Review

Energetics of Obesity and Weight Control: Does Diet Composition Matter?

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ABSTRACT

Greater average weight losses (2.5 kg over 12 weeks) have been reported for low-carbohydrate diets (<90 g/day) compared with traditional low-fat (<25% of energy), hypocaloric diets, implying a 233 kcal/day greater energy deficit. It has therefore been suggested that a low-carbohydrate diet may provide a metabolic advantage (an increase in energy expenditure), resulting in a positive effect on weight loss and maintenance. However, a review of studies in which 24-hour energy expenditure was measured did not provide evidence to support a metabolic advantage of low-carbohydrate diets and showed little evidence of a metabolic advantage of high-protein (>25% of energy) diets. Nonetheless, diets high in protein, but either low or modest in carbohydrate, have resulted in greater weight losses than traditional low-fat diets. We speculate that it is the protein, and not carbohydrate, content that is important in promoting short-term weight loss and that this effect is likely due to increased satiety caused by increased dietary protein. It has been suggested that the increased satiety might help persons to be more compliant with a hypocaloric diet and achieve greater weight loss. The current evidence, combined with the need to meet all nutrient requirements, suggests that hypocaloric weight-loss diets should be moderate in carbohydrate (35% to 50% of energy), moderate in fat (25% to 35% of energy), and protein should contribute 25% to 30% of energy intake. More studies of the efficacy of weight-loss and weight-maintenance diets that address protein content are needed. In addition, controlled studies of total energy expenditure or physical activity measured under free-living conditions that directly compare high-protein diets with those containing low and moderate carbohydrate content should also be performed.
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Between the second (1976-1980) and third (1988-1994) National Health and Nutrition Examination Surveys, the prevalence of obesity in the United States dramatically increased. Increases were observed for all ages, sexes, and racial groups. Estimates from 2001 indicate that the prevalence had continued to increase such that 21% of adults (44 million persons) were obese. This rapid increase in the prevalence of obesity in the United States began around the time the US 1980 Dietary Guidelines placed greater emphasis on reducing dietary fat and replacing that energy with carbohydrate. Because both carbohydrate intake and obesity began to increase during the 1980s, the lay and scientific communities suggested that the increase in obesity was directly related to increased carbohydrate intake. It should be remembered that a temporal relationship, while providing useful information that should not be ignored, cannot prove causality. Indeed, the number of health club franchises in the United States also increased during this same period.

Recently, a number of studies reported increased weight loss during weight-reduction trials when participants restricted carbohydrate intake to <90 g/day (1). Moreover, the greater weight losses observed as a result of these low-carbohydrate diets have been reported despite similar or even smaller self-reported dietary energy deficits during weight-loss treatments. Because of this, it has been suggested that a low-carbohydrate diet provides a metabolic advantage by increasing energy expenditure, which results in a positive effect on weight loss and possibly long-term weight control (1). In this article, the known effects of dietary macronutrient composition on energy expenditure are reviewed.

THE CURRENT LITERATURE

The greater weight losses reported for low-carbohydrate diets or very–low-carbohydrate diets (<25 g/day) compared with traditional low-fat, hypocaloric diets range from 0.5 to 4.6 kg, averaging about 2.5 kg over 12 weeks (2). This difference in weight loss is not trivial in regard to calculated difference in energy balance. If one assumes that the composition of the weight lost is 80% fat mass and 20% fat-free mass (3), then a difference of 2.5 kg over 12 weeks implies a 233 kcal/day difference in energy balance. It should be noted that this assumption applies only to weight loss in healthy persons consuming a nu-

Table. Predicted rates of weight loss, based on energy deficit, for a hypothetical 12-week weight-reduction intervention[a]

Energy deficit (kg/d)	Predicted weight loss[b] kg/wk	Predicted weight loss[b] lb/wk	Predicted reduction in energy intake to produce the energy deficit[c] (kcal/d)
250	0.22	0.5	390
500	0.44	1.0	730
750	0.67	1.5	1,050
1,000	0.90	2.0	1,360

[a]The decrease in thermic effect of food (kcal/d) was calculated as equal to 10% of the decrease in energy intake. The decrease in resting metabolic rate (kcal/d) was calculated assuming a linear reduction across the 12 weeks that is proportional to weight loss using the linear equation of Saltzman and Roberts (4) (change in RMR=12×weight change [kg/wk]×11.9−79/2) and the decrease in physical activity energy expenditure was calculated assuming an average physical activity of 12 kcal/d for each kilogram of weight loss.

