Micronutrient quality of weight-loss diets that focus on macronutrients: results from the A TO Z study[1–3]

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ABSTRACT

Background: Information on the micronutrient quality of alternative weight-loss diets is limited, despite the significant public health relevance.

Objective: Micronutrient intake was compared between overweight or obese women randomly assigned to 4 popular diets that varied primarily in macronutrient distribution.

Design: Dietary data were collected from women in the Atkins (n = 73), Zone (n = 73), LEARN (Lifestyle, Exercise, Attitudes, Relationships, Nutrition) (n = 73), and Ornish (n = 72) diet groups by using 3-d, unannounced 24-h recalls at baseline and after 8 wk of instruction. Nutrient intakes were compared between groups at 8 wk and within groups for 8-wk changes in risk of micronutrient inadequacy.

Results: At 8 wk, significant differences were observed between groups for all macronutrients and for many micronutrients ($P <$ 0.0001). Energy intake decreased from baseline in all 4 groups but was similar between groups. At 8 wk, a significant proportion of individuals shifted to intakes associated with risk of inadequacy ($P < 0.05$) in the Atkins group for thiamine, folic acid, vitamin C, iron, and magnesium; in the LEARN group for vitamin E, thiamine, and magnesium; and in the Ornish group for vitamins E and B-12 and zinc. In contrast, for the Zone group, the risk of inadequacy significantly decreased for vitamins A, E, K, and C ($P < 0.05$), and no significant increases in risk of inadequacy were observed for other micronutrients.

Conclusions: Weight-loss diets that focus on macronutrient composition should attend to the overall quality of the diet, including the adequacy of micronutrient intakes. Concerning calorie-restricted diets, there may be a micronutrient advantage to diets providing moderately low carbohydrate amounts and that contain nutrient-dense foods. *Am J Clin Nutr* 2010;92:304–12.

INTRODUCTION

Overweight or obesity is a major concern for US adults who contribute to spending an estimated $30+ billion/y on weight-loss products (1, 2). Indeed, 1 in 3 US adults report currently trying to lose weight, and the proportion is even higher among overweight and obese adults (3). In response to the ubiquity of weight-loss efforts, the public has been bombarded by a barrage of "best selling" weight-loss books (4–7) that promote various combinations of carbohydrate, fat, and protein distributions and diverge significantly from the traditional dietary guidelines that recommend a calorie-reduced eating plan consisting of 45–65% of total energy from carbohydrates, 20–35% from fat, and 10–35% from protein and reduced intakes of added sugars, fats, and alcohol (8). Given that weight-loss maintenance requires long-term adherence to dietary changes (9, 10), the overall public health implications for these diets extend beyond simple weight loss and include consideration of overall nutritional quality.

Many alternative popular weight-loss diets focus on achieving certain macronutrient distributions. However, limited data exist regarding the micronutrient content and adequacy of these diets. A few studies have presented nutrient analyses of sample menus for 1 to 7 d as described in the alternative diets' respective books or websites (11–13), which generally show that the diets were deficient in many micronutrients. Results from these computer-generated menu analyses, however, may not truly represent the diets as they are followed by free-living individuals. Whereas weight-loss trials offer an excellent opportunity to examine the nutrient adequacy of popular alternative diets, recently published weight-loss trials either did not present diet data (14), presented it for <25% of the sample (15), or included only a limited selection of nutrients (16–18).

We present here a detailed characterization of dietary composition—both macronutrients and micronutrients—for 4 diets with varying goals for macronutrient content (Atkins, Zone, LEARN, and Ornish diets) from a recently completed randomized, controlled, clinical trial (19). The objectives for this analysis were to *1*) present baseline and postintervention (8 wk) nutrient intakes for overweight or obese women randomly assigned to the 4 diets and *2*) assess changes relative to baseline, by diet group, in the proportion of individuals at risk of inadequate intake for micronutrients.

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SUBJECTS AND METHODS

Subjects

Premenopausal overweight or obese (body mass index, in kg/m^2: 27–40) women aged 25–50 y were recruited for Stanford's A TO Z trial from the local community, as described previously (19), and involved 311 women. All study participants provided written informed consent. The study was approved annually by the Stanford University Human Subjects Committee.

Intervention

Participants were randomly assigned to read and follow 1 of 4 diet books that were provided to them: *Dr. Atkins New Diet Revolution* (2002) (5); *Enter the Zone*, *A Dietary Roadmap* (1995) (6); *The LEARN Program for Weight Management 2000* (9th edition, 2000) (20); or *Eat More Weigh Less* (2001) by Dean Ornish (7). Each diet group attended 8 consecutive 1-h evening classes, once per week, for 8 wk and was assigned to read approximately one-eighth of their respective books for each class. The same registered dietitian led the 1-h class sessions and reviewed the assigned material from the book at each class for all 4 diets. It was explained to participants that their goal was to master their assigned diet by the end of the 8 wk of classes and then to continue following their diet independently for the subsequent 10 mo.

Each of the 4 diet assignments was distinct, especially in macronutrient target goals. The primary emphasis for the Atkins group was to lower total carbohydrate intake to ≤20 g/d for the "Induction" phase (the duration of which was left to the individual to decide, but which sometimes lasted for several months) and to ≤50 g total carbohydrate/d for the "Ongoing weight loss" phase. The primary emphasis of the Zone diet was to balance the distribution of macronutrients according to a 40:30:30 pattern of carbohydrate, fat, and protein, respectively. The primary emphasis of the LEARN diet was to eat less and exercise more with the help of various behavior-modification strategies while following the general guidelines of the US Department of Agriculture Food Pyramid (ie, ≤30% fat, ≈55–60% carbohydrate). The primary emphasis of the Ornish diet was to lower total fat intake to ≤10% of energy.

