Comparison of the Atkins, Zone, Ornish, and LEARN Diets for Change in Weight and Related Risk Factors Among Overweight Premenopausal Women

The A TO Z Weight Loss Study: A Randomized Trial

Christopher D. Gardner, PhD
Alexandre Kiazand, MD
Sofiya Alhassan, PhD
Soowon Kim, PhD
Randall S. Stafford, MD, PhD
Raymond R. Balise, PhD
Helena C. Kraemer, PhD
Abby C. King, PhD

The ongoing obesity epidemic, along with its health costs and consequences, and the health benefits of weight loss, have been well established. National dietary weight loss guidelines (ie, energy-restricted, low in fat, high in carbohydrate) have been challenged, particularly by proponents of low-carbohydrate diets. However, limited evidence has been available to effectively evaluate other diets.

Several recent trials compared low-carbohydrate vs traditional low-fat, high-carbohydrate weight-loss diets. A meta-analysis that pooled the results of these early trials concluded that low-carbohydrate, non-energy-restricted diets were at least as effective as low-fat, high-carbohydrate diets in inducing weight loss for up to 1 year. However, most of these trials were limited by combinations of small sample sizes, high rates of attrition, short durations, or limited diet assessment.

For the A TO Z (Atkins, Traditional, Ornish, Zone) Weight Loss Study, we selected 4 diets—3 popular and substantially different diets and 1 diet based on national guidelines—representing a spectrum of carbohydrate intake: Atkins (very low in carbohydrate), Zone (very low in carbohydrate), LEARN (very low in carbohydrate), and Ornish (low in carbohydrate).

Context  Popular diets, particularly those low in carbohydrates, have challenged current recommendations advising a low-fat, high-carbohydrate diet for weight loss. Potential benefits and risks have not been tested adequately.

Objective  To compare 4 weight-loss diets representing a spectrum of low to high carbohydrate intake for effects on weight loss and related metabolic variables.


Intervention  Participants were randomly assigned to follow the Atkins (n=77), Zone (n=79), LEARN (n=79), or Ornish (n=76) diets and received weekly instruction for 2 months, then an additional 10-month follow-up.

Main Outcome Measures  Weight loss at 12 months was the primary outcome. Secondary outcomes included lipid profile (low-density lipoprotein, high-density lipoprotein, and non–high-density lipoprotein cholesterol, and triglyceride levels), percentage of body fat, waist-hip ratio, fasting insulin and glucose levels, and blood pressure. Outcomes were assessed at months 0, 2, 6, and 12. The Tukey studentized range test was used to adjust for multiple testing.

Results  Weight loss was greater for women in the Atkins diet group compared with the other diet groups at 12 months, and mean 12-month weight loss was significantly different between the Atkins and Zone diets (P<.05). Mean 12-month weight loss was as follows: Atkins, −4.7 kg (95% confidence interval [CI], −6.3 to −3.1 kg), Zone, −1.6 kg (95% CI, −2.8 to −0.4 kg), LEARN, −2.6 kg (−3.8 to −1.3 kg), and Ornish, −2.2 kg (−3.6 to −0.8 kg). Weight loss was not statistically different among the Zone, LEARN, and Ornish groups. At 12 months, secondary outcomes for the Atkins group were comparable with or more favorable than the other diet groups.

Conclusions  In this study, premenopausal overweight and obese women assigned to follow the Atkins diet, which had the lowest carbohydrate intake, lost more weight and experienced more favorable overall metabolic effects at 12 months than women assigned to follow the Zone, Ornish, or LEARN diets. While questions remain about long-term effects and mechanisms, a low-carbohydrate, high-protein, high-fat diet may be considered a feasible alternative recommendation for weight loss.

Trial Registration  clinicaltrials.gov Identifier: NCT00079573

JAMA. 2007;297:969-977

www.jama.com

Reprinted JAMA, March 7, 2007—Vol 297, No. 9

©2007 American Medical Association. All rights reserved.
(low in carbohydrate), LEARN18 (Life-
style, Exercise, Attitudes, Relationships,
and Nutrition; low in fat, high in car-
bohydrate, based on national guidelines),
and Ornish19 (very high in car-
bohydrate). The primary study objec-
tive was to examine the effects of diets
and gradations of carbohydrate intake
on weight loss and related metabolic
variables in overweight and obese pre-
menopausal women.

METHODS
Participants
Participants were recruited from the local
community, primarily through media
advertisements. Premenopausal women
aged 25 to 50 years were invited to enroll
if their body mass index (calculated as
weight in kilograms divided by height in
meters squared) was 27 to 40. Body
weight was stable over the previous 2
months, and medications were stable for
at least 3 months. Women were excluded
if they self-reported hypertension (ex-
cept for those whose blood pressure was
stable using antihypertension medica-
tions); type 1 or 2 diabetes mellitus; heart,
renal, or liver disease; cancer or active
neoplasms; hyperthyroidism unless
treated and under control; any medica-
tion use known to affect weight/energy
expenditure; alcohol intake of at least 3
drinks/d; or pregnancy, lactation, no
menstrual period in the previous 12
months, or plans to become pregnant
for completing the 2-, 6-, and 12-
month data collection points, and in-
centive payments of $25, $50, and $75
for the other 3 diet groups. Efforts to ma-
imize retention in the study included
e-mail and telephone reminders for ap-
pointments, e-mail or telephone con-
tact from staff between the 2- and
6-month and between the 6- and 12-
month data collection points, and in-
centive payments of $25, $50, and $75
for completing the 2-, 6-, and 12-
month data collection, respectively.