[b]Calculated assuming no decrease in energy expenditure when energy intake is restricted.

[c]Calculated assuming energy expenditure would decrease during the 12-week period of energy restriction.

tritionally replete diet and is violated if either nitrogen or water balance is unusually negative. Using this same assumption, it is possible to predict the rates of weight loss for a range of energy deficits for a healthy person consuming a nutritionally replete diet (Table). Typically, reducing energy intake by the amounts shown in the Table will not produce this energy deficit. Instead, the energy deficits realized by a person will be smaller than the energy restriction because the three components of total energy expenditure (thermic effect of food [TEF], resting metabolic rate [RMR], and the energy expended in physical activity) decrease in response to an energy deficit and weight loss. If a person decreases energy intake, the TEF will decrease by an amount roughly equal to about 10% of the decrease in energy intake. Following energy restriction, RMR will also decrease, first as an adaptive response to the energy deficit and then as a result of smaller body size. Finally, the energy costs of physical activity will decrease for the same physical activities, also as a result of smaller body size (4). When reductions in these three components of total energy expenditure are averaged over a 12-week weight loss, they reduce the predicted energy deficits by one fourth to one third (see the Table).

Still, the basic relationship between body energy stores and energy deficit shown in the Table suggests the greater average weight losses reported for low-carbohydrate diets are due to a 233 kcal/day greater energy deficit. What might cause this greater energy deficit? Is it due to metabolic advantage, or a difference in energy intake? To answer this, we first turn to data on the effects of macronutrient composition of the diet on energy expenditure, generated during testing of previous hypotheses. For example, 3 decades ago, a low-carbohydrate, high-protein diet (protein-sparing modified fast) was hypothesized to be metabolically advantageous. Two decades ago, high-carbohydrate diets were hypothesized to increase sympathetic nervous system activity and energy expenditure. Many studies were performed to test these hypotheses. In a review published elsewhere (2), we identified 10 studies that provide the critical data to test these hypotheses. Briefly, in these studies, 24-hour energy expenditure was measured in participants housed in a room calorimeter while they consumed diets that exchanged carbohydrate for fat while maintaining protein intake at a value between 10% and 20% of dietary energy. When dietary fat was decreased from between 50% and 80% of energy to between 45% and 20% of energy, the average 24-hour energy expenditure did not change (lower-carbohydrate minus higher-carbohydrate diet=19±54 kcal/day) except in two studies, which reported that among previously obese women, energy expenditure decreased by 75 to 80 kcal/day while consuming the high-fat diet (Figure). The room calorimeters used in the studies provide a very precise measure of 24-hour energy expenditure, including RMR, TEF, and spontaneous physical activity (more recently called nonexercise activity thermogenesis), but limit physical activity compared to the free-living condition. In one study, total energy expenditure was measured during a low-carbohydrate diet under free-living conditions using doubly labeled water (5). This measure of free-living total energy expenditure differs from the 24-hour energy expenditure measured in a room calorimeter because of the greater and more varied energy expended in physical activity. Although RMR and TEF did not change when the percentage of energy from carbohydrate was decreased from 83% to 7% by replacement with fat, total energy expenditure decreased by 365 kcal during this initial phase of the very–low-carbohydrate (ketogenic) diet. This implies a substantial reduction in energy expended in physical activity. The macronutrient distribution of this study diet was consid-

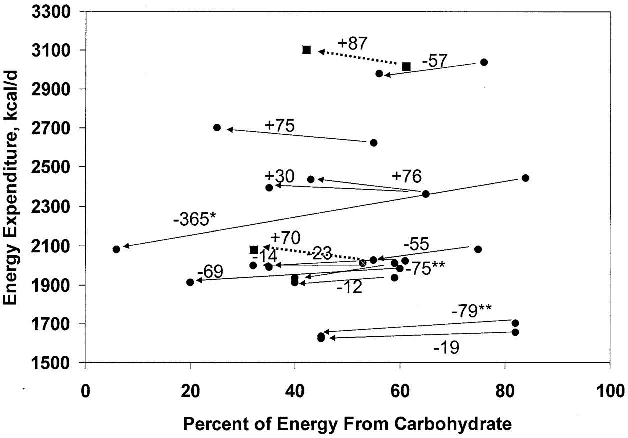

Figure. Change in 24-hour energy expenditure when participants are switched from a high-carbohydrate diet to lower-carbohydrate diet while keeping protein constant (solid arrow) or from a high-carbohydrate diet to a lower-carbohydrate and higher-protein diet (dotted arrow). The difference in energy expenditure (kcal/d) is indicated above each arrow. *Energy expenditure was measured using room indirect calorimeters except for one study that measured free-living energy expenditure using doubly labeled water. **Reduced-weight subjects who had been obese before weight loss were found to have significantly lower energy expenditure on the lower-carbohydrate diet. All other differences are not significant. Data from reference 2.