Notably, there were no specific energy-restriction goals for the Atkins or Ornish groups, but the emphasis was primarily on carbohydrate or fat restriction, respectively. The Zone diet recommended that ≤500 kcal be consumed per meal at each of 3 meals daily and that ≤100 kcal be eaten per snack for each of 2 snacks/d, resulting in a total intake of ≤1700 kcal/d; a target of 1200 kcal/d, however, was recommended. The LEARN diet recommended energy restriction sufficient to lose 1–2 lb (0.45–0.90 kg)/wk and a general recommendation of 1200 kcal/d.

Of the 4 diet books, only Atkins had specific recommendations for supplement use. The Atkins diet recommended a broad multiple vitamin and mineral supplement, essential fatty acids, and L-glutamine (5). The Zone, LEARN, and Ornish diets all stated that no vitamin or mineral supplementation was necessary if the diet was followed. Supplement use data were collected by an interviewer at baseline and at the 8-wk clinic visits.

Dietary assessment and intake relative to Dietary Reference Intakes

Dietary intake data were obtained by using unannounced 24-h dietary recalls. At each data collection point, 3 separate, nonconsecutive, telephone-administered 24-h dietary recalls were conducted, including 2 weekdays and 1 weekend day whenever possible (21). To assist portion-size estimates of foods consumed, the study participants were provided with a "Food Amounts Booklet" that contained estimation tools such as drawings representing wedges, circles, thickness, glasses, mounds, bowls, and portions of meat, chicken, and fish. To assess macro- and micronutrient intakes, the dietary recalls were collected and analyzed by using Nutrition Data System for Research (NDS-R) software developed by the Nutrition Coordinating Center (NCC), University of Minnesota, Minneapolis, MN (versions 4.05.33, 2002; 4.06.34, 2003; and 5.0.35, 2004), which has a comprehensive database of >18,000 foods, including 8000 brand-name foods and many ethnic foods. Foods that were not in the database were identified at local markets and added to the database manually. The dietary recalls were conducted by interviewers trained and certified by the NCC in Minneapolis who were either registered dietitians (RDs) or RD eligible.

In addition to presenting data on intakes of macro- and micronutrients, the prevalence of risk of inadequate intakes for micronutrients was examined by diet group using established Estimated Average Requirement (EAR) values as cutoffs for the following nutrients: vitamin A, thiamine, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin C, vitamin E, iron, magnesium, phosphorus, selenium, and zinc. We acknowledge that the interpretation of dietary iron intakes below the EAR is somewhat different from that of most other nutrients and must be made cautiously because, unlike most other nutrients, the distribution of iron requirements are not normally distributed (22). In addition to the prevalence of reported nutrient intakes below the EAR, we examined the 8-wk changes in individuals' risk of inadequate intake for those nutrients (below or above the EAR at baseline compared with the EAR at 8 wk). Because there is no established EAR for vitamins D and K and calcium, no inference could be made for the prevalence of nutrient inadequacy for these nutrients (22, 23). However, for the sake of being thorough in our examination of vitamins and minerals and for the purpose of showing shifts in the percentage of women with low intakes of micronutrients while following the 4 study diets, the Adequate Intake (AI) was used as a cutoff in some of our presentations, illustrating the prevalence of lower compared with higher intakes of vitamins D and K and calcium.

Statistical analysis

Sociodemographic characteristics and the body composition of the participants at baseline were summarized. Three days of intake data were averaged to characterize the participants' typical intake at each time point. Intakes of macronutrients and micronutrients from food intake only were summarized at baseline and at 8 wk, when adherence to the diets was found to be the highest (24) and when these intakes most closely represent the dietary characteristics of the weight-loss diets as intended. Intakes from supplements were not included in the analyses.

Because the nutrient intakes were not normally distributed, differences in the intake of macro- and micronutrients across the diet groups were initially examined by using the nonparametric Kruskal-Wallis test. When the null hypothesis was rejected, the Mann-Whitney *U* test was further used post hoc to describe the differences for each pair of diet-group comparisons for a given nutrient. In the tables, however, for clearer presentation of data, we chose to present the means and SDs of the nutrient intakes (ie, rather than median and percentile distributions of nutrient intakes) and the ANOVA and post hoc multiple *t* test statistical findings, because the parametric tests yielded results similar to those of the nonparametric tests. When the *P* value of the ANOVA test for a given nutrient was <0.05, we conducted exploratory pairwise comparisons to examine which diets were the most different from each other (for continuous variables we used Tukey's Studentized range test and for proportions we used Bonferroni corrections). McNemar's test was used to examine the difference in the proportion of individuals whose risk of inadequate micronutrient intake (below the EAR) or prevalence of lower intake (below the AI), changed between baseline and 8 wk within each diet group.

RESULTS

Of the 311 women enrolled and randomly assigned, 291 (94%) completed the 8-wk intervention protocol and completed all data-collection procedures: $n = 73$ for Atkins, $n = 73$ for Zone, $n = 73$ for LEARN, and $n = 72$ for Ornish. Retention rates varied between 91% and 95% among the different diet groups (no statistically significant differences).