Each group received specific target
goals according to the emphasis of the
assigned diet. The Atkins group aimed
for 20 g/d or less of carbohydrate for “in-
duction” (usually 2-3 months) and 50 g/d
or less of carbohydrate for the subse-
quent “ongoing weight loss” phase. The
Zone group’s primary emphasis was a
40%-30%-30% distribution of carbohy-
drate, protein, and fat, respectively. The
LEARN group was instructed to follow
a prudent diet that included 55% to 60%
energy from carbohydrate and less than
10% energy from saturated fat, caloric
restriction, increased exercise, and behav-
ior modification strategies. The pri-
mary emphasis for the Ornish group was
no more than 10% of energy from fat. Ad-
ditional recommendations given for
physical activity, nutritional supple-
ments, and behavioral strategies were
consistent with those presented in each
diet book.8,9,18,19 The guidelines for the
Zone and LEARN diets incorporated spe-
cific goals for energy restriction, while
for the Atkins and Ornish diets, there
were no specific energy restriction goals.

A range of behavior modification tech-
niques were discussed during the 2-
month classes. The Ornish and Zone
books suggest some stimulus-control
strategies but on the whole do not em-
phasize behavior modification, whereas
both the Atkins and LEARN books sug-
gest multiple strategies, such as relapse
preparation and planning strategies and
goal setting. Overall, the LEARN manual
has the greatest emphasis on behavior
modification strategies.

Process and Outcome Measures
All data were collected at baseline, 2,
6, and 12 months.

Diet and Physical Activity Data. Di-
etary intake data were collected by tele-
phone-administered, 3-day, unan-
ounced, 24-hour dietary recalls using
Nutrition Data System for Research soft-
ware, versions 4.05.33, 4.06.34, and
5.0.33 (Nutrition Coordinating Cen-
ter, University of Minnesota, Minne-
apolis). Data collectors were trained and
certified by the Nutrition Coordinat-
ing Center. The recalls occurred on 2
weekdays and 1 weekend day per time
point, on nonconsecutive days when-
ever possible. Local foods not found in
the comprehensive database were added
to the database manually. A “food
amounts booklet” was used to assist
participants with portion size estima-
tion. Energy expenditure was assessed
using the well-established Stanford
7-day physical activity recall.20

Anthropometric Data. Height was
measured to the nearest millimeter
using a standard wall-mounted stadi-
ometer. Body weight was measured to
the nearest 0.1 kg on a calibrated clini-
cal scale. Waist and hip circumference
were measured to the nearest millime-
ter by standard procedures using a
150-cm anthropometric measuring
tape.21 Whole-body fat (percentage of
body mass) was determined by dual-
energy x-ray absorptiometry using pen-
cil-beam mode on the Hologic QDR-
2000 (first 3 cohorts) and, later, the
array mode on a Hologic QDR 4500 densitometer (last cohort) (Hologic Inc, Waltham, Mass).

Metabolic Measures. Blood samples were collected after a 10-hour or longer fast. Plasma total cholesterol and triglycerides (free glycerol blank subtracted) were measured enzymatically using Stanford Clinical Chemistry Laboratory--established methods.22,23 High-density lipoprotein cholesterol (HDL-C) was measured by liquid selective detergent followed by enzymatic determination of cholesterol.24 Low-density lipoprotein cholesterol (LDL-C) was calculated according to the methods described by Friedewald et al.25 Lipid assays were monitored by the Lipid Standardization Program of the Centers for Disease Control and Prevention and were consistently within specified limits (monthly coefficients of variation were all $\leq 3.1\%$). The non–HDL-C measure was defined as total cholesterol value minus HDL-C value.26 Total plasma insulin in serum was measured by radioimmunoassay.27 Blood glucose was measured using a modification of the glucose oxidase/peroxidase method.28,29

Resting blood pressure was measured 3 times at 2-minute intervals as described elsewhere30; the initial reading was discarded and the last 2 readings were averaged. Clinic and laboratory staff members were blinded to treatment assignment.

Statistical Analyses

The primary objective was to test whether any of the 4 diets, representing a spectrum of carbohydrate intake, was more effective than any other in 12-month weight loss. The selected minimal clinically significant between-group difference in weight change was 2.7 kg (6 lb, approximately 3% for a 180-lb individual). Based on previous trials, we projected a 6.3-kg SD of weight change.31,32 The primary analysis was conducted applying intention-to-treat methods with baseline values carried forward for missing values. Thus, with 4 treatment groups and a projected 75 participants per group, the study was designed to have 80% power to detect a 2.7-kg difference for 12-month weight change between groups.

Dietary composition data (energy intake; percentage carbohydrate, fat, and protein; and grams of saturated fat and fiber) were analyzed using raw, unadjusted means (SDs) (ie, no imputation for missing data). Between-group differences in dietary intake at each time point were tested by analysis of variance (ANOVA). For weight and for all secondary outcome measures, analyses were conducted using all time points and all diets and were tested for diet group $\times$ time (log time + 1) interactions in a mixed model using autoregressive covariance structure (SAS version 9.1.3 with Service Pack 3, SAS Institute Inc, Cary, NC). Triglyceride data were log-transformed to attain normal distributions for testing; for ease of interpretation, values presented in the text and figures are untransformed.