erably higher in fat and lower in carbohydrate than the vast majority of low-carbohydrate, weight-loss diets, perhaps resulting in a greater effect on free-living physical activity than would be observed with most low-carbohydrate diets. Taken together, these studies provide little support for the hypothesis that a low-carbohydrate diet increases energy expenditure and, if anything, a low-carbohydrate diet may decrease energy expenditure, particularly if the carbohydrate intake is very low.

There are far fewer studies in which 24-hour energy expenditure has been measured when the percentage of dietary protein is manipulated (2). In one study (6), protein was increased from 11% to between 28% and 29% of energy, while fat remained at 29% and carbohydrate was reduced from 60% to between 42% and 43%. As a result of this manipulation, 24-hour energy expenditure increased by about 60 to 120 kcal, depending on whether the protein source was of plant or animal origin, respectively. In a second study (7), subjects consumed a 50% energy-restricted diet in which the percentage of energy as protein was changed from 15% to 36% of energy. Compared with a weight-maintenance diet, both experimental diets resulted in a reduction of 24-hour energy expenditure, but the decrease was smaller for the high-protein diet by 71 kcal/day compared with the low-protein diet. This difference in 24-hour energy expenditure was due to a lesser (≈50 kcal/day) decrease in RMR and lesser (≈20 kcal/day) decrease in the TEF on the higher-protein diet. Thus, the 36% protein energy-restricted diet was associated with a slightly (3% to 5%) greater energy expenditure than the 12% protein energy-restricted diet; but again, both diets resulted in an overall decrease in 24-hour energy expenditure. No data have been reported on the effects of increasing dietary protein on total energy expenditure (using doubly labeled water), and thus physical activity energy expenditure, under free-living conditions.

Combining the results of these studies, there is an effect of dietary macronutrient composition on energy expenditure, but the effect of substituting fat for carbohydrate is generally small and in the opposite direction needed to support the suggestion of a metabolic advantage. In the case of the two studies that substituted protein for carbohydrate, the effects were contradictory. Thus, these observations do not explain the 2.5 kg, or more, greater weight losses reported for low-carbohydrate diets compared with traditional low-fat diets and thus do not support the hypothesis of a metabolic advantage for low-carbohydrate diets.

Buchholz and Schoeller (2) also reviewed weight-loss studies prescribing 22% to 30% of energy as protein rather than the more commonly prescribed 12% to 20%. These studies reported comparable weight losses after 12 weeks, whether diets had 30% or more of energy coming from carbohydrate or whether they were low in carbohydrate. Thus, there is some evidence that the greater weight loss commonly reported for low-carbohydrate diets may be due to their higher protein content rather than their low carbohydrate content, although there are no direct comparisons of weight loss on diets in which the percentage of energy from fat is held constant while the protein intake is increased at the expense of carbohydrate.

If the effect of dietary macronutrient distribution on energy expenditure is minimal, what else might explain the greater weight loss observed for low-carbohydrate or high-protein diets? The likely explanation is greater dietary compliance. This is difficult to document because self-reported food diaries and diet recalls are subject to large systematic reporting errors that result in poor accuracy of energy intakes (8). Energy prescriptions of studies comparing low-carbohydrate diets with low-fat diets have varied, but have generally ranged from 1,500 to 1,800 kcal/day, which would be expected to produce a reduction in energy intake on the order of 700 to 1,000 kcal/day compared with a weight-maintenance diet. According to the Table, the predicted weight loss, assuming that energy expenditure would decrease during dietary energy restriction, would be 5 to 8 kg in 12 weeks. In comparison, the average observed weight losses were 7 kg for low-carbohydrate diets and 4.5 kg for low-fat diets. Thus, on a theoretical basis, low-carbohydrate diets with a high protein content are producing the expected weight loss, whereas low-fat diets are not. Given the minimal effect of macronutrient composition on energy expenditure, the most likely explanation of the greater weight loss is that participants complied with the energy prescription of the low-carbohydrate/high-protein diet, but not the low-fat diet. In support of this, it has been reported that protein has a higher satiating effect than carbohydrate; thus, a high-protein diet may help participants comply with energy restriction (9). The effects of macronutrients on satiety are reviewed elsewhere in this supplement.