Baseline demographics and anthropometric measurements

Baseline characteristics of the 4 diet groups are presented in **Table 1**. The overall mean (±SD) age was 41 ± 6 y. The racial and ethnic distribution was 71% white, 11% Hispanic, 10% Asian or Pacific Islander, 6% African American, and 2% "other" among the participants overall. The mean (±SD) level of education was 16 ± 2 y, and 55% of the women were married. At baseline, mean (±SD) body weight and percentage body fat were 85 ± 12 kg and 40 ± 6%, respectively.

Baseline diet

The baseline diet of the 291 women included in these analyses was estimated to provide a mean (±SD) energy intake of 1903 ± 553 kcal/d and to have a distribution of percentage energy from carbohydrate:fat:protein of 46:35:19. There were no statistically significant differences between the groups in baseline intakes of macronutrients or in any of the 11 vitamins or 6 minerals presented in **Tables 2** and **3**.

Eight-week diet: energy and macronutrients

Estimated energy intake decreased significantly at 8 wk within all 4 groups, as expected. Despite a differential emphasis on energy restriction among the 4 diet groups, all 4 groups reported roughly similar reductions of ≈500 kcal/d relative to baseline diets: –556 ± 486 kcal for Atkins, –515 ± 506 kcal for Zone, –482 ± 505 kcal for LEARN, and –454 ± 483 kcal for Ornish (presented as mean ± SD, $P = 0.76$). At 8 wk there were statistically significant differences, however, in the percentage of energy from carbohydrate, fat, and protein in every pair of diet-group comparisons (**Table 4**). The percentage of energy from carbohydrate was lowest in Atkins (17%) and higher in the other diet groups in a graded manner, consistent with the design of the study: 42% for Zone, 49% for LEARN, and 63% for Ornish. The percentage of energy from protein and fat showed the opposite trends, again in a graded manner: 28% for Atkins, 24% for Zone, 20% for LEARN, and 17% for Ornish for protein and 55%, 35%, 30%, and 21% for fat, respectively.

Results for the specific types of fatty acids (saturated, monounsaturated, and polyunsaturated) paralleled the results for total fat and were all statistically different between almost every pair of the 4 diet groups, highest to lowest in amount from Atkins

TABLE 1
Participants' characteristics at baseline by diet[1]

Characteristic	Atkins ($n = 73$)	Zone ($n = 73$)	LEARN ($n = 73$)	Ornish ($n = 72$)
Demographics				
Age (y)	42 ± 5[2]	40 ± 6	41 ± 7	42 ± 6
Education (y)	16 ± 2	16 ± 2	16 ± 2	16 ± 2
Race-ethnicity [*n* (%)]				
White	56 (77)	49 (67)	56 (77)	48 (66)
Black	2 (3)	7 (10)	4 (5)	4 (6)
Hispanic	7 (10)	8 (11)	6 (8)	10 (14)
Asian/Pacific Islander	6 (8)	7 (10)	6 (8)	8 (11)
Other	2 (3)	2 (3)	1 (1)	2 (3)
Marital status [*n* (%)]				
Single	17 (23)	27 (37)	26 (36)	28 (39)
Married	49 (67)	37 (51)	38 (52)	36 (50)
Widowed	1 (1)	0 (0)	0 (0)	0 (0)
Divorced or separated	6 (8)	9 (12)	9 (12)	8 (11)
Anthropometric measures				
Weight (kg)	87 ± 13	85 ± 12	85 ± 15	86 ± 11
BMI (kg/m^2)	32 ± 4	31 ± 3	31 ± 4	32 ± 3
Supplement use [*n* (%)]				
Multivitamins, multiminerals	26 (36)	21 (29)	25 (34)	22 (31)
Calcium	5 (7)	5 (7)	9 (12)	9 (13)

[1] LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition.
[2] Mean ± SD (all such values).

TABLE 2
Energy and macronutrient intakes by diet group (*n* = 291)[1]

	Atkins (*n* = 73)	Zone (*n* = 73)	LEARN (*n* = 73)	Ornish (*n* = 72)	*P* value
Energy (kcal)	1929 ± 509	1984 ± 582	1960 ± 539	1866 ± 539	0.6
Energy (kJ)	8070 ± 2130	8300 ± 2437	8201 ± 2253	7807 ± 2253	0.6
Carbohydrate (g)	222 ± 77	232 ± 89	231 ± 65	223 ± 66	0.8
Carbohydrate (% of energy)	46.1 ± 9.5	47.0 ± 9.4	48.0 ± 8.5	48.4 ± 8.1	0.4
Protein (g)	77 ± 21	74 ± 23	80 ± 23	74 ± 22	0.3
Protein (% of energy)	16.5 ± 4.0	15.4 ± 3.3	16.6 ± 3.2	16.1 ± 2.8	0.1
Total fat (g)	80 ± 27	79 ± 27	74 ± 32	73 ± 26	0.5
Total fat (% of energy)	35.8 ± 6.7	35.7 ± 6.6	33.4 ± 7.3	34.8 ± 6.7	0.1
Saturated fat (g)	27 ± 11	27 ± 10	25 ± 11	25 ± 10	0.4
Saturated fat (% of energy)	12.1 ± 2.9	12.1 ± 3.1	11.0 ± 3.0	11.7 ± 2.9	0.1
Monounsaturated fat (g)	30 ± 12	31 ± 12	29 ± 13	27 ± 10	0.4
Monounsaturated fat (% of energy)	13.6 ± 3.6	13.8 ± 3.1	12.7 ± 3.3	13.1 ± 3.3	0.2
Polyunsaturated fat (g)	15 ± 6	16 ± 7	16 ± 8	15 ± 6	1.0
Polyunsaturated fat (% of energy)	7.2 ± 2.4	7.1 ± 2.4	7.0 ± 2.3	7.3 ± 2.2	0.8
Alcohol (g)	9.4 ± 12.3	11.8 ± 17.9	11.4 ± 13.7	8.3 ± 17.5	0.5
Alcohol (% of energy)	3.4 ± 4.4	3.8 ± 5.5	4.0 ± 5.0	2.6 ± 4.9	0.4
Total dietary fiber (g)	18 ± 7	18 ± 10	18 ± 8	17 ± 7	0.9
Soluble fiber (g)	5.8 ± 2.1	6.0 ± 2.7	6.1 ± 2.6	5.7 ± 2.1	0.8

