The Effect of a Plant-Based Low-Carbohydrate ("Eco-Atkins") Diet on Body Weight and Blood Lipid Concentrations in Hyperlipidemic Subjects

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Background: Low-carbohydrate, high–animal protein diets, which are advocated for weight loss, may not promote the desired reduction in low-density lipoprotein cholesterol (LDL-C) concentration. The effect of exchanging the animal proteins and fats for those of vegetable origin has not been tested. Our objective was to determine the effect on weight loss and LDL-C concentration of a low-carbohydrate diet high in vegetable proteins from gluten, soy, nuts, fruits, vegetables, cereals, and vegetable oils compared with a high-carbohydrate diet based on low-fat dairy and whole grain products.

Methods: A total of 47 overweight hyperlipidemic men and women consumed either (1) a low-carbohydrate (26% of total calories), high–vegetable protein (31% from gluten, soy, nuts, fruits, vegetables, and cereals), and vegetable oil (43%) plant-based diet or (2) a high-carbohydrate diet based on low-fat dairy and whole grain products.

Results: Of the 47 subjects, 44 (94%) (test, n=22 [92%]; control, n=22 [96%]) completed the study. Weight loss was similar for both diets (approximately 4.0 kg). However, reductions in LDL-C concentration and total cholesterol–HDL-C and apolipoprotein B–apolipoprotein AI ratios were greater for the low-carbohydrate compared with the high-carbohydrate diet (−8.1% [P <.002], −8.7% [P =.004], and −9.6% [P =.001], respectively). Reductions in systolic and diastolic blood pressure were also seen (−1.9% [P =.052] and −2.4% [P =.02], respectively).

Conclusion: A low-carbohydrate plant-based diet has lipid-lowering advantages over a high-carbohydrate, low-fat weight-loss diet in improving heart disease risk factors not seen with conventional low-fat diets with animal products.

Trial Registration: clinicaltrials.gov Identifier: NCT00256516

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Original Investigation

THERE IS A DILEMMA RELATING TO THE PROPORTION AND SOURCE OF FAT, PROTEIN, AND CARBOHYDRATE THAT CONSTITUTES THE OPTIMAL WEIGHT LOSS AND CHOLESTEROL-LOWERING DIET. NEWER DIETARY APPROACHES FOR THE PREVENTION AND TREATMENT OF CHRONIC DISEASE INCREASE THE CONSUMPTION OF FRUIT AND VEGETABLES BUT REDUCE MEAT CONSUMPTION EITHER DIRECTLY AS PART OF THE DIETARY STRATEGY OR DISPLACE MEAT BY ADVOCATING INCREASED INTAKES OF FISH, POULTRY, AND LOW-FAT DAIRY FOODS.

For editorial comment see page 1027

Running counter to this advice has been the promotion of low-carbohydrate diets with increased meat consumption for body weight reduction and also in the longer term for the prevention and treatment of diabetes and coronary heart disease (CHD). These diets not only challenge the concept that red meat intakes should be reduced but also reverse the dietary macronutrient profile with fat and protein as the major macronutrients and carbohydrates as the minor macronutrient. Such low-carbohydrate diets have been shown to be effective in inducing weight loss, reducing insulin resistance, lowering serum triglyceride (TG) concentrations, and raising high-density lipoprotein cholesterol (HDL-C) concentrations. However, the higher meat diets have not resulted in lower low-density lipoprotein cholesterol (LDL-C) concentrations, but have tended to increase LDL-C concentrations except when vegetarian sources of fat and protein were included. This lack of a benefit for LDL-C control is a major disadvantage in using this dietary strategy in those already at increased risk of CHD.

In view of the apparent success of low-carbohydrate diets for weight loss and the...
demonstration that relatively high-carbohydrate diets low in animal products lower CHD risk factors.³⁰⁻¹¹ we determined the effect of a low-carbohydrate weight-loss diet, without the use of animal products, on serum lipid concentrations compared with a higher carbohydrate diet.

**METHODS**

**PARTICIPANTS**

Fifty overweight participants, recruited by newspaper advertisement and hospital clinic notices, were randomized, and 47 subjects were available to start the study. Of these, 44 (18 men and 26 postmenopausal women) completed the 1-month metabolic study (Figure 1). More than half the participants reported being busy lifestyle (n=13), not interested (n=8), study too demanding (n=3), currently on another diet (n=2), no compensation (n=2), work-related reason (n=2), dislike prepackaged foods (n=1). Other reasons (n=44): unable to contact (n=19), unable to come to clinic (n=13), away (n=5), throat surgery (n=1), bowel resection (n=1), high potassium concentration (n=1), elevated liver function test results (n=1), not interested (n=1), medical insurance issue (n=1).