Differences among diets for 12-month changes from baseline were tested by ANOVA. For statistically significant ANOVAs, all pairwise comparisons among the 4 diets were tested using the Tukey studentized range adjustment. Statistical testing of changes from baseline to 2 months and to 6 months using pairwise comparisons are presented for descriptive purposes.

For exploratory purposes, ancillary analyses were conducted to determine the effect of diet group assignment on secondary outcomes at 12 months after adjusting for changes in weight loss using linear regression. Also for exploratory purposes, all analyses of weight and secondary outcome measures were tested using only available data, without using baseline values carried forward for missing data or other imputation methods. There were no substantive differences in any of these findings compared with the analyses with baseline values carried forward and, therefore, only the primary analyses are presented. Multiple regression was used to examine potential interactions between race/ethnicity and diet.
group for effects on weight loss; there were no significant interactions. All statistical tests were 2-tailed using a significance level of .05.

**RESULTS**

Participant enrollment began in February 2003, and the study ended in October 2005. Figure 1 shows participant flow; Table 1 shows baseline characteristics.

In all 4 diet groups, 85% to 89% of participants attended at least 75% of their assigned classes (≥6 of 8). Attendance was not different by diet group (P = .68). Retention at 12 months was 88%, 77%, 76%, and 78% for the Atkins, Zone, LEARN, and Ornish groups, respectively, and was not significantly different among groups (P = .30). Participant ratings for class instructor enthusiasm and knowledge of material were very high for both among all diet groups and were not significantly different among groups; average scores ranged from 4.4 to 4.7 on a scale of 1 to 5, with 5 as the highest rating.

### Dietary Intake and Energy Expenditure

Total energy intake was not different among diet groups at baseline or any subsequent time point (P > .40 for all) (Table 2). However, relative to baseline, there was a significant mean decrease in reported energy intake at all postrandomization time points.

### Table 1. Baseline Participant Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Atkins (n = 77)</th>
<th>Zone (n = 78)</th>
<th>LEARN (n = 78)</th>
<th>Ornish (n = 76)</th>
<th>All Diets (n = 312)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>42 (5)</td>
<td>40 (6)</td>
<td>40 (7)</td>
<td>42 (6)</td>
<td>41 (6)</td>
</tr>
<tr>
<td>Education, y</td>
<td>16 (2)</td>
<td>16 (2)</td>
<td>16 (2)</td>
<td>16 (2)</td>
<td>16 (2)</td>
</tr>
<tr>
<td>Race/ethnicity, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>59 (76)</td>
<td>52 (66)</td>
<td>59 (75)</td>
<td>52 (69)</td>
<td>71</td>
</tr>
<tr>
<td>Black</td>
<td>2 (3)</td>
<td>7 (9)</td>
<td>6 (7)</td>
<td>4 (5)</td>
<td>6</td>
</tr>
<tr>
<td>Hispanic</td>
<td>7 (9)</td>
<td>8 (10)</td>
<td>7 (9)</td>
<td>11 (14)</td>
<td>11</td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>7 (9)</td>
<td>9 (11)</td>
<td>6 (8)</td>
<td>8 (10)</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>2 (3)</td>
<td>3 (4)</td>
<td>1 (1)</td>
<td>1 (1)</td>
<td>2</td>
</tr>
<tr>
<td>Smokers, No. (%)</td>
<td>2 (3)</td>
<td>4 (5)</td>
<td>4 (5)</td>
<td>3 (4)</td>
<td>4</td>
</tr>
<tr>
<td>Physical activity, kcal/kg per d</td>
<td>34 (6)</td>
<td>34 (6)</td>
<td>34 (5)</td>
<td>35 (7)</td>
<td>34 (6)</td>
</tr>
</tbody>
</table>

| Anthropometrics |                |              |               |                |                   |
| Weight, kg      | 86 (13)        | 84 (12)      | 85 (14)       | 86 (10)        | 85 (12)           |
| Body fat, %     | 41 (6)         | 40 (6)       | 38 (6)        | 40 (6)         | 40 (6)            |
| Body mass index†| 32 (4)         | 31 (3)       | 31 (4)        | 32 (3)         | 32 (4)            |
| Waist:hip-ratio | 0.843 (0.067)  | 0.841 (0.068)| 0.839 (0.066)| 0.840 (0.066)  | 0.841 (0.065)     |

| Cardiovascular disease risk factors |               |              |               |                |                   |
| LDL-C, mg/dL     | 109 (29)       | 114 (32)     | 104 (29)      | 111 (27)       | 110 (29)          |
| HDL-C, mg/dL     | 53 (14)        | 52 (11)      | 51 (11)       | 50 (11)        | 52 (12)           |
| Triglycerides, mg/dL | 125 (78) | 123 (98) | 119 (73) | 118 (62) | 121 (78) |
| Non-HDL-C, mg/dL | 134 (33)       | 139 (39)     | 127 (34)      | 135 (33)       | 134 (35)          |
| Ratio of total cholesterol to HDL-C | 3.7 (1.0) | 3.8 (1.1) | 3.6 (1.0) | 3.8 (1.0) | 3.7 (1.0) |
| Fasting insulin, µU/mL | 10 (7) | 10 (7) | 10 (8) | 10 (5) | 10 (6) |
| Fasting glucose, mg/dL | 92 (9) | 94 (20) | 96 (17) | 93 (13) | 94 (15) |

| Blood pressure, mm Hg |               |              |               |                |                   |
| Systolic            | 118 (11)       | 115 (13)     | 116 (12)      | 116 (10)       | 116 (11)          |
| Diastolic           | 75 (8)         | 74 (9)       | 76 (9)        | 75 (8)         | 75 (8)            |

| Metabolic syndrome, No. (%) | 22 (29) | 20 (25) | 29 (37) | 27 (36) | 99 (32) |

Abbreviations: HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

SI conversions: To convert LDL-C, HDL-C, and total cholesterol to mmol/L, multiply by 0.0259. To convert triglycerides to mmol/L, multiply by 0.0113. To convert glucose to mmol/L, multiply by 0.0555.