[1] All values are means ± SDs. LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition. *P* values were derived from ANOVA.

to Zone to LEARN to Ornish. The reported alcohol intake was low in all 4 groups (<3% of energy for all groups) and was not statistically different between any of the groups. Total dietary fiber and soluble fiber intakes were lowest for Atkins, highest for Ornish, and intermediate and not statistically different between Zone and LEARN. In summary, at 8 wk, whereas total energy intake and alcohol intake were similar between the 4 groups, these groups of women were eating diets of significantly different macronutrient composition, consistent with the design of the study.

Eight-week diet: micronutrients

The mean (± SD) intakes of a select set of 11 vitamins and 6 minerals from food sources alone are presented in **Table 5**. Statistical analyses indicated that at least one diet group was significantly different from at least one other diet group for 12 of the 17 nutrients examined: vitamin A, thiamine, niacin, vitamin B-6, folic acid, vitamin C, vitamin E, vitamin K, iron, magnesium, selenium, and zinc.

For these 12 vitamins and minerals with group differences, there were no clear gradations of intake across the 4 diet groups that paralleled the differences in macronutrient composition. There were notable patterns, however, regarding which specific diet groups were high or low in specific nutrients. The Zone diet group is worth mentioning for having the highest intake of the 4 diet groups for vitamin A, niacin, vitamin B-6, vitamin C, vitamin E, and vitamin K. The Zone, LEARN, and Ornish groups had higher folic acid intakes than did the Atkins groups, and the Zone

TABLE 3
Vitamin and mineral intakes by diet group (*n* = 291)[1]

	Atkins (*n* = 73)	Zone (*n* = 73)	LEARN (*n* = 73)	Ornish (*n* = 72)	*P* value
Vitamins					
Vitamin A (μg)	681 ± 289	655 ± 320	678 ± 266	711 ± 368	0.8
Thiamine (mg)	1.6 ± 0.5	1.6 ± 0.5	1.7 ± 0.6	1.5 ± 0.5	0.4
Riboflavin (mg)	1.9 ± 0.6	1.7 ± 0.6	2.0 ± 0.7	1.8 ± 0.7	0.2
Niacin (mg)	22 ± 7	22 ± 8	23 ± 9	21 ± 8	0.5
Vitamin B-6 (mg)	1.7 ± 0.6	1.6 ± 0.7	1.9 ± 0.7	1.7 ± 0.8	0.3
Folic acid (μg)	535 ± 207	493 ± 212	567 ± 276	534 ± 232	0.3
Vitamin B-12 (μg)	4.9 ± 4.3	4.4 ± 4.1	5.7 ± 6.6	5.5 ± 7.5	0.5
Vitamin C (mg)	94 ± 59	99 ± 57	94 ± 57	95 ± 61	0.9
Vitamin D (μg)	3.9 ± 2.2	3.9 ± 3.3	4.8 ± 3.3	4.5 ± 3.4	0.2
Vitamin E (mg)	8.4 ± 4.1	9.7 ± 7.8	10.2 ± 6.3	8.3 ± 4.9	0.2
Vitamin K (μg)	118 ± 89	123 ± 89	131 ± 94	124 ± 81	0.9
Minerals					
Calcium (mg)	851 ± 314	808 ± 363	909 ± 318	867 ± 409	0.4
Iron (mg)	14.8 ± 4.8	14.3 ± 5.4	15.6 ± 6.5	14.9 ± 6.4	0.6
Magnesium (mg)	291 ± 88	296 ± 135	312 ± 96	292 ± 108	0.6
Phosphorus (mg)	1209 ± 308	1180 ± 428	1273 ± 377	1211 ± 406	0.5
Selenium (μg)	107 ± 36	108 ± 48	119 ± 65	105 ± 45	0.3
Zinc (mg)	10.7 ± 3.7	9.8 ± 3.4	10.7 ± 4.1	10.1 ± 5.1	0.5

[1] All values are means ± SDs. LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition. *P* values were derived from ANOVA.

