ORIGINAL INVESTIGATION

Effects of an Ad Libitum Low-Fat, High-Carbohydrate Diet on Body Weight, Body Composition, and Fat Distribution in Older Men and Women

A Randomized Controlled Trial

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Background: The efficacy of ad libitum low-fat diets in reducing body weight and fat in overweight and obese adults remains controversial.

Methods: We examined the effect of a 12-week low-fat, high–complex carbohydrate diet alone (HI-CHO) and in combination with aerobic exercise training (HI-CHO+EX) on body weight and composition in 34 individuals with impaired glucose tolerance (20 women and 14 men; mean±SEM age, 66±1 years). Participants were randomly assigned to a control diet (41% fat, 14% protein, 45% carbohydrates, and 7 g of fiber per 1000 kcal), a HI-CHO diet (18% fat, 19% protein, 63% carbohydrates, and 26 g of fiber per 1000 kcal), or a HI-CHO diet plus endurance exercise 4 d/wk, 45 min/d, at 80% peak oxygen consumption (HI-CHO+EX). Participants were provided 150% of estimated energy needs and were instructed to consume food ad libitum. Total food intake, body composition, resting metabolic rate, and substrate oxidation were measured.

Results: There was no significant difference in total food intake among the 3 groups and no change in energy intake over time. The HI-CHO+EX and HI-CHO groups lost more body weight (−4.8±0.9 kg [*P*=.003] and −3.2±1.2 kg [*P*=.02]) and a higher percentage of body fat (−3.5%±0.7% [*P*=.01] and −2.2%±1.2% [*P*=.049]) than controls (−0.1±0.6 kg and 0.2%±0.6%). In addition, thigh fat area decreased in the HI-CHO (*P*=.003) and HI-CHO+EX (*P*<.001) groups compared with controls. High carbohydrate intake and weight loss did not result in a decreased resting metabolic rate or reduced fat oxidation.

Conclusion: A high-carbohydrate diet consumed ad libitum, with no attempt at energy restriction or change in energy intake, results in losses of body weight and body fat in older men and women.

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THE INCREASING PREVALENCE of obesity in the adult US population[1,2] and the profound morbidity risks associated with this condition[3,4] provide a compelling rationale for the development of effective strategies to promote weight loss. The relationship between obesity and energy intake from fat is strong in a broad representative sample of countries.[5] Low-fat, high–complex carbohydrate (HI-CHO) diets have been extensively recommended to prevent obesity and promote weight loss in overweight individuals, based on evidence suggesting that these diets reduce total energy intake, increase satiation, and are metabolized with less energetic efficiency compared with high-fat diets.[6-8] The efficacy of high-carbohydrate diets administered ad libitum and with no overt attempt at energy restriction remains uncertain, however.

Short-term intervention studies[9-11] have demonstrated significant weight loss after the administration of hypocaloric diets under rigidly controlled laboratory conditions. Outpatient studies[12-14] in which participants were provided dietary goals but were allowed to consume a self-selected diet have provided similar results. Although some data suggest that reduced energy intake may be a more important mediator of weight loss than a change in macronutrient composition specifically,[15] the results of nutrient utilization studies indicate that dietary fat is metabolized more efficiently than dietary carbohydrate[16,17] and that high-fat diets may promote greater energy intake because of their higher palatability and energy density.[6,18] Thus, HI-CHO diets have gained prominence as a popular dietary intervention strategy for weight loss.

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There is considerable uncertainty, however, regarding the efficacy of HI-CHO diets administered ad libitum with no overt attempt at energy restriction.[19,20] A meta-analysis by Astrup et al[19] of controlled ad libitum low-fat studies of 2 months' duration or longer indicated that dietary fat reduction of approximately 11% (as percentage energy intake) is generally associated with modest weight loss in overweight individuals. Recently, Poppitt et al[21] demonstrated moderate weight loss in middle-aged overweight individuals after administration of a HI-CHO diet. However, it has been suggested that ad libitum low-fat diets are not effective in promoting clinically relevant weight loss in obese individuals (body mass index [calculated as weight in kilograms divided by the square of height in meters] >30),[22] despite a lack of well-controlled studies examining this issue in an obese population.[19]

The importance of exercise training in body weight and fat reduction programs has been emphasized for many years; however, previous evidence[23] suggests that losses of body weight attributable to exercise tend to be minimal, with perhaps a greater effect on fat mass reduction and fat-free mass maintenance during weight loss. There is little information on whether the addition of an aerobic exercise training program contributes to differing patterns of appendicular adipose tissue loss compared with consumption of an ad libitum low-fat diet without exercise.