*Data are expressed as mean (SD) unless otherwise indicated.

*Calculated as weight in kilograms divided by height in meters squared.

**Dietary Intake and Energy Expenditure**

Total energy intake was not different among diet groups at baseline or any subsequent time point (P > .40 for all) (Table 2). However, relative to baseline, there was a significant mean decrease in reported energy intake at all postrandomization time points.

Total energy expenditure was slightly higher for the Ornish group vs the other 3 groups at baseline but was not significantly different among groups at any subsequent time point (Table 1). Relative to baseline, there was a modest and significant mean increase (P < .05) in energy expenditure at all time points for all groups combined: +0.5 (SD, 2.8), +0.4 (SD, 2.7), and +1.0 (SD, 3.0) kcal/kg per day at 2, 6, and 12 months, respectively.

### Weight and Anthropometric Outcomes

Mean 12-month weight change was −4.7 kg (95% confidence interval [CI], −6.3 to −3.1 kg) for Atkins, −1.6 kg (95% CI, −2.8 to −0.4 kg) for Zone, −2.2 kg (95% CI, −3.6 to −0.8 kg) for LEARN, and −2.6 kg (95% CI, −3.8 to −1.3 kg) for Ornish and was significantly different for Atkins vs Zone (Figure 2). At the 2- and 6-month intermediate time points, the weight change for the Atkins group was significantly greater than for all other groups (P < .005). Weight change among
the Zone, LEARN, and Ornish groups did not differ significantly at any time point. The pattern of changes in body mass index, percentage of body fat, and waist-hip ratio among groups paralleled the changes in weight, although the between-group differences at 12 months did not achieve statistical significance for percentage of body fat ($P = .07$) or waist-hip ratio ($P = .10$) (Table 3).

**Lipid Outcomes**

Results generated by 84% of the study population ($n = 262$) with baseline blood samples (Atkins, $n = 70$; Zone, $n = 65$; LEARN, $n = 63$; and Ornish, $n = 64$) were available for testing. Four of the LDL-C values could not be calculated because of triglyceride concentrations greater than 400 mg/dL (4.52 mmol/L) and were treated as missing data. At all time points, the statistically significant findings for HDL-C and triglycerides concentrations favored the Atkins group (Table 3). Changes in LDL-C concentrations at 2 months favored the LEARN and Ornish diets over the Atkins diet; however, these differences diminished and were no longer significant at 6 and 12 months. Non-HDL-C differences among groups were not significant at any time point.

**Insulin, Glucose, and Blood Pressure Outcomes**

Insulin and glucose measurements were obtained from the same aforementioned 84% of the total sample for lipids. Neither the overall trajectory (ie, across all time points) nor the 12-month differences were significantly different among groups for either fasting insulin or fasting glucose concentrations (Table 3).

Parallel to the group changes in weight, the decrease in mean blood pressure levels was largest in the Atkins group at all time points. At 12 months, the decrease in systolic blood pressure was significantly greater for the Atkins group than for any other group. For diastolic pressure, the only significantly pairwise difference at 12 months favored the Atkins over the Ornish group.

**Ancillary Analyses of Diet Group Effects Independent of Changes in Weight**

For the 249 participants who completed the full 12-month protocol, we examined the independent effect of diet group on secondary outcomes after adjusting for 12-month changes in weight using linear regression. Each of the statistically significant 12-month differences between diet groups (ie, triglycerides, HDL-C, and systolic and diastolic blood pressure; Table 3) remained statistically significant after including weight loss in the model; however, the level of significance was diminished.