TABLE 4
Energy and macronutrient intakes by diet group (n = 291)[1]

	Atkins (n = 73)	Zone (n = 73)	LEARN (n = 73)	Ornish (n = 72)	P value
Energy (kcal)	1373 ± 340	1469 ± 459	1478 ± 444	1412 ± 445	0.4
Energy (kJ)	5745 ± 1424	6145 ± 1919	6185 ± 1857	5911 ± 1860	0.4
Carbohydrate (g)	58^a ± 38	155^b ± 61	179^b ± 52	220^c ± 76	<0.0001
Carbohydrate (% of energy)	17.1^a ± 10.5	42.0^b ± 8.3	49.3^c ± 8.7	63.1^d ± 11.1	<0.0001
Protein (g)	94^a ± 28	82^b ± 21	72^b ± 22	58^c ± 21	<0.0001
Protein (% of energy)	27.9^a ± 5.3	24.0^b ± 6.1	20.2^c ± 4.8	16.9^d ± 4.2	<0.0001
Total fat (g)	85^a ± 25	58^b ± 24	52^b ± 25	34^c ± 20	<0.0001
Total fat (% of energy)	55.2^a ± 7.9	35.1^b ± 6.6	30.1^c ± 7.4	21.0^d ± 8.0	<0.0001
Saturated fat (g)	31^a ± 10	20^b ± 10	17^b ± 10	10^c ± 8	<0.0001
Saturated fat (% of energy)	20.1^a ± 4.4	11.6^b ± 3.0	9.6^c ± 3.0	6.2^d ± 3.4	<0.0001
Monounsaturated fat (g)	33^a ± 10	22^b ± 10	20^b ± 9	12^c ± 7	<0.0001
Monounsaturated fat (% of energy)	21.2^a ± 3.6	13.2^b ± 3.5	11.4^c ± 3.2	7.7^d ± 3.2	<0.0001
Polyunsaturated fat (g)	15^a ± 8	12^b ± 5	11^b ± 6	8^c ± 5	<0.0001
Polyunsaturated fat (% of energy)	9.3^a ± 3.2	7.4^b ± 2.3	6.5^b ± 2.2	5.2^c ± 2.1	<0.0001
Alcohol (g)	3.3 ± 7.9	5.5 ± 8.1	6.2 ± 8.9	4.7 ± 9.1	0.2
Alcohol (% of energy)	1.8 ± 4.3	2.3 ± 3.6	2.9 ± 4.2	2.2 ± 4.0	0.5
Total dietary fiber (g)	11^a ± 6	17^b ± 7	18^b ± 7	22^c ± 9	<0.0001
Soluble fiber (g)	3.3^a ± 2.1	5.6^b ± 2.0	5.7^b ± 2.2	7.2^c ± 3.3	<0.0001

[1] All values are means ± SDs. LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition. P values were derived from ANOVA. Pairwise comparisons (Tukey's Studentized range tests) were performed only for those nutrients for which the ANOVA test was significant. Pairs of diet-group contrasts with different superscript letters are significantly different, $P < 0.05$.

and Atkins groups had higher selenium and zinc intakes than did the other 2 diet groups. The Atkins diet group had significantly lower thiamine, folic acid, vitamin C, and magnesium intakes than did the other 3 diet groups, and the Ornish diet group had a lower selenium intake than did the other 3 groups.

Supplement use

Baseline supplement use is shown in Table 1. Change in supplement use in the 4 diet groups was negligible. In the Atkins diet group at 8 wk, only 3 additional individuals began taking a multivitamin or multimineral supplement (MVMM) and 3 additional individuals began taking a calcium supplement. No additional subjects initiated MVMM use in the Zone and Ornish diet groups from baseline to 8 wk. By 8 wk, one individual in the Zone and 4 individuals in the Ornish diet group had stopped taking calcium supplements. In the LEARN diet group at 8 wk, 4 individuals stopped taking an MVMM, and 3 individuals began taking a calcium supplement.

Proportions of participants with a low probability of adequate intakes for vitamins and minerals

The proportions of study participants at baseline and 8 wk estimated to be at risk of inadequate intake (below the EAR) are

TABLE 5
Vitamin and mineral intakes by diet group at 8 wk (n = 291)[1]

	Atkins (n = 73)	Zone (n = 73)	LEARN (n = 73)	Ornish (n = 72)	P value
Vitamins					
Vitamin A (μg)	743^a ± 323	986^b ± 450	689^a ± 327	668^a ± 364	<0.0001
Thiamine (mg)	0.9^a ± 0.4	1.5^b ± 0.5	1.4^b ± 0.4	1.5^b ± 0.5	0.02
Riboflavin (mg)	1.6 ± 0.5	1.9 ± 0.6	1.7 ± 0.6	1.7 ± 0.7	0.2
Niacin (mg)	21^a ± 8	27^b ± 10	$20^{a,c}$ ± 6	17^c ± 6	<0.0001
Vitamin B-6 (mg)	1.6^a ± 0.5	3.1^b ± 1.9	1.7^a ± 0.6	1.6^a ± 0.6	<0.0001
Folic acid (μg)	329^a ± 141	560^b ± 205	470^b ± 190	541^b ± 213	<0.0001
Vitamin B-12 (μg)	6.6 ± 7.9	4.7 ± 2.4	5.7 ± 10.2	4.0 ± 6.2	0.2
Vitamin C (mg)	66^a ± 39	164^b ± 86	100^c ± 62	119^c ± 78	<0.0001
Vitamin D (μg)	5.4 ± 5.7	4.0 ± 3.3	4.3 ± 3.0	3.6 ± 3.0	0.054
Vitamin E (mg)	8.7^a ± 4.8	19.2^b ± 18.6	7.2^a ± 4.2	5.9^a ± 3.3	<0.0001
Vitamin K (μg)	161^a ± 102	222^b ± 198	143^a ± 114	123^a ± 104	0.0001
Minerals					
Calcium (mg)	742 ± 273	767 ± 297	801 ± 339	804 ± 409	0.7
Iron (mg)	10.5^a ± 4.1	$12.6^{a,b}$ ± 3.5	13.7^b ± 5.2	14.2^b ± 5.7	<0.0001
Magnesium (mg)	231^a ± 86	286^b ± 85	286^b ± 89	289^b ± 100	0.002
Phosphorus (mg)	1174 ± 309	1144 ± 301	1133 ± 384	1042 ± 371	0.1
Selenium (μg)	114^a ± 44	117^a ± 39	97^b ± 34	81^c ± 29	<0.0001
Zinc (mg)	11.0^a ± 3.5	11.7^a ± 4.1	8.9^b ± 3.1	8.2^b ± 5.7	<0.0001