Recently, increasing attention has been directed toward a constellation of risk factors, including obesity and impaired glucose tolerance, that makes up a metabolic condition known as *syndrome X* or *insulin-resistance syndrome*.[24] The incidence of this syndrome in adults has been estimated to be 24%,[25] and the combination of obesity and impaired glucose tolerance likely plays an important role in the high prevalence of disability, morbidity, and mortality in older individuals.

The present study was designed to examine the effect of an ad libitum HI-CHO diet alone and in combination with an aerobic exercise training program (HI-CHO+EX) on body weight, body composition, and appendicular fat distribution in older individuals with impaired glucose tolerance. In this study, we measured actual energy and nutrient intake and hypothesized that ad libitum consumption of this diet would result in a negative fat balance compared with controls with no change in total energy intake. We further hypothesized greater weight losses in individuals also undergoing aerobic exercise training and that those undergoing exercise training would experience significantly greater losses of appendicular fat and maintenance of appendicular lean tissue compared with those consuming the HI-CHO diet alone.

METHODS

PARTICIPANTS AND SCREENING PROCEDURES

Thirty-six men and women aged 55 to 80 years were recruited from the central Arkansas area between July 1, 1999, and August 31, 2001, using newspaper advertisements. Participants were overweight, nonsmoking, sedentary (≤2 d/wk of structured physical activity), and weight stable (±≤5 kg) during the past 6 months. Individuals with a plasma glucose concentration of 140 to 200 mg/dL (7.8-11.1 mmol/L) 2 hours after consumption of a 75-g oral glucose load, and who were not taking any medication known to affect glucose metabolism, were eligible for study participation. Participants also completed a comprehensive medical screening that included a medical history, a physical examination, and routine blood and urine chemical analysis. Two individuals withdrew from the study for personal or health reasons, and the remaining 34 individuals were assigned to the control (n=12), the HI-CHO (n=11), or the HI-CHO+EX (n=11) group (**Figure 1**). A stratified random allocation strategy (stratified on sex) was used to assign individuals to each intervention group. Each participant provided written informed consent before study participation, and the study procedures were in accord with the ethics standards of the Human Research Advisory Committee of the University of Arkansas for Medical Sciences and the Research and Development Committee of the Central Arkansas Veterans Healthcare System.

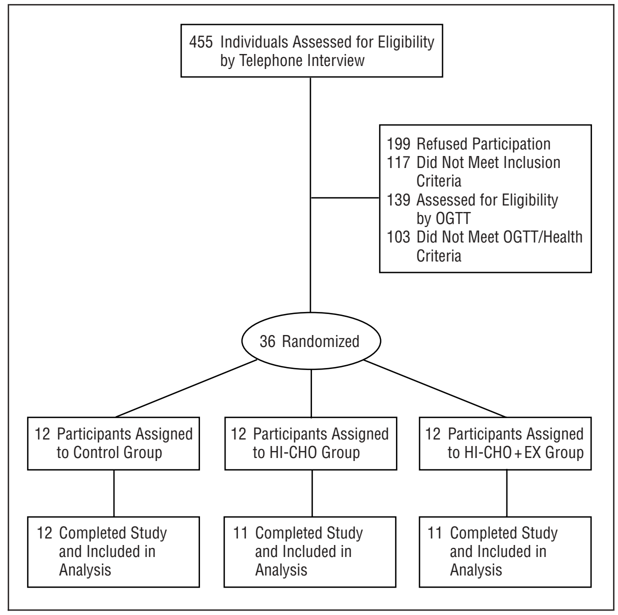

Figure 1. Study flow diagram. OGTT indicates oral glucose tolerance test; HI-CHO, low-fat, high–complex carbohydrate diet; and HI-CHO+EX, low-fat, high–complex carbohydrate diet plus aerobic exercise.

Participants who passed the initial screening were asked to return to the Nutrition, Metabolism, and Exercise Laboratory at a later date to complete a progressive exercise test to exhaustion. Briefly, individuals cycled at a warm-up intensity (50 W for men and 25 W for women) for 3 minutes on a cycle ergometer (Excalibur Sport; Lode, Groningen, the Netherlands), followed by another 3 minutes at a slightly higher intensity (+25 W), with incremental increases (+25 W) in intensity every subsequent minute until volitional fatigue. Concentrations of expired oxygen and carbon dioxide were analyzed (models S-3A/I and CD-3A, respectively; AEI Technologies, Pittsburgh, Pa), and gas volume was measured using a dry-gas meter (Rayfield Equipment, Waitsfield, Vt). This test was used to screen enrolled individuals for ischemic heart disease and to determine maximal aerobic capacity and heart rate. At this time, participants also received instruction in the assessment of dietary intake using a food record booklet and a food scale accurate to 25 g. Reported habitual dietary intake was measured for each participant on 3 weekdays and 2 weekend days, and diet records were coded and analyzed using Nutritionist Five software (version 2.0; First DataBank Inc, San Bruno, Calif).