**Figure 1.** Patient flow diagram. *Chose not to participate (n=29): busy lifestyle (n=13), not interested (n=8), study too demanding (n=3), currently on another diet (n=2), no compensation (n=2), work-related reason (n=2), dislike prepackaged foods (n=1). †Other reasons (n=44): unable to contact (n=19), unable to come to clinic (n=13), away (n=5), throat surgery (n=1), bowel resection (n=1), high potassium concentration and blood pressure (n=1), high potassium concentration (n=1), elevated liver function test results (n=1), not interested (n=1), medical insurance issue (n=1).

**Table 1. Baseline Characteristics at Randomization for 50 Subjects**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>High-Carbohydrate Control Diet (n=25)</th>
<th>Low-Carbohydrate Test Diet (n=25)</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>56.1 (7.5)</td>
<td>57.8 (7.1)</td>
<td>.41</td>
</tr>
<tr>
<td>Male/female</td>
<td>12/13</td>
<td>10/15</td>
<td>.57</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>87.4 (11.7)</td>
<td>82.7 (11.1)</td>
<td>.15</td>
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<tr>
<td>BMI</td>
<td>31.0 (2.4)</td>
<td>30.6 (2.9)</td>
<td>.61</td>
</tr>
<tr>
<td>Blood pressure, mm Hg</td>
<td>126.1 (10.2)</td>
<td>127.7 (13.7)</td>
<td>.64</td>
</tr>
<tr>
<td>Systolic</td>
<td>79.4 (8.1)</td>
<td>79.0 (7.7)</td>
<td>.86</td>
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<tr>
<td>Diastolic</td>
<td>166 (39)</td>
<td>153 (49)</td>
<td>.29</td>
</tr>
<tr>
<td>Cholesterol, mg/dL</td>
<td>49 (11)</td>
<td>49 (15)</td>
<td>.90</td>
</tr>
<tr>
<td>Total</td>
<td>142 (73)</td>
<td>148 (87)</td>
<td>.80</td>
</tr>
<tr>
<td>LDL-C</td>
<td>5.18 (1.42)</td>
<td>5.01 (1.60)</td>
<td>.70</td>
</tr>
<tr>
<td>HDL-C</td>
<td>3.51 (1.00)</td>
<td>3.33 (1.29)</td>
<td>.57</td>
</tr>
<tr>
<td>TC–HDL-C</td>
<td>93 (8)</td>
<td>97 (8)</td>
<td>.16</td>
</tr>
<tr>
<td>TC–HDL-C</td>
<td>16.7 (8.6)</td>
<td>24.0 (23.0)</td>
<td>.17</td>
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<table>
<thead>
<tr>
<th>Ratios</th>
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<tr>
<td>Lipid lowering</td>
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<tr>
<td>Blood pressure</td>
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<td></td>
<td>.33</td>
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<tr>
<td>Diabetes</td>
<td></td>
<td></td>
<td>. . .</td>
</tr>
<tr>
<td>Thyroid</td>
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<td>.55</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; METs, metabolic equivalent of tasks; TC, total cholesterol.

*Si conversion factors: To convert cholesterol to millimoles per liter, multiply by 0.0259, to convert triglycerides to millimoles per liter, multiply by 0.0113; to convert glucose to millimoles per liter, multiply by 0.0555.

†Other reasons (n=44): unable to contact (n=19), unable to come to clinic (n=13), away (n=5), throat surgery (n=1), bowel resection (n=1), high potassium concentration (n=1), elevated liver function test results (n=1), not interested (n=1), medical insurance issue (n=1).