**COMMENT**

Compared with women who were assigned to follow diets having higher car-

---

**Table 2. Mean Dietary Intake and Energy Expenditure by Diet Group and Time Point**

<table>
<thead>
<tr>
<th></th>
<th>Atkins</th>
<th>Zone</th>
<th>LEARN</th>
<th>Ornish</th>
<th>Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, kcal/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>1888 (512)</td>
<td>1975 (567)</td>
<td>1925 (553)</td>
<td>1850 (541)</td>
<td>.52</td>
</tr>
<tr>
<td>2 mo</td>
<td>1381 (345)</td>
<td>1455 (464)</td>
<td>1476 (448)</td>
<td>1408 (453)</td>
<td>.52</td>
</tr>
<tr>
<td>6 mo</td>
<td>1538 (401)</td>
<td>1503 (348)</td>
<td>1598 (418)</td>
<td>1553 (530)</td>
<td>.64</td>
</tr>
<tr>
<td>12 mo</td>
<td>1599 (494)</td>
<td>1594 (523)</td>
<td>1654 (492)</td>
<td>1505 (437)</td>
<td>.43</td>
</tr>
<tr>
<td>Carbohydrate (% energy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>45.6 (10.5)</td>
<td>47.1 (9.0)</td>
<td>48.3 (9.2)</td>
<td>47.9 (8.6)</td>
<td>.31</td>
</tr>
<tr>
<td>2 mo</td>
<td>17.7 (11.8)a</td>
<td>42.0 (8.5)b</td>
<td>49.3 (8.6)c</td>
<td>63.1 (11.0)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>29.5 (14.5)a</td>
<td>43.7 (9.2)b</td>
<td>48.2 (8.6)c</td>
<td>53.4 (13.4)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>34.5 (14.4)a</td>
<td>45.4 (11.1)b</td>
<td>47.2 (8.9)c</td>
<td>52.4 (12.3)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Protein (% energy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>16.6 (4.1)</td>
<td>15.6 (3.3)</td>
<td>16.7 (3.9)</td>
<td>16.3 (3.1)</td>
<td>.21</td>
</tr>
<tr>
<td>2 mo</td>
<td>27.7 (5.5)a</td>
<td>23.7 (5.8)b</td>
<td>20.1 (4.8)c</td>
<td>19.6 (4.3)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>22.4 (6.3)a</td>
<td>20.1 (5.2)c</td>
<td>18.4 (4.6)d</td>
<td>18.1 (4.8)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>20.6 (5.3)a</td>
<td>20.0 (5.2)c</td>
<td>18.5 (4.6)d</td>
<td>18.3 (4.0)d &lt; .02</td>
<td></td>
</tr>
<tr>
<td>Fat (% energy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>36.2 (7.8)a</td>
<td>35.6 (6.5)ab</td>
<td>33.2 (7.2)a</td>
<td>35.1 (7.0)ab &lt; .05</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>54.7 (9.0)a</td>
<td>34.8 (6.6)c</td>
<td>30.2 (7.3)c</td>
<td>21.1 (8.0)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>47.0 (11.9)a</td>
<td>35.7 (7.3)c</td>
<td>31.3 (7.8)c</td>
<td>28.3 (10.7)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>44.3 (12.5)a</td>
<td>34.5 (7.8)c</td>
<td>32.9 (7.1)c</td>
<td>29.8 (10.5)d &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Saturated fat, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>26.5 (11.1)</td>
<td>27.0 (10.9)</td>
<td>24.3 (11.0)</td>
<td>24.8 (10.3)</td>
<td>.34</td>
</tr>
<tr>
<td>2 mo</td>
<td>30.7 (9.8)a</td>
<td>19.3 (10.3)c</td>
<td>16.8 (9.8)c</td>
<td>10.3 (7.8)c &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>28.1 (11.1)a</td>
<td>20.5 (8.0)c</td>
<td>19.0 (8.9)c</td>
<td>16.2 (10.1)c &lt; .001</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>27.2 (13.3)a</td>
<td>21.6 (11.2)c</td>
<td>20.1 (9.8)c</td>
<td>16.9 (11.4)c &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Fiber, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>17.4 (6.6)</td>
<td>17.8 (8.7)</td>
<td>17.6 (7.5)</td>
<td>16.6 (6.6)</td>
<td>.79</td>
</tr>
<tr>
<td>2 mo</td>
<td>11.0 (6.3)a</td>
<td>16.9 (6.7)c</td>
<td>17.8 (7.1)c</td>
<td>22.1 (9.4)c &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>14.0 (6.3)a</td>
<td>15.3 (7.6)c</td>
<td>16.7 (6.3)c</td>
<td>19.3 (11.1)c &lt; .001</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>15.2 (6.6)a</td>
<td>16.7 (9.4)c</td>
<td>18.3 (7.9)c</td>
<td>19.3 (9.4)c &lt; .03</td>
<td></td>
</tr>
<tr>
<td>Energy expenditure, kcal/kg per d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>33.7 (1.8)a</td>
<td>34.1 (2.6)a</td>
<td>33.9 (1.5)a</td>
<td>34.9 (3.2)d &lt; .007</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>34.6 (2.1)</td>
<td>34.5 (2.4)</td>
<td>34.8 (2.4)</td>
<td>34.7 (2.3)</td>
<td>.88</td>
</tr>
<tr>
<td>6 mo</td>
<td>34.3 (2.4)</td>
<td>34.4 (1.9)</td>
<td>34.8 (2.0)</td>
<td>34.6 (2.3)</td>
<td>.65</td>
</tr>
<tr>
<td>12 mo</td>
<td>34.8 (2.7)</td>
<td>34.5 (3.3)</td>
<td>35.6 (2.2)</td>
<td>35.8 (5.8)</td>
<td>.42</td>
</tr>
</tbody>
</table>

*Data presented are unadjusted raw data with no imputations for missing data. Standard deviations are presented in parentheses. Sample sizes for baseline and 2, 6, and 12 months, respectively, are: Atkins, n = 77, 73, 71, and 68; Zone, n = 79, 73, 67, and 57; LEARN, n = 79, 73, 66, and 60; and Ornish, n = 76, 72, 67, and 66.†By analysis of variance.** When the analysis of variance (last column) was statistically significant ($P < .05$), all pairwise comparisons among diet groups were tested for statistical significance using the Tukey studentized range test. Pairwise comparisons that were significantly different from one another are indicated by superscripts as follows: whereas the values for 2 diet groups within a row do not share a common superscript, they are significantly different, whereas if the values do share a common superscript, they are not significantly different.