STUDY DESIGN AND INTERVENTIONS

The study was a 14-week randomized intervention trial. During the baseline testing period (week 1), each participant was provided an isoenergetic mixed diet (35% fat, 20% protein, and 45% carbohydrates) designed to maintain body weight and adjusted to each individual's predicted energy requirements using the Harris-Benedict equation.[26] Participants were instructed to consume only those foods provided by our metabolic kitchen and to consume the entire amount of food provided each day to standardize dietary intake during this measurement period.

After baseline measures, participants were given either the control or the HI-CHO diet for 12 weeks (a list of the foods provided for the control and the HI-CHO diets is available from the authors). For each participant, allocation to the intervention group was performed after completion of baseline testing. Diets were designed to provide 150% of predicted energy requirements, and participants were instructed to consume foods ad libitum for the duration of the study. Participants were informed that the kitchen would provide excess food and that they should eat as much or as little of the foods provided until they were no longer hungry. Diets consisted of usual foods and beverages, and a guar gum supplement (Benefiber; Novartis, Minneapolis, Minn) was added to several beverages of the HI-CHO diet to increase the fiber content of this diet. Meals were served according to a 3-day rotational menu and consisted of breakfast, lunch, dinner, and a snack. Participants reported to the dining facility each weekday morning to obtain packed food for the day, and food for weekend days was obtained each Friday for consumption at home. Participants were also instructed to return to the kitchen each day any food that had not been consumed along with the empty food containers, and food consumption was measured by subtracting the weight of unconsumed food from the recorded weight of provided food. Dietary intake was assessed in this fashion for 4 to 6 consecutive days at weeks 3, 7, and 13 of the study. Postintervention testing was performed during week 14, with participants continuing to consume their assigned diets ad libitum through the completion of testing procedures.

Participants who were randomized to the HI-CHO+EX group trained 4 d/wk during weeks 2 to 13 on a cycle ergometer (model 818E; Monarch, Varberg, Sweden). The exercise intensity was set at 80% to 85% of maximal heart rate (determined during the aerobic capacity test performed at screening), and the duration of each training session was 45 minutes. Each training session was supervised, and heart rate was continuously monitored (Vantage XL; Polar Electro, Woodbury, NY).

TESTING PROCEDURES

Fasting body weight, with participants wearing a hospital gown or other minimal clothing, was measured to the nearest 0.1 kg using an electronic scale (Ohaus Corp, Pine Brook, NJ). Standing height without shoes was measured using a wall-mounted stadiometer (Novel Instruments, Rockton, Ill). Height was measured at baseline, and weight measurements were obtained at baseline and at weeks 3, 5, 7, 9, 11, 13, and 14.

Total body density was estimated using air displacement plethysmography (BOD POD; Life Measurement Instruments, Concord, Calif). After calibration and explanation of the testing procedures, each participant entered the BOD POD while wearing a swimsuit and a bathing cap. Raw body volume was determined, and body density was calculated using this value, body weight, predicted thoracic gas volume, and calculated surface area artifact. Body density was measured in the fasting state in duplicate at baseline, week 7, and week 14, and the mean of each duplicate was used in subsequent analyses. Percentage of body fat was calculated from body density using the Siri equation.[27] Fat and fat-free masses were calculated from the body weight and percentage of body fat data.

A computed tomographic scan of the thigh was obtained at weeks 1 and 14 to assess muscle and adipose tissue cross-sectional area using a HiSpeed scanner (General Electric Medical Systems, Waukesha, Wis) at 120 kV (peak), 280 mA, a 512×512 matrix, and a scanning duration of 1 second. Participants rested supine for 1 hour before each scan to minimize muscle size changes due to posturally related fluid shifts.[28] A scout image was obtained to establish orientation of skeletal landmarks, and a single 10-mm slice was subsequently obtained at the midpoint between the right iliac crest and the patella of the dominant leg (with a scan of both legs simultaneously obtained). Digitized computed tomographic images were stored on magnetic tape and then transferred to a personal computer and analyzed using medical imaging software (SliceOmatic version 4.2; TomoVision, Montreal, Quebec). Muscle, adipose, and bone areas were determined by ranges of attenuation values (fat, −250 to −40 Hounsfield units; muscle, −25 to +145 Hounsfield units; and bone, >+150 Hounsfield units).