A second factor that can contribute to improved compliance is the limitation of food choices associated with low-carbohydrate diets. Many foods are not permitted in low-carbohydrate diets because they contain too much carbohydrate. Both food-specific satiety (10) and a reduction in food choices (11) may help participants reduce energy intake. This may be particularly influential when eating outside the home. By avoiding the carbohydrate-containing foods served when dining out, the likelihood of being over-served with respect to energy is also reduced.

In addition to improved compliance, low-carbohydrate diets are also known to induce small losses of body water that can contribute to weight loss (12). The loss of liver and muscle glycogen secondary to carbohydrate intakes below that required to sustain glycogen stores results in water loss of 1.9 kg in the first 10 days of a very–low-carbohydrate diet (12). This contributes to the early rapid weight loss often reported by participants consuming low-carbohydrate diets. Aside from the weight itself, this water loss may also help participants comply with their diets during the early phase of the diet, because modest increases in carbohydrate intake will result in the return of the glycogen stores and associated water. The water will result in a small rapid weight gain that may serve as negative feedback and help direct the participant back to compliance.

Water loss does not explain the differences generally reported for comparisons between low-carbohydrate and low-fat diets. On one hand, the 1.9 kg water weight loss reported for a very extreme diet treatment is smaller than the differences reported after 12 weeks of energy restriction. On the other hand, the few studies comparing low-carbohydrate diets with low-fat diets that included body composition measurements (13) report that the weight loss difference is due to greater fat loss.

LIMITATIONS

Our literature review provides no support for a metabolic advantage of low-carbohydrate diets and little support for a metabolic advantage for high-protein diets. Despite this, recent studies have demonstrated that such diets generally produce greater average weight loss in the short term than traditional low-fat, hypocaloric diets and that this appears to be more related to the protein content of the diet than the carbohydrate content. Energy-restricted diets providing 22% to 30% of energy from protein have resulted in comparable weight losses after 12 weeks whether they have 30% or more of energy coming from carbohydrate or whether they are low in carbohydrate (2). A higher-protein diet may also be protective against weight regain, as confirmed by a recent study by Westerterp-Plantenga and colleagues (14), in which two post–weight-loss, weight-maintenance diets were compared. The authors found that increasing protein from 15% to just 18% of energy resulted in better weight maintenance. Thus, we speculate that protein—and not carbohydrate—content is the more important factor in promoting short-term weight loss, but that this may be due to increased satiety rather than increased energy expenditure.

Making specific recommendations for the percent of energy from each macronutrient is not simple. Indeed, major limitations are encountered when interpreting weight-loss data resulting from low-carbohydrate and/or high-protein diets. The first is that it is impossible to manipulate the proportion of a single macronutrient in an experimental diet without affecting the proportion of at least one other macronutrient. That is, if one macronutrient is increased, another must be decreased. Because of this it is difficult to attribute weight loss to changes in the quantity of a single macronutrient. The second limitation is that most studies in which energy expenditure was measured have been performed after the participants consumed the diet for only days or a week and effects of any changes in energy expenditure cannot be related to body weight change in such a short time frame. Similarly, most weight-loss interventions last only 12 weeks or less and these are too short to reach conclusions regarding long-term weight control and health. One long-term study found no significant differences in weight loss between participants on a high-protein and a high-carbohydrate diet after 1 year (15). The third limitation is that most studies investigate only one side of the energy balance equation. Flatt (16) has repeatedly made the point that to understand weight control and the factors leading to obesity, it is necessary to think in terms of energy balance—that is, intake and expenditure—and seek to understand and model factors that disturb that balance. Finally, it is important to note that weight control is not the only factor that determines health. Changes in dietary macronutrient composition may affect other health outcomes. For example, habitual carbohydrate restriction limits the intake of many fruits, vegetables, and whole grains, making it very difficult to meet the recommendations for some vitamins and trace elements as well as some phytochemicals and fiber (17). Numerous cross-sectional studies have provided excellent data on the negative health effects of high–saturated-fat diets and more recently high–simple-carbohydrate diets (18). Little cross-sectional, and more importantly longitudinal, data are available for high-protein diets. For these reasons, long-term use of low-carbohydrate diets is not recommended for healthful control of body weight, particularly given the apparent lack of a metabolic advantage. The current evidence, combined with the need to meet all nutrient requirements, suggests that weight-loss diets should be moderate in carbohydrate, moderate in fat, and that protein should possibly contribute one fourth to one third of energy intake.