[1] All values are means ± SDs. LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition. P values were derived from ANOVA. Pairwise comparisons (Tukey's Studentized range tests) were performed only for those nutrients for which the ANOVA test was significant. Pairs of diet-group contrasts with different superscript letters are significantly different, $P < 0.05$.

presented in **Table 6**. Data for vitamins D and K and calcium were not included in Table 6 because these nutrients do not have an established EAR (22). At baseline, the highest prevalence of risk of inadequate intake was observed for vitamin E intakes; >65% in all 4 diet groups. Greater than 25% of women in all 4 diet groups also had intakes indicating risk of inadequate intakes for vitamins A and C and magnesium. At 8 wk, the nutrients for which ≥25% of women had intake levels below the EAR, by diet group, were as follows: thiamine, folic acid, vitamins C and E, iron, and magnesium with Atkins; vitamin E and magnesium with ZONE; vitamins A, C, and E and magnesium with LEARN; and magnesium, zinc, and vitamins A, B-12, and E with Ornish.

Within each diet group, the proportions of individuals who shifted from not at risk of inadequate intake (at or above the EAR) at baseline to at risk of inadequate intake (below the EAR) at 8 wk or vice versa (ie, from at risk to not at risk) are presented in **Figure 1** for the micronutrients with significant changes in proportion. Also presented in this figure are data for those individuals who had shifts in intakes of vitamins D and K or calcium from above to below the AI or vice versa. Those individuals whose risk of inadequate or low intakes did not change from baseline to 8 wk (ie, intake was estimated to be below the EAR or AI at both time points or above the EAR or AI at both time points) are not represented in the figure. At 8 wk, a significantly higher proportion of individuals shifted to intakes at risk of inadequacy ($P < 0.05$) in the Atkins group for thiamine, folic acid, vitamin C, iron, and magnesium; in the LEARN group for vitamin E, thiamine, calcium, and magnesium; and in the Ornish group for vitamins E and B-12 and zinc. In contrast, for the Zone group, the risk of inadequacies significantly decreased for vitamins A, E, K, and C ($P < 0.05$) with no significant increases in risk of inadequacy for other micronutrients. A significant decrease in the risk of inadequacy of vitamin K was also observed in the Atkins diet group. There were no similar improvements in any of the vitamins or minerals for either the LEARN or Ornish diet groups.

DISCUSSION

The extensive dietary assessment conducted with a large number of participants in the A TO Z study enabled us to examine the vitamin and mineral intakes consumed when the primary focus of the weight-loss intervention was macronutrient intakes. That is, this study illustrated a comprehensive picture of dietary patterns when the participants tried to follow 4 different weight-loss diets. Along with significant group differences in macronutrient intakes, many significant differences in vitamin and mineral intakes were observed—not only group differences in absolute intakes of micronutrients but also the risk of inadequate intakes. A significant number of Atkins, LEARN, and Ornish participants shifted from obtaining intakes at or above the EAR at baseline to intakes below the EAR at 8 wk, which suggested an increased risk of inadequacy for several micronutrients. In contrast, for the Zone group, positive shifts were observed for intakes of several vitamins at 8 wk relative to baseline.

Of the specific weight-loss diets that are defined largely by their macronutrient content (eg, "low-fat," "low-carb"), micronutrient intakes tend to be overlooked. Given the established roles of vitamins and minerals in acute and chronic health conditions, micronutrient adequacy should be an important consideration when assessing the overall quality of weight-loss diets. Very little published data exist on the micronutrient intakes of free-living individuals following popular, alternative weight-loss diets. Of the women randomly assigned for 6 mo to either a very-low-carbohydrate (VLC) diet (n = 22) or a low-fat diet (n = 20),

TABLE 6
Proportion of participants at risk of deficiency (below the Estimated Average Requirement; EAR) at baseline and at 8 wk (n = 291)[1]

		Baseline				8 wk				
	EAR	Atkins (n = 73)	Zone (n = 73)	LEARN (n = 73)	Ornish (n = 72)	Atkins (n = 73)	Zone (n = 73)	LEARN (n = 73)	Ornish (n = 72)	P value
		%				%				
Vitamins										
Vitamin A	500 μg	26	38	29	31	18[a,c]	15[a]	34[b,c]	42[b]	0.0004
Thiamine	0.9 mg	5	8	3	11	51[a]	8[b]	11[b]	7[b]	<0.0001
Riboflavin	0.9 mg	1	4	0	6	3	7	5	8	0.52
Niacin	11 mg	3	5	3	8	5	8	4	17	0.03
Vitamin B-6	1.1 mg	14	18	12	18	21	8	10	12	0.11
Folate	320 μg	10	25	11	14	55[a]	11[b]	16[b]	15[b]	<0.0001
Vitamin B-12	2 μg	7	19	7	19	4[a]	10[a]	10[a]	38[b]	<0.0001
Vitamin C	60 mg	32	27	34	32	52[a]	5[b]	30[c]	21[c]	<0.0001
Vitamin E	12 μg	88	80	66	81	81[a]	55[b]	90[a]	94[a]	<0.0001
Minerals										
Iron	8.1 mg	3	5	5	11	32[a]	11[b]	10[b]	8[b]	0.0001
Magnesium	265 mg	41	51	29	44	70[a]	47[b]	51[a,b]	44[b]	0.008
Phosphorus	580 mg	0	1	1	1	0	4	1	7	0.08
Selenium	45 μg	0	0	0	4	0[a]	0[a]	1[a,b]	11[b]	0.0001
Zinc	6.8 mg	16	21	11	18	7[a]	12[a,b]	23[b]	49[c]	<0.0001