Resting energy expenditure was measured at weeks 1 and 14 by open circuit indirect calorimetry using the ventilated hood technique (Vmax 29N; Sensormedics, Yorba Linda, Calif). Measurements of oxygen consumption and carbon dioxide production were obtained under thermoneutral conditions in fasting individuals according to our usual protocol.[29] Reported physical activity was assessed at weeks 1 and 14 using the Yale Physical Activity Questionnaire.[30]

One-way analysis of variance was used to examine differences in participant characteristics and dietary intake among groups at baseline and to assess whether changes in variables over time differed significantly among groups. For post hoc comparisons of means, a Student-Newman-Keuls adjustment was used to control overall type I error. In addition, a mixed 2-factor analysis of variance with interaction term (dietary group × time) was used to examine differences in dietary intake, body weight, body composition, physical activity, and resting energy expenditure variables among groups and changes in these variables over time. Change over time within each group was assessed if the group × time interaction term was significant at the $P<.05$ level. Statistical analyses were performed using statistical software (SPSS 11.0, SigmaStat 2.0; SPSS Inc, Chicago, Ill), and graphs were constructed using a spreadsheet program (Excel 97; Microsoft Corp, Redmond, Wash).

RESULTS

Participant characteristics for the control, HI-CHO, and HI-CHO+EX groups are given in **Table 1**. There were no significant differences in demographic characteristics among groups at baseline, and the proportion of men and women within each group was approximately equal. Blood glucose concentrations after an overnight fast and 2 hours after administration of an oral glucose load were also not significantly different among groups (data not shown).

Reported dietary energy and macronutrient intakes (expressed as a percentage of energy intake) of participants at baseline are given in **Table 2**. Differences in reported energy, protein, fat, carbohydrate, and fiber intakes among groups at baseline were not significant. Baseline dietary differences were also examined in the subset of participants (n=26) classified as accurate dietary reporters (individuals were deemed to be accurate reporters if their reported energy intake was >1.2 times their resting metabolic rate), and results were similar (data not shown). For dietary intake during the study intervention (**Table 3**), the macronutrient composition of the diet consumed by the HI-CHO and HI-CHO+EX groups was significantly different (by design) from the diet consumed by controls ($P<.001$). Mean energy intake during the intervention did not significantly differ among groups (similar results were obtained when energy intake was expressed per kilogram of body weight). There were no significant time × group interactions for any variable, and although monounsaturated fat intake increased over time in all groups (time effect, $P=.03$), the change was minimal. These differences suggest that when instructed to consume food ad libitum, energy intake among participants was approximately equal, despite significant differences in macronutrient dietary composition. The apparent discrepancy between baseline energy intake and energy intake during the study intervention is most likely due to methodologic differences between the 2 intake assessment periods (ie, food record data at baseline and food weigh-back data during the intervention).

Reported physical activity, aerobic capacity, and resting energy expenditure data are given in **Table 4**. Total physical activity at baseline and change in activity over time, as assessed using the Yale Physical Activity Questionnaire,[30] did not significantly differ among groups. However, individuals in the HI-CHO+EX group reported a significantly greater increase in vigorous activity score ($P<.001$) compared with the other 2 groups. A similar result was observed for peak oxygen consumption and exercise duration assessed during the maximal aerobic capacity test, with individuals in the HI-CHO+EX group demonstrating significant increases in these variables over time compared with the other 2 groups ($P<.001$). These results suggest that the exercise intervention in the HI-CHO+EX group was of sufficient intensity to promote increased cardiovascular fitness in these individuals and that individuals in the control and HI-CHO groups did not substantially alter their physical activity during the study.

Mean changes in body weight, body mass index, and percentage of body fat during the study intervention are shown in **Figure 2**. Changes over time were significantly different among groups (time × group interaction, $P<.001$ for body weight and body mass index analyses; interaction $P=.01$ for percentage of body fat analysis). When groups were analyzed separately, significant losses of body weight and body mass index were observed in the HI-CHO (week 1 to week 14 comparison, $P<.001$ for both analyses) and HI-CHO+EX (week 1 to week 14 comparison, $P<.001$ for both analyses) groups, with changes in the control group not significant during the 14-week period. Percentage of body fat also decreased significantly over time in the HI-CHO+EX (week 1 to week 14 comparison, $P<.001$) and HI-CHO (week 1 to week 14 comparison, $P=.01$) groups, but changes were not significant in the control group.