investigators. Baseline characteristics of the participants are given in Table 1. Study inclusion criteria included healthy men and postmenopausal women between the ages of 21 and 70 years, with a high-normal or raised LDL-C concentration (>131 mg/dL; [to convert to millimoles per liter, multiply by 0.0259]) at diagnosis), TG concentration higher than 44 mg/dL (to convert to millimoles per liter, multiply by 0.0113) but lower than 442 mg/dL, a body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared) of 25 or less, total cholesterol (TC) <240 mg/dL (to convert to millimoles per liter, multiply by 0.0259), LDL-C <130 mg/dL (to convert to millimoles per liter, multiply by 0.0259), and a non-fasting total cholesterol–HDL-C ratio <4.6 (to convert to millimoles per liter, multiply by 0.0259). Exclusion criteria included lipid-lowering medications, hormone therapy, alcohol consumption of more than 2 drinks/d, tobacco use, major cardiovascular event or surgery in the preceding 6 months, diabetes, untreated hypothyroidism, blood pressure (BP) higher than 140/90 mm Hg, renal or liver disease, cancer (excluding nonmelanoma skin cancer), or any food allergies. At recruitment, 13 subjects were taking lipid-lowering medications; however, these were discontinued at least 2 weeks prior to the start of the study after obtaining approval from their family physician. Thirty-three participants were taking antihypertensive medications at a constant dose before and during the study. One participant altered the antihypertensive medication dosage during the study. Three participants took thyroxine at a constant dose before and during the study.
STUDY PROTOCOL

The intervention was a randomized parallel study stratified by sex in which participants were assigned to either low- or high-carbohydrate, calorie-reduced diets. The 1-month study was metabolically controlled with all food provided, and participants were seen at weekly intervals. At each visit, fasting body weights and BP were measured. Serum samples were obtained after 12-hour overnight fasts before treatment and at the end of weeks 2 and 4. Body weights were determined, with shoes removed and in indoor clothing, using a stationary beam balance scale (Healthometer; Continental Scale Corp, Bridgeview, Illinois). Blood pressure was measured 3 times in the non-dominant arm after sitting for 15 to 20 minutes using an automated digital BP machine (OMRON Healthcare Inc, Vernon Hills, Illinois). Food to be eaten by subjects for the entire metabolic month was prepackaged and delivered to subjects by courier. A “no starch” high-protein nut bread was obtained from the clinic at weekly intervals. Participants were asked to hold exercise constant over the metabolic period. Exercise dairies were also completed weekly with type of exercise, duration, and intensity recorded as light, moderate, or vigorous in accordance with the Guidelines of the Centers of Disease Control and Prevention and the American College of Sports Medicine, and exercise was calculated as metabolic equivalent of tasks (METs).12,13 Body fat percentage was measured by bioelectrical impedance (Quantum II; RJL Systems, Clinton Township, Michigan) and waist and hip measurements were measured biweekly. Waist measurements were made at the umbilicus and hip measurements at the maximum lateral protrusion of the greater trochanter of the femur.

Subjects rated their overall feeling of satiety for the previous week at each study visit using a 9-point bipolar semantic scale, where −4 was extremely hungry, 0 was neutral, and +4 was uncomfortably full.10 Palatability was rated at the end of the study using a 7-point bipolar semantic scale, where −3 was very unpalatable, 0 was neutral, and +3 was very palatable. The ethics committees of St Michael’s Hospital and the University of Toronto, Ontario, Canada, and the Therapeutic Products Directorate of Health Canada approved the study. Written informed consent was obtained from the participants.

DIETS

Metabolically controlled diets in which all food was provided were consumed by the participants. The low-carbohydrate diet provided the minimum level of carbohydrates currently recommended (130 g/d)14 and eliminated common starch-containing foods, such as bread, baked goods, potatoes, and rice. The protein content was provided by gluten (34.8% of total protein), soy (23.0%), fruits and vegetables (8.7%), nuts (7.3%), and cereals (6.0%). Gluten was provided in the nut bread and wheat gluten (also called “seitan”) products and, together with soy, in burgers, veggie bacon, deli slices, and breakfast links. In addition, soy was provided as tofu and soy beverages. Nuts including almond, cashews, hazelnuts, macadamia, pecans, and pistachios. The fat was provided by nuts (43.6% of total fat), vegetable oils (24.4%), soy products (18.5%), avocado (7.1%), cereals (2.7%), fruits and vegetables (2.3%), and seitan products (1.4%). The diet was designed to provide 26% of calories as carbohydrates, 31% as protein, and 43% as fat. The high-carbohydrate diet was a low-fat lacto-ovo vegetarian diet (38% carbohydrates, 16% protein, and 25% fat) using low-fat or skim milk dairy products and liquid egg whites or egg substitute to ensure a low-saturated fat and low-cholesterol intake.15 All diets were provided at 60% of estimated calorie requirements13 using the Harris-Benedict equation with allowance for exercise.16,17

The low-carbohydrate diet featured viscous fiber-containing foods, including oats and barley, for the relatively limited amount of carbohydrates allowed, and the production of a “no starch” high-protein bread made entirely from ground almonds, hazel nuts, and wheat gluten. The carbohydrate foods and low-starch vegetables, emphasizing okra and eggplant, provided 6 to 7 g of viscous fiber per 2000-kcal diet.18 The bread was provided as part of the diet.