[1] LEARN, Lifestyle, Exercise, Attitudes, Relationships, Nutrition. P values were derived from chi-square tests for comparison between groups at 8 wk. Differences between groups at baseline (preassignment to diets) were not tested. Pairwise comparisons (t tests) were performed only for those nutrients for which the chi-square test was significant at $P < 0.05$. Pairs of diet-group contrasts with different superscript letters are significantly different, $P < 0.05$. Bonferroni adjustments were made for multiple pairwise comparisons.

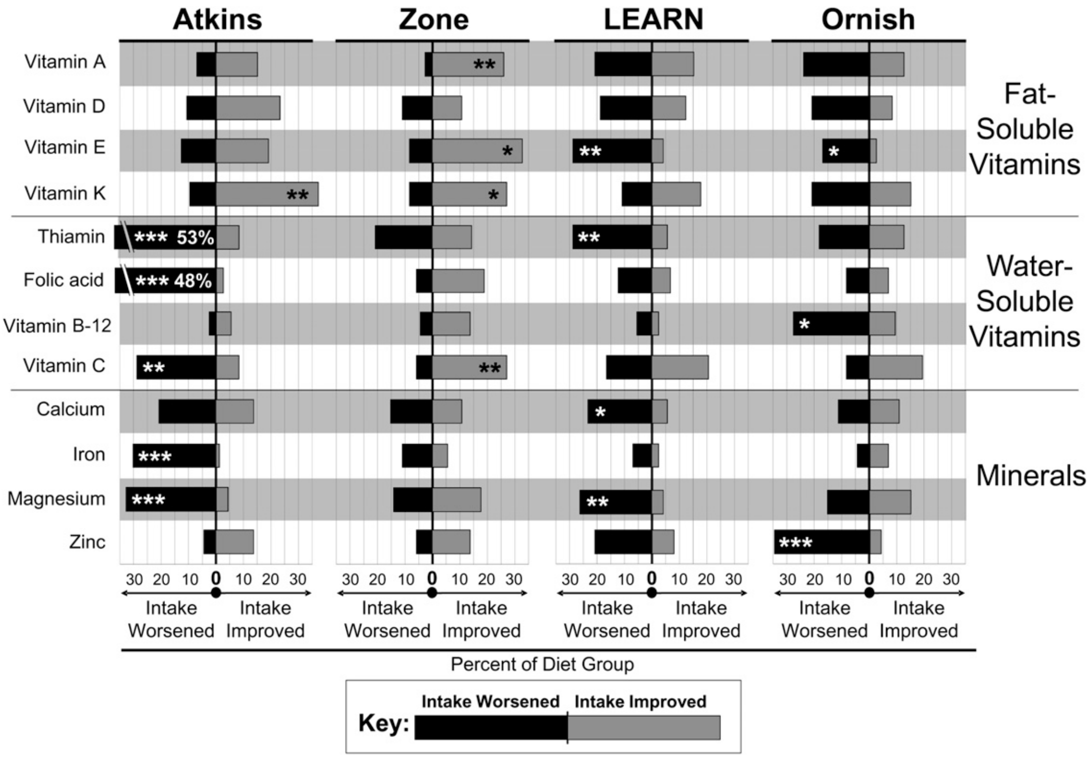

FIGURE 1. Shifts in risk of micronutrient inadequacy (below the Estimated Average Requirement; EAR) or lower intake (below the Adequate Intake; AI) after 8 wk of the study diets. "Intake Worsened" indicates that the intake at baseline was above the EAR or above the AI for vitamins D and K and for calcium, which do not have an EAR, but below this level at 8 wk. "Intake Improved" reflects the opposite, ie, an intake below the EAR or AI at baseline and above the EAR or AI at 8 wk. Data reflect percentages of the full study population [Atkins, $n = 73$; Zone, $n = 73$; LEARN (Lifestyle, Exercise, Attitudes, Relationships, Nutrition), $n = 73$; and Ornish, $n = 72$] that fell into these categories. The figure does not show the percentage in each diet group with an intake above the EAR or AI both before and after or below the EAR or AI both before and after (ie, no change in at-risk status). No data are presented for micronutrients for which the percentages of "worsened" or "improved" were <20% and not significant for any of the 4 diet groups (riboflavin, niacin, vitamin B-6, phosphorous, and selenium). McNemar's test was used for differences in the proportion of individuals whose risk of deficiency or inadequacy improved or worsened from baseline to 8 wk. *$P < 0.01$, **$P < 0.001$, ***$P < 0.0001$.