Changes in fat and lean tissue cross-sectional areas in the thigh are shown in **Figure 3**. Thigh fat area in the HI-CHO and HI-CHO+EX groups significantly decreased compared with that of the control group ($P=.008$ and $P<.001$, respectively). Changes in thigh lean tissue area did not significantly differ among groups.

Table 1. Baseline Characteristics of 34 Individuals Who Completed the 14-Week Dietary Intervention*

Variable	Control Group (n = 12)	HI-CHO Group (n = 11)	HI-CHO ± EX Group (n = 11)
Age, y	65.5 (2.3)	67.5 (2.2)	64.8 (2.0)
Sex, M/F, No.	5/7	5/6	4/7
Weight, kg	89.0 (5.8)	89.6 (3.4)	82.9 (3.4)
Height, cm	169.6 (3.2)	169.9 (3.2)	164.3 (2.9)
BMI, kg/m^2	30.8 (1.5)	31.0 (0.8)	30.8 (1.1)
Body fat, %	40.7 (2.3)	42.1 (2.2)	41.2 (2.9)
Fat-free mass, kg	52.6 (4.1)	52.4 (3.5)	48.9 (3.4)

Abbreviations: BMI, body mass index; HI-CHO, low-fat, high-carbohydrate diet; HI-CHO ± EX, HI-CHO diet plus aerobic exercise.
*Data are given as mean (SEM) except where noted otherwise. There were no significant differences among groups at baseline.

Table 2. Reported 5-Day Energy and Macronutrient Intakes at Baseline*

Variable†	Control Group (n = 12)	HI-CHO Group (n = 11)	HI-CHO ± EX Group (n = 10)‡
Energy, kcal/d	1915 (132)	1936 (135)	1904 (169)
Protein	16.9 (0.7)	17.1 (0.7)	16.9 (1.2)
Fat	32.5 (2.4)	35.7 (2.3)	32.3 (1.4)
Saturated fat	10.4 (1.0)	12.0 (0.7)	10.1 (0.6)
Polyunsaturated fat	6.1 (0.6)	6.6 (0.6)	6.1 (0.4)
Monounsaturated fat	10.7 (1.2)	11.8 (0.8)	10.8 (0.7)
Carbohydrates	52.3 (2.7)	48.5 (2.7)	52.7 (2.1)
Fiber, g/d	21.8 (3.6)	15.7 (1.1)	20.5 (3.2)

Abbreviations: HI-CHO, low-fat, high-carbohydrate diet; HI-CHO ± EX, HI-CHO diet plus aerobic exercise.
*Data are given as mean (SEM). There were no significant differences among groups at baseline.
†Presented as percentage of energy intake, except where indicated.
‡Data were missing for 1 participant.

COMMENT

In this study, ad libitum consumption of a HI-CHO diet for 12 weeks, with no attempt at energy restriction, resulted in significant decreases in body weight. The addition of aerobic exercise training seemed to augment weight loss and loss of body fat. These data further show that body weight and percentage of body fat were reduced on this low-fat diet, even with no measurable decrease in total energy intake. Participants were informed that the purpose of the present study was to examine the effects of a heart healthy diet on general disease risk, and thus there was little overt motivation for participants to lose weight via voluntary energy restriction. The stable weight observed in individuals randomized to the control group suggests that weight loss did not occur owing to intentional energy restriction or because of reduced food intake attributable to boredom with the meals provided to participants. Bias in previous studies demonstrating weight loss with a reduction in fat in-

Table 3. Energy and Macronutrient Intake of Food Consumed at Weeks 2, 6, and 12 of the 12-Week Dietary Intervention*