©2007 American Medical Association. All rights reserved.
The exception to this pattern has been LDL-C concentrations. Two of the most consistent findings in recent trials of low-carbohydrate vs low-fat diets have been higher LDL-C concentrations and lower triglyceride concentrations in the low-carbohydrate diets. Although a higher LDL-C concentration would appear to be an adverse effect, this may not be the case under these study conditions. The triglyceride-lowering effect of a low-carbohydrate diet leads to an increase in LDL particle size, which is known to decrease LDL atherogenicity. In the current study, at 2 months, mean LDL-C concentrations increased by 2% and mean triglyceride concentrations decreased by 30% in the Atkins group. These findings are consistent with a beneficial increase in LDL particle size, although LDL particle size was not assessed in our study. In addition, we examined non-HDL-C concentrations as an alternate indicator of atherogenic lipoproteins—a variable not substantially influenced by changes in triglyceride concentrations—and observed no significant differences among groups at any time point.

Therefore, we interpret these findings to suggest that there were no adverse effects on the lipid variables for women following the Atkins diet compared with the other diets and, furthermore, no adverse effects were observed on any weight-related variable measured in this study at any time point for the Atkins group. Further examination of the dietary effects on lipid variables would benefit from analyses of lipoprotein particle subfractions and follow-up of longer than 12 months.

Our study and the study by Dansinger et al were similar in several design features, including similar number and types of treatment groups and the same duration. Despite the similarities in design, several conclusions differed between the trials. Dansinger et al reported that weight loss at 12 months did not differ by diet group but only by level of adherence, regardless of diet type. In addition, Dansinger et al reported improvements within groups over 12 months for cardiac risk factors but did not report any significant differences between groups. In contrast, we observed statistically significant differences among diet groups for both weight loss and risk factors at 12 months.

These differences are likely attributable to at least 2 factors. One factor concerns the different study populations: our study was restricted to women aged 20 to 50 years who did not have diabetes and were not taking medications for cardiac risk factors, whereas the population in the study by Dansinger et al was much broader in its inclusion criteria. A second likely factor was differences in statistical power; in the study by Dansinger et al, 93 of 160 enrolled participants completed the trial (42% attrition at 12 months; ie, n=21-26 per treatment group); in the current study, 248 of 311 women completed the trial (20% attrition; ie, n=58-68 per treatment group).

The current study examined whether risk factor responses to diets were independent of weight loss. After statistically adjusting for weight loss differentials among groups, the secondary outcome differences among groups at 12 months that were significant in the unadjusted model remained significant in the adjusted model, although the level of significance was diminished. This supports a combined effect of benefit for the very-low-carbohydrate Atkins diet attributable to both increased weight loss and dietary composition. However, our study was not designed to specifically address this ancillary question. Krauss et al recently addressed this issue directly in a study testing diets that ranged from low to high carbohydrate intake under conditions of weight stability followed by conditions of weight loss. Improvements in lipids and lipoproteins were greater for participants in the very-low-carbohydrate diet during the weight-stable phase but were greater for those in the high-carbohydrate diet.
Table 3. Mean Changes in Secondary Outcomes Relative to Baseline, by Diet Group and Time*