Food preparation by participants was made as straightforward as possible by the provision of commercial dishes or food items, which were ready for microwave or oven cooking or could be reconstituted with boiling water, as with instant soups. Diet foods were packed in a central location and shipped by courier in separate boxes for dry, refrigerated, and frozen foods. Egg substitutes and soy dairy foods were shipped in their commercial packages to be refrigerated on receipt by the participants.

With the low-carbohydrate diet, plant- or microbially derived vitamin and mineral supplements were also provided, including vitamin B12, 1000 µg/wk (microbiologically synthesized B12; Genestra Brands, Toronto, Ontario, Canada), and vitamin D (as vegan ergocalciferol). 200 IU/d (VegLife, Park City, Utah). Women were also provided with calcium, 500 mg/d, and magnesium, 250 mg/d (VegLife).

Self-taring electronic scales (My Weigh Scales, Vancouver, British Columbia, Canada, or Tanita Corporation, Arlington Heights, Illinois) were provided to all participants to weigh all food items consumed during the study and record the weights on the menu plan.

Adherence was assessed from the completed menu plans, and subjects were also requested to weigh any leftover food items. Subjects were asked to record the intake of prescribed vitamin and mineral supplements as a further measure of compliance throughout the study. Supplement bottles were returned at the end of the study. Participants were offered no financial compensation for participation in the study.

LABORATORY ANALYSES

Serum was analyzed according to the Lipid Research Clinics protocol18 for TC, TG, and HDL-C concentrations, after dextran sulfatemagnesium chloride precipitation (Bayer Technicon RA1000; Bayer Healthcare, Toronto)19 or by detergent solubilization and measurement of HDL-C (Roche Hitachi 917; Roche Diagnostics, Laval, Quebec, Canada), in the J. Alick Little Lipid Research Laboratory. Low-density lipoprotein cholesterol was calculated by the method of Friedewald et al20 in millimoles per liter (LDL-C=total cholesterol [TC]−[TG/2.2 + HDL-C]).21 Apolipoproteins A1 (apo A1) and B (apo B) were measured by a nephelometric method (Dade Behring BN ProSpec; Dade Behring Canada Inc, Mississauga, Ontario). High-sensitivity C-reactive protein (hs-CRP) was measured by end-point nephelometry (Dade Behring BN ProSpec; Dade Behring Canada Inc.). C-reactive protein values higher than 10 mg/L to convert to nanomoles per liter, multiply by 9.24) were eliminated13 providing that they spiked more than 5 mg/L above the mean for the individual’s series.

Blood glucose was measured in the hospital routine analytical laboratory by a glucose oxidase method (SYNCHRON LX Systems; Beckman Coulter Canada Inc, Mississauga). Insulin was measured by Access Ultrasensitive Insulin Assay, which is a simultaneous 1-step immunoenzymatic (“sandwich”) assay (Beckman Coulter Canada Inc). A measure of insulin resistance was derived for fasting glucose and insulin using the homeostasis model assessment–insulin resistance model: fasting glucose and insulin using the homeostasis model assessment–insulin resistance model: fasting glucose (in millimoles per liter) × insulin (in milliunits per liter/22.5.22 Hemoglobin A1c (HbA1c) was measured by a designated high-performance liquid chromatography method (Tosoh G7 Automated HPLC Analyzer; Tosoh Bioscience Inc, Grove City, Ohio).
Dietary data were analyzed using the 2-sample t test (2 tailed). Differences between groups in baseline characteristics, obtained at randomization, for the control and low-carbohydrate diets are provided in Table 1. No significant differences were found in any of the variables between the 2 groups. There were no significant differences in the mean macronutrient profiles between individuals assigned to the test and control diets at baseline (Table 2). Both diets were well complied with, with no significant difference between treatments (Table 3). More than 90% of the calories provided were consumed for the test (95%) and control (94%) diets. Of those who started, all but 3 subjects completed the study: 2 withdrew from the control diet and 1 withdrew from the low-carbohydrate diet for reasons unrelated to the study protocol (Figure 1). The mean weight loss after 4 weeks of the metabolic phase was similar for both treatment diets at 4.7% (0.4%) (3.9 [0.4] kg) for the test and 4.9% (0.3%) (4.2 [0.3] kg) for the control (P=.94) diets. A similar pattern was seen with the completers (Figure 2). There were no absolute differences in calculated change in energy expenditure between the weeks 1 to 4 test and control treatments (−3.6 [2.7] vs 1.4 [1.7] METs; P=.12). Mean absolute subjective satiety ratings were significantly higher for the low-carbohydrate diet (1.5 [0.3] [low-carbohydrate diet] vs 0.8 [0.3] [high-carbohydrate diet]; P=.003). Satiety scores were positive for both treatments, indicating that the diets tended to satisfy participants (scale, −4 to +4).