Variable	Control Group (n = 12)				HI-CHO Group (n = 11)				HI-CHO ± EX Group (n = 11)			
	Wk 2	Wk 6	Wk 12	Mean (SEM)	Wk 2	Wk 6	Wk 12	Mean (SEM)	Wk 2	Wk 6	Wk 12	Mean (SEM)
Energy, kcal/d	2870	2810	2794	2825 (229)	2206	2197	2348	2250 (146)	2461	2354	2425	2413 (155)
Protein, % of energy intake	14.2	14.6	14.7	14.5 (0.4)[a]	19.1	19.2	19.4	19.2 (0.5)[b]	19.3	19.0	18.8	19.1 (0.3)[b]
Fat, % of energy intake	40.6	40.7	40.9	40.7 (0.5)[a]	17.2	18.2	18.4	18.0 (0.5)[b]	18.2	18.7	18.3	18.4 (0.6)[b]
Saturated fat, % of energy intake	14.7	15.1	15.1	15.0 (0.2)[a]	5.9	6.3	6.5	6.2 (0.3)[b]	6.5	6.5	6.4	6.5 (0.2)[b]
Polyunsaturated fat, % of energy intake	6.7	6.8	7.1	6.9 (0.2)[a]	4.5	4.9	4.8	4.7 (0.2)[b]	4.4	4.8	4.9	4.7 (0.2)[b]
Monounsaturated fat, % of energy intake	13.6	14.3	13.8	13.9 (0.2)[a]	4.3	4.7	4.6	4.5 (0.2)[b]	4.4	4.7	4.6	4.6 (0.1)[b]
Cholesterol, mg/d	343.0	345.3	342.1	343.5 (30.1)[a]	159.7	164.5	177.0	167.1 (12.0)[b]	185.8	180.9	186.5	184.4 (12.0)[b]
Carbohydrates, % of energy intake	45.2	44.7	44.4	44.8 (0.8)[a]	63.6	62.6	62.2	62.8 (0.7)[b]	62.5	62.3	62.8	62.5 (0.5)[b]
Fiber, g/d	19.4	18.5	17.7	18.5 (1.8)[a]	58.8	57.1	56.8	57.6 (3.1)[b]	65.7	57.4	59.5	60.9 (4.3)[b]
Soluble fiber, g/d	4.8	4.5	4.7	4.7 (0.5)[a]	20.5	18.7	19.5	19.6 (1.0)[b]	22.4	19.1	19.8	20.4 (1.9)[b]
Insoluble fiber, g/d	14.5	13.8	13.4	13.9 (1.3)[a]	35.6	35.4	34.8	35.2 (2.3)[b]	42.1	35.6	36.2	38.0 (2.4)[b]

Abbreviations: HI-CHO, low-fat, high-carbohydrate diet; HI-CHO ± EX, HI-CHO diet plus aerobic exercise.

*Mean changes over time were not significant for any variable except monounsaturated fat (7.5%, 7.9%, and 7.7% at weeks 2, 6, and 12, respectively; $P = .03$). Changes over time did not differ among groups for any variable (ie, the time × group interaction term was not significant). Means within a row with different superscript letters are significantly different ($P < .001$).

Table 4. Reported Physical Activity, Aerobic Capacity, and Resting Energy Expenditure at Baseline (Week 1) and Week 14*

Variable	Control Group (n = 12)		HI-CHO Group (n = 11)		HI-CHO ± EX Group (n = 11)	
	Wk 1	Wk 14	Wk 1	Wk 14	Wk 1	Wk 14
Reported physical activity						
Total activity, kcal/wk	4730 (679)	5157 (820)	3034 (411)	3495 (954)	4549 (808)	4988 (477)
Total activity, h/wk	21.9 (3.7)	23.2 (3.6)	15.8 (2.2)	16.0 (3.4)	23.5 (4.4)	22.2 (2.4)
Vigorous activity score†	15.4 (5.3)	11.7 (2.7)	10.4 (3.5)	7.7 (3.0)	11.8 (3.4)	36.4 (1.5)‡
Maximal aerobic capacity						
Peak oxygen consumption (mL · kg^{-1} · min^{-1})†	17.0 (1.0)	17.0 (1.0)	17.8 (0.9)	17.8 (1.0)§	18.5 (1.3)	23.1 (1.3)‡
Maximal heart rate, bpm	149 (7)	148 (7)	148 (4)	142 (4)§	162 (3)	161 (4)
Exercise duration†	500 (21)	492 (22)	500 (33)	500 (30)§	515 (27)	592 (27)‡
Resting energy expenditure, kcal/d	1357 (92)	1318 (81)	1356 (69)	1343 (68)	1286 (53)	1224 (52)
Resting respiratory exchange ratio	0.85 (0.02)	0.87 (0.02)	0.80 (0.02)	0.84 (0.03)	0.85 (0.04)	0.85 (0.02)

Abbreviations: HI-CHO, low-fat, high-carbohydrate diet; HI-CHO ± EX, HI-CHO diet plus aerobic exercise.
*Data are given as mean (SEM).
†Significant time × group interaction term ($P < .001$).
‡Week 14 variable is significantly different from the week 1 variable for this group ($P < .001$).
§Data were missing for 1 participant at this time.

take may be present when individuals are informed that they are participating in a weight loss study.