<table>
<thead>
<tr>
<th></th>
<th>Atkins (n = 77)</th>
<th>Zone (n = 79)</th>
<th>LEARN (n = 79)</th>
<th>Ornish (n = 76)</th>
<th>Overall Diet Group × Time†</th>
<th>12 Month‡</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body mass index§</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−1.60 (0.98)</td>
<td>−0.76 (0.99)</td>
<td>−0.99 (1.00)</td>
<td>−0.95 (0.90)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−2.16 (2.14)</td>
<td>−0.73 (0.90)</td>
<td>−1.13 (1.91)</td>
<td>−0.85 (1.60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−1.65 (2.54)</td>
<td>−0.53 (2.00)</td>
<td>−0.92 (2.00)</td>
<td>−0.77 (2.14)</td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td><strong>Body fat, %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−2.1 (1.8)</td>
<td>−1.8 (2.0)</td>
<td>−1.5 (1.8)</td>
<td>−1.2 (1.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−3.6 (4.1)</td>
<td>−1.7 (3.1)</td>
<td>−2.0 (3.2)</td>
<td>−1.4 (2.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−2.9 (4.8)</td>
<td>−1.3 (3.4)</td>
<td>−1.0 (3.4)</td>
<td>−1.5 (4.0)</td>
<td></td>
<td>.07</td>
</tr>
<tr>
<td><strong>Waist-hip ratio</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.04</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−0.019 (0.016)</td>
<td>−0.012 (0.019)</td>
<td>−0.012 (0.022)</td>
<td>−0.009 (0.019)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−0.021 (0.023)</td>
<td>−0.014 (0.023)</td>
<td>−0.010 (0.022)</td>
<td>−0.010 (0.023)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−0.019 (0.026)</td>
<td>−0.013 (0.023)</td>
<td>−0.009 (0.024)</td>
<td>−0.012 (0.024)</td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td><strong>LDL-C, mg/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.26</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>2.3 (23.5)</td>
<td>−5.3 (17.8)</td>
<td>−7.3 (20.8)</td>
<td>−10.1 (19.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>1.7 (22.3)</td>
<td>0.5 (14.9)</td>
<td>−2.4 (19.4)</td>
<td>−3.2 (19.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>0.8 (22.6)</td>
<td>0.0 (17.6)</td>
<td>0.6 (17.0)</td>
<td>−3.8 (19.0)</td>
<td></td>
<td>.49</td>
</tr>
<tr>
<td><strong>HDL-C, mg/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−0.4 (7.7)</td>
<td>−0.5 (5.4)</td>
<td>−3.8 (6.1)</td>
<td>−5.3 (9.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>5.1 (9.6)</td>
<td>3.3 (6.9)</td>
<td>2.1 (6.7)</td>
<td>0.0 (9.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>4.9 (9.1)</td>
<td>2.2 (6.1)</td>
<td>2.8 (7.7)</td>
<td>0.0 (6.3)</td>
<td></td>
<td>.002</td>
</tr>
<tr>
<td><strong>Triglycerides, mg/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.003</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−52.3 (66.8)</td>
<td>−24.8 (63.1)</td>
<td>−17.4 (48.9)</td>
<td>10.9 (65.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−35.6 (64.4)</td>
<td>−21.3 (58.9)</td>
<td>−16.1 (60.1)</td>
<td>−7.6 (54.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−29.3 (69.0)</td>
<td>−4.2 (48.5)</td>
<td>−14.6 (60.9)</td>
<td>−14.9 (46.2)</td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td><strong>Non–HDL-C, mg/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.92</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−8.0 (26.3)</td>
<td>−10.2 (21.7)</td>
<td>−10.7 (19.0)</td>
<td>−7.8 (17.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−4.7 (23.1)</td>
<td>−3.7 (18.8)</td>
<td>−5.6 (18.6)</td>
<td>−4.7 (22.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−5.1 (22.5)</td>
<td>−0.5 (20.0)</td>
<td>−4.0 (19.7)</td>
<td>−6.8 (20.3)</td>
<td></td>
<td>.36</td>
</tr>
<tr>
<td><strong>Insulin, µU/mL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.23</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−3.0 (3.9)</td>
<td>1.0 (6.0)</td>
<td>−1.9 (4.7)</td>
<td>−1.1 (3.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−2.8 (4.1)</td>
<td>0.1 (8.9)</td>
<td>−2.1 (5.4)</td>
<td>−0.1 (3.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−1.8 (4.8)</td>
<td>−1.5 (4.9)</td>
<td>−1.8 (5.1)</td>
<td>−0.2 (5.8)</td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td><strong>Glucose, mg/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.77</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−0.4 (6.8)</td>
<td>−1.6 (10.6)</td>
<td>−0.8 (8.3)</td>
<td>−1.4 (6.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>0.2 (7.6)</td>
<td>−1.7 (9.6)</td>
<td>−0.9 (9.9)</td>
<td>−0.6 (7.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−1.8 (13.4)</td>
<td>−1.6 (6.5)</td>
<td>0.5 (9.2)</td>
<td>−0.8 (7.9)</td>
<td></td>
<td>.54</td>
</tr>
<tr>
<td><strong>Systolic blood pressure, mm Hg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−6.8 (8.0)</td>
<td>−3.2 (8.2)</td>
<td>−3.6 (6.9)</td>
<td>−1.6 (6.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−6.4 (9.5)</td>
<td>−3.6 (8.0)</td>
<td>−4.3 (7.6)</td>
<td>−1.7 (7.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−7.6 (11.0)</td>
<td>−3.3 (8.1)</td>
<td>−3.1 (9.3)</td>
<td>−1.9 (7.7)</td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td><strong>Diastolic blood pressure, mm Hg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>2 mo</td>
<td>−2.9 (6.2)</td>
<td>−2.1 (5.6)</td>
<td>−1.4 (4.4)</td>
<td>−0.4 (6.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>−3.3 (6.9)</td>
<td>−1.8 (5.6)</td>
<td>−2.5 (6.8)</td>
<td>−1.0 (6.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>−4.4 (8.4)</td>
<td>−2.1 (5.8)</td>
<td>−2.2 (6.7)</td>
<td>−0.7 (6.0)</td>
<td></td>
<td>.009</td>
</tr>
</tbody>
</table>

SI conversions: To convert LDL-C, HDL-C, and total cholesterol to mmol/L, multiply by 0.0259. To convert triglycerides to mmol/L, multiply by 0.0113. To convert glucose to mmol/L, multiply by 0.0555.

*Intention-to-treat analysis, with baseline data carried forward for missing values. Standard deviations are presented in parentheses. For LDL-C, HDL-C, triglyceride, non–HDL-C, insulin, and glucose data, results are presented for those with available blood sample data (84% of full sample): Atkins, n = 70; Zone, n = 65; LEARN, n = 63; and Ornish, n = 64.

†P value for diet group × time interaction, determined using mixed-model and autoregressive covariance structure.

‡P values for 12-month change from baseline results, determined by analysis of variance.

§Calculated as weight in kilograms divided by height in meters squared.

For a given outcome measure at the 12-month time point, when the analysis of variance (last column) was statistically significant (P < .05), all pairwise comparisons among diet groups were tested for statistical significance using the Tukey studentized range test. Pairwise comparisons that were significantly different from one another are indicated by superscripts as follows: when the values for 2 diet groups within a row do not share a common superscript, they are significantly different, whereas if the values do share a common superscript, they are not significantly different.
after weight loss and restabilization; overall the low-carbohydrate and weight-loss effects were reported to be equivalent but not additive under the tightly controlled conditions of this study.