STATISTICAL ANALYSES

The results are expressed as mean (SE). Serum lipid concentrations are expressed as absolute values in the Tables and percentage changes from baseline in the article text and Figures, unless otherwise stated. Differences between groups in baseline variables were assessed by the 2-sample t test (2 tailed). Intention-to-treat (ITT) analysis was undertaken with baseline observation carried forward for subjects who dropped out. Unless otherwise stated, ITT data are presented throughout. Time zero was used as the baseline. Within treatment groups, serum lipid concentrations and other measurements were not found to be significantly different between weeks 2 and 4 during the metabolic phase. For these reasons, the respective treatment differences were assessed by the CONTRAST statement in SAS using all available data and reported as changes from baseline to weeks 2 and 4. The model specified change from baseline as the response variable with week as the main effect and baseline as covariate, except when percentage changes from baseline were assessed. A significant difference was found between weeks 2 and 4 for body weight and BMI; therefore, the end of treatment values were assessed with baseline observation carried forward using the General Linear Model in SAS. Dietary data were analyzed using the 2-sample t tests for mean differences between the 2 treatment diets and at baseline.

RESULTS

Baseline characteristics, obtained at randomization, for the control and low-carbohydrate diets are provided in Table 1. No significant differences were found in any of the variables between the 2 groups. There were no significant differences in the mean macronutrient profiles between individuals assigned to the test and control diets at baseline (Table 2). Both diets were well complied with, with no significant difference between treatments (Table 3). More than 90% of the calories provided were consumed for the test (95%) and control (94%) diets. Of those who started, all but 3 subjects completed the study: 2 withdrew from the control diet and 1 withdrew from the low-carbohydrate plant-based diet for reasons unrelated to the study protocol (Figure 1). The mean weight loss after 4 weeks of the metabolic phase was similar for both treatment diets at 4.7% (0.4%) (3.9 [0.4] kg) for the test and 4.9% (0.3%) (4.2 [0.3] kg) for the control (P=.94) diets. A similar pattern was seen with the completers (Figure 2). There were no absolute differences in calculated change in energy expenditure between the weeks 1 to 4 test and control treatments (−3.6 [2.7] vs 1.4 [1.7] METs; P=.12). Mean absolute subjective satiety ratings were significantly higher for the low-carbohydrate diet (1.5 [0.3] [low-carbohydrate diet] vs 0.8 [0.3] [high-carbohydrate diet]; P=.003). Satiety scores were positive for both treatments, indicating that the diets tended to satisfy participants (scale, −4 to +4).

### Table 2. Nutritional Profiles at Baseline

| Variable                          | High-Carbohydrate Control Diet | Low-Carbohydrate Test Diet | P Value  
|----------------------------------|-------------------------------|---------------------------|---------
| Calories, mean (SE), kcal        | 1726.2 (113.8)                | 1779.0 (129.3)            | .76     |
| Total calories, % (SE)           |                               |                           |         |
| Available carbohydrate           | 46.4 (1.7)                    | 45.0 (1.9)                | .60     |
| Protein                          | 20.1 (0.8)                    | 19.6 (0.9)                | .68     |
| Vegetable protein                | 5.9 (0.3)                     | 5.7 (0.3)                 | .69     |
| Soy protein                       | 0.0 (0.0)                     | 0.0 (0.0)                 | . . .   |
| Fat                              | 31.5 (1.5)                    | 34.0 (1.6)                | .25     |
| Saturated                        | 10.8 (0.7)                    | 11.8 (0.8)                | .36     |
| Monounsaturated                  | 12.5 (0.7)                    | 12.9 (0.6)                | .66     |
| Polysaturated                    | 5.5 (0.4)                     | 6.4 (0.5)                 | .14     |
| Alcohol                          | 2.9 (0.8)                     | 1.4 (0.7)                 | .53     |
| Dietary fiber, mean (SE), g/1000 kcal | 12.0 (0.9)                  | 12.4 (1.1)                | .76     |
| Dietary cholesterol, mean (SE), mg/1000 kcal | 144.2 (9.7)            | 152.4 (10.9)              | .58     |

*Calculated using the 2-sample t test between high- vs low-carbohydrate diets.