FUTURE DIRECTIONS

Additional data on the effects of macronutrient composition on energy expenditure, weight loss, and weight control are needed. In particular, direct comparisons of low-carbohydrate, high-fat, and high-protein weight-loss diets against moderate-carbohydrate, moderate-fat, and high-protein weight-loss diets are needed. In addition, almost all studies of weight-loss diets to date lack data on total energy expenditure measured under free-living conditions (using doubly labeled water) or on energy expended in physical activity (using activity monitors or other objective measures). Energy expended during physical activity is highly variable between subjects and is thus an important component of the energy budget. Given that energy intake must equal energy expenditure in the absence of changes in body weight and body composition, the widely recognized phenomenon of underreporting of energy intake highlights the importance of measuring total energy expenditure. There is also a need for more long-term studies of the effects of dietary macronutrient composition on weight control and health.

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References

1. Feinman RD, Fine EJ. Thermodynamics and metabolic advantage of weight loss diets. *Metabol Syndr Related Dis*. 2003;1:209-219.
2. Buchholz A, Schoeller DA. Is a calorie a calorie? *Am J Clin Nutr*. 2004;79(suppl):S899-S906.
3. Forbes GB. Body fat content influences the body composition response to nutrition and exercise. *Ann NY Acad Sci*. 2000;904:359-365.
4. Saltzman E, Roberts SB. The role of energy expenditure in energy regulation: Findings from a decade of research. *Nutr Rev*. 1995;53:209-220.
5. Bandini LG, Schoeller DA, Dietz WH. Metabolic differences in response to a high-fat vs a high-carbohydrate diet. *Obes Res*. 1994;2:348-354.
6. Mikkelsen PB, Toubro S, Astrup A. Effect of fat-reduced diets on 24-h energy expenditure: Comparisons between animal protein, vegetable protein, and carbohydrate. *Am J Clin Nutr*. 2000;72:1135-1141.

7. Whitehead JM, McNeill G, Smith JS. The effect of protein intake on 24-h energy expenditure during energy restriction. *Int J Obes Relat Metab Disord.* 1996;20:727-732.
8. Trabulsi J, Schoeller DA. Evaluation of dietary assessment instruments against doubly labeled water, a biomarker of habitual energy intake. *Am J Physiol.* 2001;281:E891-E899.
9. Westerterp-Plantenga MS. The significance of protein in food intake and body weight regulation. *Curr Opin Clin Nutr Metab Care.* 2003;6:635-638.
10. Sorensen LB, Moller P, Flint A, Martens M, Raben A. Effect of sensory perception of foods on appetite and food intake: A review of studies on humans. *Int J Obes.* 2003:27:1152-1166.
11. Raynor HA, Jeffery RW, Tate DF, Wing RR. Relationship between changes in food group variety, dietary intake, and weight during obesity treatment. *Int J Obes.* 2004;28:813-820.
12. Yang MU, Van Itallie TB. Composition of weight lost during short-term weight reduction. Metabolic responses of obese subjects to starvation and low-calorie ketogenic and nonketogenic diets. *J Clin Invest.* 1976;58:722-730.
13. Yancy WS Jr, Olsen MK, Guyton JR, Bakst RP, Westman EC. A low-carbohydrate, ketogenic diet versus a low-fat diet to treat obesity and hyperlipidemia: A randomized, controlled trial. *Ann Intern Med.* 2004; 140:769-777.
14. Westerterp-Plantenga MS, Lejeune MP, Nijs I, van Ooijen M, Kovacs EM. High protein intake sustains weight maintenance after body weight loss in humans. *Int J Obes.* 2004;28:57-64.
15. Foster GD, Wyatt HR, Hill JO, McGuckin BG, Brill C, Mohammed BS, Szapary PO, Rader DJ, Edman JS, Klein S. A randomized trial of a low-carbohydrate diet for obesity. *N Engl J Med.* 2003;348:2082-2090.
16. Flatt JP. How NOT to approach the obesity problem. *Obes Res.* 1997;5:632-623.
17. Kappagoda CT, Hyson DA, Amsterdam EA. Low-carbohydrate-high-protein diets: Is there a place for them in clinical cardiology? *Am Coll Cardiol.* 2004; 43:725-730.
18. Hung T, Sievenpiper JL, Marchie A, Kendall CW, Jenkins DJ. Fat versus carbohydrate in insulin resistance, obesity, diabetes, and cardiovascular disease. *Curr Opin Metab Care.* 2003;6:165-176.