These results are consistent with previous examinations of ad libitum high-carbohydrate diets and weight loss.[20,21,31-38] It has been previously reported that the magnitude of weight loss in longer-term studies[21,31-33,37] (6-12 months in duration) is relatively modest, with decreases in body weight 3 to 4 kg greater in dietary intervention groups than in controls. Schaefer and coworkers[36] also demonstrated that an ad libitum high-carbohydrate diet resulted in significant weight loss in men and women with chronic hyperlipidemia and that the amount of weight loss experienced by their participants was positively related to initial weight. Shorter-term studies[39,40] (2-3 weeks in duration) typically report smaller weight losses of approximately 1 kg or less. However, one shorter-term study,[41] in which individuals were fed a very–low-fat (12% of energy), high–complex carbohydrate (77% of energy) diet ad libitum for 21 days, demonstrated a mean weight loss of 4.9 kg. Overall, previous studies indicate that ad libitum low-fat diets produce weight losses of approximately 1.6 g/d for each 1% reduction in energy supplied by dietary fat.[42] According to this formula, we would expect weight losses of approximately 2.5 kg in our study, an amount slightly less than the actual loss observed.

The results of previous studies have been difficult to interpret because it has been unclear whether the weight loss observed was due to total energy restriction or to decreased fat intake. Dietary intervention studies in which individuals consume food ad libitum are, by definition, less fully controlled than studies that provide a fixed, low-calorie diet. Accurate fat and energy intake information

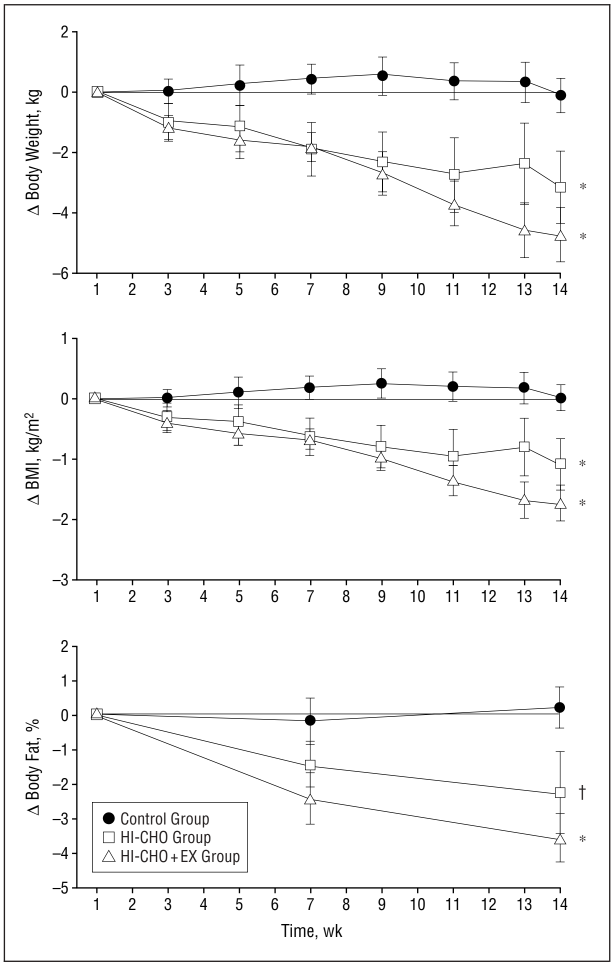

Figure 2. Mean changes in body weight, body mass index (BMI), and percentage of body fat relative to baseline (week 1) in participants consuming the control diet; the low-fat, high–complex carbohydrate diet (HI-CHO); and the low-fat, high–complex carbohydrate diet plus aerobic exercise (HI-CHO+EX). The time × group interaction term was significant for all 3 outcome variables ($P<.001$, $P<.001$, and $P=.01$, respectively). *Significant decrease over time in this group (week 1 to week 14 comparison, $P<.001$). †Significant decrease over time in this group (week 1 to week 14 comparison, $P=.01$). Error bars represent SEM.

is therefore difficult to obtain in individuals who are allowed to consume a self-selected diet while following general low-fat dietary guidelines or in participants who are provided a selection of foods from a laboratory-run grocery store system. One strength of this study is our ability to more accurately assess dietary intake through the use of food weigh-back measurements (ie, by subtracting the weight of food returned to the metabolic kitchen from the weight of food provided); our dietary intake data indicate that participants did not change total energy intake despite significant reductions in total fat. However, since the successful pattern of weight loss in the HI-CHO group cannot be explained by any differential in reported energy intake between this group and the control group, our data suggest either bias in this method of food intake assessment or the existence of metabolic differences attributable to dietary macronutrient composition differences among groups.