### Table 3. Nutritional Profiles During the Study

| Variable                          | High-Carbohydrate Control Diet | Low-Carbohydrate Test Diet | P Value  
|----------------------------------|-------------------------------|---------------------------|---------
| Calories, mean (SE), kcal        | 1488.2 (48.1)                 | 1451.4 (47.3)             | .59     |
| Calorie compliance, % (SE)       | 94.2 (1.3)                    | 94.8 (1.4)                | .76     |
| Total calories, % (SE)           |                               |                           |         |
| Available carbohydrate           | 58.2 (0.4)                    | 26.8 (0.3)                | <.001   |
| Protein                          | 16.8 (0.1)                    | 30.0 (0.3)                | <.001   |
| Vegetable protein                | 7.0 (0.1)                     | 29.9 (0.3)                | <.001   |
| Soy protein                       | 0.2 (0.0)                     | 6.8 (0.1)                 | <.001   |
| Fat                              | 24.5 (0.4)                    | 43.1 (0.2)                | <.001   |
| Saturated                        | 4.6 (0.0)                     | 6.3 (0.1)                 | <.001   |
| Monounsaturated                  | 7.9 (0.2)                     | 25.0 (0.2)                | <.001   |
| Polysaturated                    | 9.1 (0.2)                     | 9.6 (0.1)                 | .02     |
| Alcohol                          | 0.3 (0.2)                     | 0.0 (0.0)                 | .15     |
| Dietary fiber, mean (SE), g/1000 kcal | 21.3 (0.2)                  | 28.3 (0.2)                | <.001   |
| Dietary cholesterol, mean (SE), mg/1000 kcal | 30.1 (1.4)            | 0.4 (0.3)                 | <.001   |

*Calculated using the 2-sample t test between high- vs low-carbohydrate diets.

Figure 2. Weight loss from both diets during the 4 weeks of the study (P=.98) for completers.
Both treatment groups had similar lipid values at baseline (Table 1). During the metabolic phase, reductions in LDL-C concentration and TC–HDL-C ratio were greater with the low-carbohydrate diet vs the high-carbohydrate diet (Table 1). During the metabolic phase, reductions in systolic BP of −2.2 mm Hg (−1.9%; P = .0052) and diastolic BP of −1.7 mm Hg (−2.4%; P = .023) were seen for the low-carbohydrate vs high-carbohydrate diet.

### COMMENT

The present study demonstrated that consumption of a low-carbohydrate plant-based diet resulted in body weight reductions of 4 kg that were similar to those reported for low-carbohydrate Atkins-like diets. In addition to weight loss, the consumption of a low-carbohydrate diet containing vegetable proteins and oils was associated with significantly reduced concentrations of LDL-C, not reported in the majority of low-carbohydrate diet studies in which the protein and fat are largely of animal origin. These diets result in increases in LDL-C concentrations compared with routinely used higher carbohydrate therapeutic diets. The reduction in LDL-C concentration is a potentially important attribute of the diet in reducing CHD risk.

Our data support earlier conclusions that differences in weight loss between treatments are likely to result from a reduction in caloric intake rather than metabolic changes associated with an altered macronutrient profile, despite the possibility that high-protein low-carbohydrate diets might enhance postprandial thermogenesis. In addition, the satiating effect of protein on self-selected diets, together with mild ketonemia following low-carbohydrate Atkins-like diets.1,5-8 In addition to weight loss, the consumption of a low-carbohydrate diet containing vegetable proteins and oils was associated with significantly reduced concentrations of LDL-C, not reported in the majority of low-carbohydrate diet studies in which the protein and fat are largely of animal origin. These diets result in increases in LDL-C concentrations compared with routinely used higher carbohydrate therapeutic diets. The reduction in LDL-C concentration is a potentially important attribute of the diet in reducing CHD risk.

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bohydride intake, might also favor weight reduction. In the present study, carbohydrate intake on the low-carbohydrate diet met the minimum recommended level, thus, significant ketonuria is unlikely, although it was not assessed.