Brehm et al (16) observed a significantly lower vitamin C intake in the VLC group, but only at an intermediate 3-mo time point. Miller et al (25) reported inadequate intakes of vitamin C, calcium, iron, and magnesium among 18 adults in a 4-wk study of the Atkins diet. Several additional recent weight-loss diet studies either lacked a diet assessment (14) or conducted a limited diet assessment (15, 17, 18, 26, 27) and did not report vitamin or mineral intakes.

Given the reported decrease in caloric intake in our study of ≈500 kcal/d for all diet groups at 8 wk relative to baseline, parallel decreases in absolute intakes of many micronutrients would be expected. Lower intakes per se need not be of concern provided they are still adequate. However, for several nutrients, a significant number of women shifted from intakes not at risk of inadequacy at baseline to intakes at 8 wk considered to indicate risk of inadequacy.

For the Ornish group, nutrients that shifted significantly in the direction of increased risk of inadequacy were intuitive. The Ornish diet is very low in fat and primarily a vegetarian diet. The 3 nutrients of greatest concern for this group were vitamin E, obtained primarily from food sources rich in fats, and vitamin B-12 and zinc, whose primary sources are animal-derived foods (28).

The nutrients of greatest concern at 8 wk for the Atkins group included thiamine, folic acid, vitamin C, and iron. The fact that iron is included in this list might at first appear counter-intuitive because the Atkins diet is often interpreted as allowing for, and even promoting, liberal amounts of red meat. Although red meat is an excellent source of iron, the largest contributors to iron in the US diet are fortified cereals and breads (28). Because the Atkins diet discourages the consumption of refined grains, it is not surprising that the nutrients fortified in these refined grains (eg, thiamine, folic acid, and iron) shifted significantly toward an increased risk of inadequacy. The Atkins diet also limits fruit intakes as a component of carbohydrate restriction, which would explain why vitamin C was one of the nutrients at risk in the Atkins group. It is worth noting that, whereas the 8-wk time point was selected for its higher diet adherence relative to later time points in the 12 mo protocol for all 4 diet groups, the Atkins diet group participants were often still trying to follow the induction phase at 8 wk, which is significantly more restrictive of carbohydrates than is the later ongoing weight-loss phase; the less restrictive later phase may have been associated with relatively fewer micronutrient concerns.

The nutrients of concern for those in the LEARN group—vitamin E, thiamine, and magnesium—are not easy to explain but were similarly observed by Ashley et al (29) for women ($n = 35$) using the LEARN materials and following the Food Pyramid guidelines. In our study, the diet approach for the LEARN group was to consume a balanced diet, based on the food groups of the US Department of Agriculture Food Pyramid, while incorporating daily caloric restriction. These nutrients of concern, therefore, may be some of those most susceptible to inadequate intakes during consumption of reduced-calorie diets modeled after national dietary guidelines.

One of the most interesting findings observed in these analyses was the contrast between the Zone group and the other 3 diet groups for nutrients at risk of inadequacy. Even with a reported average decrease of ≈500 kcal/d at 8 wk relative to baseline, similar to the other diet groups, there were no vitamins or minerals among those examined whose risk of inadequacy increased significantly for the Zone group. To the contrary, a statistically greater proportion of women in the Zone group reported 8-wk intakes that decreased their risk of inadequacy relative to baseline (ie, improved intake) for vitamins A, C, and E. The primary difference between the Zone diet and the diet recommended by national guidelines is a relatively lower carbohydrate content and a higher protein content, the target being a 40:30:30 distribution of energy from carbohydrate, fat, and protein. The actual observed distribution of macronutrients achieved by participants in the Zone group, on average, was 42:35:24—higher in carbohydrate and fat and lower in protein than the target, yet still notably lower in carbohydrate and higher in protein and fat than the distribution achieved by the LEARN group (49:30:20).

The analyses reported here had several strengths, including the large sample size, high the retention rate, the extensive dietary assessment with 3-d unannounced 24-h recalls at each dietary assessment time point using the NDS-R software, and the high percentage of completed dietary data collection. An additional strength to the study was the inclusion of 4 diet groups that had a wide range of significantly different carbohydrate, fat, and protein distributions.

Our data should be interpreted with the following points in mind. First, our analyses of nutrient intakes were based on food intake alone, without inclusion of dietary supplements. The use of multivitamin, multimineral supplements in our study population was infrequent. In addition, most notably, despite the recommended use of vitamin and mineral supplements in the Aktins diet, only 3 individuals began taking a multivitamin/multimineral supplement and 3 additional individuals began taking a calcium supplement. Therefore, based on our sample, we anticipate that many individuals who follow a diet book will not initiate the recommended supplement use and, thus, analysis on a diet-only basis is warranted. Second, the use of self-reported dietary recall data has been associated with underreporting among dieting individuals and overweight women (30, 31).

We found that among a free-living population trying to follow alternative weight-loss diets, the intakes of several micronutrients were potentially inadequate, which differed by diet group. Given that successful weight loss and its maintenance require adopting new dietary habits and sustaining them on an ongoing basis, the long-term implications of these potentially inadequate intakes could result in clinically relevant nutritional deficiencies. Of our 4 diet groups, the Zone diet, characterized by a moderate but not extreme reduction in carbohydrate—particularly through a reduction in refined carbohydrate—a low nutrient density, and moderately increased protein intake provided the most optimal micronutrient levels during energy restriction. This type of diet merits further investigation given its potential micronutrient advantage. Our findings indicate that public health efforts should be attentive to the overall diet quality of popular weight-loss regimens that focus on altering macronutrient composition and producing weight-loss results.

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