changes in fat and FFM (at 12 months of CR by approximately 0.76 MJ/d (180 kcal/d), equivalent to 6.6% of baseline TEE) suggesting an adaptive response to the long-term CR that may contribute to the recognized risk of weight regain following weight loss in mildly overweight individuals such as those studied here [58].

The other main finding of this study was that weight loss at the end of the food provided phase (month 6) contained a higher percentage of fat and a lower percentage of FFM in subjects randomized to the LG diet compared to the HG diet. The finding approached significance when all subjects were included in the analysis, and was significant when three subjects with <5% weight loss were excluded on the grounds that such subjects were not consuming the dietary prescrip-

tion. This finding is consistent with a previous study reporting a non-significant reduced nitrogen loss [15] in individuals consuming LG diets compared to HG diets, and one study in an animal model [27]. The observed difference may be attributed to the anabolic effects of the increased circulating post-prandial insulin associated with the consumption of HG diets which favors fat deposition through increase in lipogenesis [59] and also to the higher protein content of our LG diets which may have favored a reduced loss of FFM as suggested by some but not all studies of protein intake and FFM [60].

CONCLUSION

This 1-year study of healthy overweight adults found significantly reduced TEE beyond that expected for loss of FFM and fat mass during CR. There was no statistically significant difference in metabolic adaptation to the HG and LG diets but adherence to the LG regimen apparently caused greater loss of body fat and less loss of FFM for the same amount of overall weight loss. Additional studies are needed to confirm these findings, which suggest a beneficial effect of consuming LG diets for weight control independent of an effect on absolute weight loss.

ABBREVIATIONS

BMI	=	Body Mass Index
CR	=	Caloric Restriction
CALERIE	=	Comprehensive Assessment of the Long-term Effects of Restricting Intake of Energy
FFM	=	Fat free mass
GL	=	Glycemic Load
GI	=	Glycemic Index
HG	=	High glycemic load
LG	=	Low glycemic load
RMR	=	Resting metabolic rate
TEE	=	Total energy expenditure
USDA	=	United States Department of Agriculture

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