Low–glycemic load diets have been associated with greater weight loss in adolescents. Increased subjective ratings of satiety were also found for the low-carbohydrate test diet in the present study, which by virtue of being low in carbohydrates was also a low–glycemic load diet. A similar finding of increased satiety was found in a metabolically controlled study using a low–glycemic load weight-loss diet in younger adults.

High-carbohydrate vegetarian diets such as the original Ornish diet, which emphasized soy and legume protein, have been associated with reduced progression of coronary artery disease, as well as weight loss and reduced LDL-C concentrations. However, such diets also lower HDL-C concentrations due to the impressively low intake of fats. Concern has been expressed over the use of high-carbohydrate diets, which may depress already low HDL-C concentrations further. The test diet in the present study, while lowering LDL-C concentration, did not depress HDL-C concentration significantly and resulted in a 16% reduction in the TC–HDL-C ratio. These changes would be expected to reduce CHD risk. Both soy and nuts, as key components of the present study, have been shown to increase HDL-C concentrations when included in low-fat diets.

Triglyceride concentrations were lower with consumption of the low-carbohydrate diet by comparison with the control diet, possibly reflecting the lower glycemic load and the presence of gluten, soy protein, and nuts, all of which have been associated with lower fasting serum TG concentrations.

Most low-carbohydrate diets have not reported the effects on apolipoproteins. The reduction in apo B and the apo B–apo Al ratio observed in the present study is a further confirmation of the potential CHD benefit that might be expected from this dietary approach to body weight reduction. In some studies, the apolipoprotein concentrations have been claimed to have greater predictive value for CHD events than more conventional lipid variables.

Both diets tended to reduce systolic and diastolic BP as expected relative to the degree to which body weight was reduced, but with a greater BP reduction with the low-carbohydrate diet. High-protein diets have been associated with lower BP. No treatment difference in hs-CRP concentration was seen in the present study, possibly related to the great variability in this measurement. In other studies, hs-CRP concentration tended to be lowest with the diets containing the highest proportion of carbohydrates, although low-glycemic index and low–glycemic load diets have also been associated with a lower hs-CRP concentration.

To our knowledge, no randomized controlled trials have been undertaken to assess the effect of low-carbohydrate diets on CHD events. Nevertheless, a recent cohort study reported that a low-carbohydrate diet high in protein and oil from vegetable rather than animal sources was associated with reduced CHD risk and incidence of diabetes. The mean level with each decile of vegetable protein and oil in this cohort study was only 4.2% to 5.6% of energy for vegetable protein and 9.6% to 18.9% of energy for vegetable oil, considerably less than used in the present study. Had the intakes been similar to the levels in the present study, the effects might have been greater.

In the present study, the high-carbohydrate control diet can be seen as providing a positive control because lacto-ovo vegetarians appear to be at generally lower risk of CHD than nonvegetarians, with notable studies demonstrating reduced CHD events in cohorts of California Seventh Day Adventists and the earlier assessment of British vegetarians. Furthermore, low-fat dairy diets em-

Figure 3. Mean (SE) percentage change from baseline in completers for both treatments for low-density lipoprotein cholesterol (P=.001) (A), total cholesterol–high-density lipoprotein cholesterol ratio (P=.003) (B), apolipoprotein B (apo B) (P=.001) (C), and apo B–apo Al ratio (P=.001) (D) (significance of difference between treatments).

Figure 4. Mean (SE) percentage change from baseline in completers for both treatments for triglyceride concentration (P=.02) (significance of difference between treatments).
Phasizing higher intakes of fruits and vegetables, such as the Dietary Approaches to Stop Hypertension (DASH) and Optimal Macro Nutrient Intake (OMNI) diets, have been associated with lower BP and improved serum lipid profiles. As such, the benefits for CHD risk reduction seen in the present study might have been much more marked had the low-carbohydrate diet been compared with those from a more typical low-fat diet.

According to the Mensink and Katan equation, the mean (SE) reductions in LDL-C concentration seen with the low-carbohydrate diet (−37.07 [5.79] mg/dL) were greater than predicted (−16.22 [1.16] mg/dL), even when adjusted for weight loss (P < .001). We believe that the greater than expected reductions in LDL-C concentrations are likely to be due in part to the cholesterol-lowering properties of soy protein and nuts, which have been demonstrated in previous studies. Furthermore, the small amount of carbohydrates included in the low-carbohydrate treatment diet was associated with viscous fiber in low-starch vegetables and β-glucan in oats and barley. Viscous fiber is also expected to contribute to the overall cholesterol-lowering effect of the diet. Vegetable protein has also been shown to be inversely related to BP in the cross-sectional epidemiological INTERMAP Study of 4680 individuals aged 40 to 59 from 4 countries. Soy protein consumption has been associated with lower blood pressure in a number of feeding trials (ie, meta-analysis), providing a further reason why vegetable proteins would be expected to reduce the risk of CHD.