It has been suggested that high-carbohydrate diets may contribute, over time, to excess body fat storage owing to

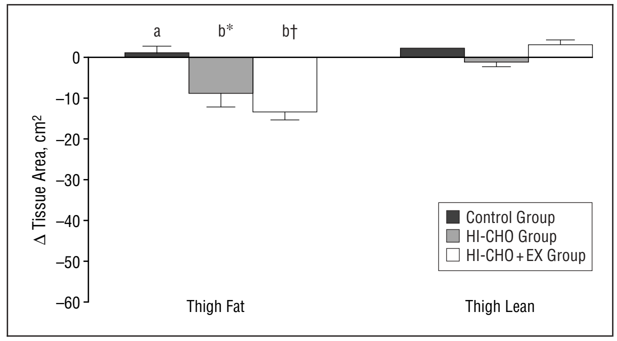

Figure 3. Mean changes in the fat and lean tissue cross-sectional area at the thigh relative to baseline in participants consuming the control diet; the low-fat, high–complex carbohydrate diet (HI-CHO); and the low-fat, high–complex carbohydrate diet plus aerobic exercise (HI-CHO+EX). Differences among groups were significant for thigh fat area; bars with different superscript letters are significantly different. *$P=.008$. †$P<.001$. Error bars represent SEM.

reduced fat oxidation and increased de novo lipogenesis.[15] In contrast, the results of the present study support the hypothesis that fat balance is maintained not by total energy intake but by total fat intake.[43] Previous studies[44,45] have clearly demonstrated that overconsumption of carbohydrates does not result in lipogenesis to any great extent. The few studies[46,47] that have demonstrated a significant increase in lipogenesis have involved massive carbohydrate overfeeding in amounts that do not occur in daily life. Concerning the effect of a high-carbohydrate diet on substrate oxidation, we did not observe a significant increase in the respiratory exchange ratio during the dietary intervention in the present study. Hughes et al[48] previously demonstrated that a eucaloric high-carbohydrate diet resulted in a substantial increase in the rate of total body carbohydrate oxidation and a suppression of fat oxidation. It is possible that the suppression of fat oxidation did not occur as expected in the present study as a result of participants being in negative fat balance subsequent to consuming a low-fat diet. Further research is needed to examine the specific substrate oxidation and lipogenic responses to an ad libitum high-carbohydrate diet.

Exercise is known to result in increased fat oxidation. The results of the present study demonstrate that compared with the HI-CHO group, a trend toward greater loss of body weight and body fat was experienced in the HI-CHO+EX group, which is consistent with many previous studies.[49] It is unclear, however, whether aerobic exercise training enhances the effect of weight loss on metabolic risk factors such as insulin resistance. Hughes et al[48] reported that aerobic exercise without weight loss is ineffective in improving insulin sensitivity in older individuals. More recently, Janssen et al[50] reported that although weight loss was associated with an improved metabolic profile in premenopausal obese women, this improvement was not augmented by the addition of either aerobic or resistance exercise. These results are in contrast to findings in older men published by the same group.[51] Further research is needed to examine the effect of exercise in combination with dietary-induced weight loss on the metabolic profile in older men and women.

Low-fat, high-carbohydrate diets may reduce body weight via reduced food intake, since complex carbohydrate–rich foods are more satiating and less energy dense than higher-fat foods.[6,52] Hughes et al[48] demonstrated that a similar high-carbohydrate diet fed to individuals to maintain body weight resulted in a slight decrease in weight along with a significant decline in the high-density lipoprotein concentration and a significant increase in circulating triacylglycerols. Despite being fed to maintain body weight, individuals complained that they were given too much food and were never hungry.

Recently, low-carbohydrate diets have become popular for individuals attempting to lose weight.[53] The proponents of these diets claim that because dietary carbohydrates stimulate insulin production, de novo lipogenesis results in positive fat balance. As described herein, however, little evidence exists to support this idea. Our data provide a potentially useful intervention for body weight and body fat loss. Hypocaloric diets often result in metabolic adaptations consistent with weight maintenance or even weight gain, such as a significant reduction in resting metabolic rate, although specific findings have been mixed.[54,55] The individuals consuming the HI-CHO diet in our study did not demonstrate a metabolic adjustment resulting in a decreased metabolic rate, possibly owing to our observation that energy intake was not compromised with the ad libitum diet. In addition, participants never complained of feeling hungry, an important consideration in the formulation of dietary strategies to promote weight loss and long-term maintenance of a healthy body weight. In conclusion, our data support the alteration of dietary macronutrient composition without emphasis on caloric restriction as an effective means of promoting weight loss in an older, at risk, population.

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