The 4 study diets used in our study differed significantly in composition beyond carbohydrate content. Protein, fat, and saturated fat followed a continuum across diets, inverse to carbohydrate content. In a series of recent weight-loss trials that substituted either protein for fat while holding carbohydrate constant \(^{40,41}\) or protein for carbohydrate while holding fat constant, \(^{38,42-43}\) the higher-protein diets led to improvements in weight loss, triglycerides, and HDL-C and increased satiety. In the OmniHeart study, under weight-stable conditions, blood pressure–lowering benefits were observed for a high-protein relative to a high-carbohydrate diet. \(^{44}\) Therefore, the reported effects of the current study should be interpreted as resulting from the combination of macronutrient changes that occur when following low-vs high-carbohydrate diets, not just changes in carbohydrates alone. For example, greater satiety from the higher protein content of the Atkins diet may have contributed to the benefits observed for that group, although satiety was not assessed.

The amount of weight loss at 12 months relative to baseline among all groups was modest at 2% to 5%. However, even modest reductions in excess weight have clinically significant effects on risk factors such as triglycerides and blood pressure and, therefore, can have an important public health impact at the population level. \(^{4-6,45,46}\) Greater success with long-term weight loss is likely dependent on a number of factors beyond macronutrient composition, including improved behavioral strategies, longer-term structured guidance, greater emphasis on increasing energy expenditure (ie, regular physical activity), and addressing societal and environmental factors, such as portion sizes of restaurant meals. \(^{45,47-49}\)

Strengths of the current study relative to previous trials include a larger sample size, a 12-month duration, lower attrition rates, the contrast of 4 rather than 2 diets differing in carbohydrate content, and the significant differences in macronutrient intake achieved by the diet groups. Although adherence to the 4 sets of dietary guidelines varied within each treatment group and waned over time, especially for the Atkins and Ornish diets, we believe that the adherence levels obtained are a fair representation of studying the diets and variations in macronutrient intake under realistic conditions and, therefore, increase the external validity of the findings. Other strengths include the extensive dietary assessment and the comprehensive health and risk factor data collected. The restriction of our study to premenopausal women allowed us to avoid possible interactions of effects with sex and menopausal status, but because of our focus on this population, generalizations of findings to other populations should be made with caution.

This study also has several limitations. Menstrual cycle timing was not taken into consideration for blood sampling for lipid analyses, which likely increased within-person variability and diminished the ability to detect between-group differences. Moreover, weight-loss trajectories for each group had not stabilized at 12 months; the trajectories of weight change between 6 and 12 months suggest that longer follow-up would likely have resulted in progressively diminished group differences. Other limitations included the lack of a valid and comparable assessment of individual adherence to the 4 different diets, the lack of data on whether participants had familiarity using any of the specific study diets prior to enrolling in the trial, and the lack of assessment of satiety.

CONCLUSIONS

In this study of overweight and obese premenopausal women, those assigned to follow the Atkins diet had more weight loss and more favorable outcomes for metabolic effects at 1 year than women assigned to the Zone, Ornish, or LEARN diets. Concerns about adverse metabolic effects of the Atkins diet were not substantiated within the 12-month study period. It could not be determined whether the benefits were attributable specifically to the low carbohydrate intake vs other aspects of the diet (eg, high protein intake).

While questions remain about long-term effects and mechanisms, these findings have important implications for clinical practice and health care policy. Physicians whose patients initiate a low-carbohydrate diet can be reassured that weight loss is likely to be at least as large as for any other dietary pattern and that the lipid effects are unlikely to be of immediate concern. As with any diet, physicians should caution patients that long-term success requires permanent alterations in energy intake and energy expenditure, regardless of macronutrient content.

Author Contributions: Drs Gardner and Balise had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Gardner, Kraemer, King. Acquisition of data: Gardner. Analysis and interpretation of data: Gardner, Kiazand, Alhassan, Kim, Stafford, Balise, Kraemer, King. Drafting of the manuscript: Gardner, Kiazand, Balise, Kraemer, King. Critical revision of the manuscript for important intellectual content: Gardner, Kiazand, Alhassan, Kim, Stafford, Kraemer, King. Statistical analysis: Gardner, Alhassan, Stafford, Balise, Kraemer, King. Obtained funding: Gardner, King. Administrative, technical, or material support: Kiazand.

Study supervision: Gardner.

Financial Disclosures: None reported.

Funding/Support: This investigation was supported by National Institutes of Health grant R21AT1098, by a grant from the Community Foundation of Southeastern Michigan, and by Human Health Service grant M01-RR00070, General Clinical Research Centers, National Center for Research Resources, National Institutes of Health.

Role of the Sponsor: None of the funding agencies played any role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; or preparation, review, and approval of the manuscript.

Acknowledgment: We gratefully acknowledge the work of the study staff who worked with participants in recruitment, intervention, and data collection, including Rise Chein, MS, RD, Kathryn Newell, MS, Suzanne Olson, MS, Jennifer Morris, PhD, Jane Borchers, MS, RD, Laurie Auserer, MS, Ellen DiNucci, MA, Kelly Boifyington, Jana Stone, Andrea Vaccarella, RD, Noel Segali, RD, and Gretchen George, MS, RD, all of Stanford University Hospital General Clinical Research Center.

976 JAMA, March 7, 2007—Vol 297, No. 9 (Reprinted) ©2007 American Medical Association. All rights reserved.
ONE-YEAR EFFECT OF WEIGHT-LOSS DIETS

REFERENCES


©2007 American Medical Association. All rights reserved.