In addition to reduction in LDL-C concentration, lower saturated fat intake may have other advantages, including reduced insulin resistance, chronic inflammation, and improved endothelial function, all of which would contribute to the lower risk of CHD associated with reduced saturated fat intake. However, polyunsaturated fats and vegetable oils in general in epidemiological studies have been shown to be associated with a reduced risk of CHD as opposed to saturated and trans fats, which are associated with increased risks. Key characteristics of a plant-based diet include fiber, vegetable oils and vegetable proteins, and foods such as nuts and seeds. These foods and food components benefit CHD risk factors, and it is therefore not surprising that plant-based diets have been associated with reduced CHD events in epidemiological studies.

We conclude that low-carbohydrate diets emphasizing vegetable sources of protein, such as gluten, soy, and nuts, together with vegetable oils can be used in weight reduction diets to improve serum lipid concentrations. There are, however, currently no trials of diets high in vegetable protein and oils with disease end points. The impact of low-carbohydrate diets in primary and secondary CHD prevention, therefore, remain to be determined. Nevertheless, recent studies indicate beneficial effects of vegetable oils and proteins on both CHD risk factors and CHD risk. Consumption of foods rich in these components including nuts and soy have been shown to reduce serum lipid concentrations, and nut consumption has been associated with lower CHD risk.

Important questions remain. Can the advantages be maintained if some of the vegetable protein is replaced by vegetable oil, and in this context, can carbohydrate intake be further reduced or is there an optimal carbohydrate load, perhaps determined by an individual's BMI and insulin resistance? There may also be certain advantages for higher carbohydrate intakes, providing the carbohydrate comes from high fiber, low–glycemic index foods. Pending answers to these questions, a plant-based low-carbohydrate diet high in vegetable proteins and oils may be an effective option in treating those with dyslipidemia for whom both weight loss and lower LDL-C concentrations are treatment goals.

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Author Contributions: Dr Jenkins, together with those responsible for analysis and interpretation of data, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Jenkins, Wong, Kendall, Faulkner, Greaves, Paul, and Singer. Acquisition of data: Jenkins, Wong, Kendall, Esfahani, Ng, and Leong. Analysis and interpretation of data: Jenkins, Wong, Kendall, and Vidgen. Drafting of the manuscript: Jenkins, Wong, and Singer. Critical revision of the manuscript for important intellectual content: Jenkins, Wong, Kendall, Esfahani, Ng, Leong, and Faulkner. Study supervision: Jenkins, Kendall, and Singer. Financial Disclosure: Dr Jenkins has served on the Scientific Advisory Board of Unilever, the Sanitarium Company, and the California Strawberry Commission and received research grants from Loblaw’s, Unilever, Barilla, and the Almond Board of California. Drs Jenkins and Kendall have been on the speaker’s panel for the Almond Board of California. Drs Jenkins and Mr Vidgen have received partial salary funding from research grants provided by Unilever, Loblaw’s, and the Almond Board of California. Dr Jenkins has received honoraria for scientific advice from the Almond Board of California, Barilla, Unilever Canada, and Solae, LLC. Dr Greaves was a former employee of Solae, LLC, and is now an employee of Kellogg’s. Dr Paul is an employee of Solae, LLC.

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REFERENCES


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Correction

Error in “Methods” Section. In the article titled “The Effect of a Plant-Based Low-Carbohydrate (‘Eco-Atkins’) Diet on Body Weight and Blood Lipid Concentrations in Hyperlipidemic Subjects” by Jenkins et al, published in the June 8 issue of the Archives (2009;169[11]:1046-1054), the description of the bread in the “Diets” subsection of the “Methods” section on page 1048 (first 2 sentences, right column) should have read as follows: “The low-carbohydrate diet featured viscous fiber–containing foods, including oats and barley, for the relatively limited amount of carbohydrates allowed, and the production of a ‘no starch’ high-protein bread made from ground almonds, hazelnuts, and wheat gluten. The bread also contained a small amount of psyllium (mean intake, 1.1 g/d), which would contribute additional viscous fiber to the diet.”