



Applied nutritional investigation

Comparative effectiveness of plant-based diets for weight loss: A randomized controlled trial of five different diets



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ARTICLE INFO

Article history:

Received 2 July 2014

Accepted 5 September 2014

Keywords:

Vegetarian

Vegan

Obesity

Weight loss

Diet

ABSTRACT

Objective: The aim of this study was to determine the effect of plant-based diets on weight loss. **Methods:** Participants were enrolled in a 6-mo, five-arm, randomized controlled trial in 2013 in South Carolina. Participants attended weekly group meetings, with the exception of the omnivorous group, which served as the control and attended monthly meetings augmented with weekly e-mail lessons. All groups attended monthly meetings for the last 4 mo of the study. Diets did not emphasize caloric restriction.

Results: Overweight adults (body mass index 25–49.9 kg/m²; age 18–65 y, 19% non-white, and 27% men) were randomized to a low-fat, low-glycemic index diet: vegan (n = 12), vegetarian (n = 13), pesco-vegetarian (n = 13), semi-vegetarian (n = 13), or omnivorous (n = 12). Fifty (79%) participants completed the study. In intention-to-treat analysis, the linear trend for weight loss across the five groups was significant at both 2 ($P < 0.01$) and 6 mo ($P < 0.01$). At 6 mo, the weight loss in the vegan group ($-7.5\% \pm 4.5\%$) was significantly different from the omnivorous ($-3.1\% \pm 3.6\%$; $P = 0.03$), semi-vegetarian ($-3.2\% \pm 3.8\%$; $P = 0.03$), and pesco-vegetarian ($-3.2\% \pm 3.4\%$; $P = 0.03$) groups. Vegan participants decreased their fat and saturated fat more than the pesco-vegetarian, semi-vegetarian, and omnivorous groups at both 2 and 6 mo ($P < 0.05$).

Conclusions: Vegan diets may result in greater weight loss than more modest recommendations.

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Introduction

Well-planned vegan and vegetarian diets can provide adequate nutrition, and have demonstrated health benefits in disease prevention and treatment [1]. Vegan and vegetarian diets have been used effectively for weight loss and maintenance [2,3]. Anchoring the two ends of the plant-based dietary spectrum are vegan diets (exclude all animal products) and omnivorous diets (omni: no foods excluded). Between these two diets are other plant-based diets, such as semi-vegetarian (semi-veg:

occasional meat intake), pesco-vegetarian (pesco-veg: excludes meat except seafood), and vegetarian (veg: excludes all meat and seafood, but contains eggs and dairy products). Several epidemiologic studies have examined differences in weight-related outcomes among these diets, finding lower body weights [4] and less weight gain over time among vegans compared with other groups [5].

These prospective cohort studies [4,5] examining the five diets along the plant-based dietary spectrum have categorized participants according to their preexisting dietary patterns, making it difficult to account for the inherent differences that may exist among individuals who self-select different patterns. To date, there have been no randomized trials comparing the effectiveness of these five different diets on weight loss. Therefore, the goal of this study was to examine the differences in weight loss among participants randomized to adopt an omnivorous, semi-vegetarian, pesco-vegetarian, vegetarian, or

GTM and SW designed the research study. GTM, EEW, and CRD conducted the research. EAF performed statistical analysis. GTM, SW, and EAF wrote the paper. GTM had primary responsibility for final content. The authors have no conflicts of interest to declare.

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vegan diet. Transitioning to plant-based diets may lead to greater increases in fiber [6–8], with high-fiber diets being associated with lower body weights in epidemiologic studies [9], and greater decreases in dietary fat [6–8], with studies showing that low-fat diets are associated with weight loss [10]. Because of these potential changes in nutrients among groups, we hypothesized that differences in weight loss would follow similar patterns seen in epidemiologic studies with weight loss being incrementally greater along the plant-based dietary spectrum from omni to semi-veg to pesco-veg to veg to vegan diets. Furthermore, we hypothesized that the vegan group would have significantly greater weight loss compared with the pesco-veg, semi-veg, and omni groups.

Materials and methods

The New DIETs (New Dietary Interventions to Enhance the Treatments) for weight loss study was a 2-mo weight loss intervention with a 4-mo follow-up period. Recruitment and exclusion criteria are described elsewhere [11]. Briefly, overweight or obese (body mass index [BMI] 25–49.9 kg/m²) adults, who were interested in losing weight, were between the ages of 18 and 65 y with a stable medical status (e.g., no uncontrolled thyroid conditions or diabetes), and were willing to accept random assignment of diet, were recruited through worksite listserv messages and newspaper ads. Participants attended an orientation session to learn about questionnaires and complete a consent form. Participants were informed that the purpose of the study was to assess changes in body weight after randomization to one of five different diets. Questionnaires assessed demographic characteristics, dietary intake from 2 d of unannounced 24-h dietary recalls (one weekday and one weekend day) collected and analyzed using the automated self-administered 24-h dietary recall [12], and physical activity (Paffenbarger Physical Activity Questionnaire) [13].

Once all participants completed baseline questionnaires, they were randomized to one of the five diets using a computerized random-number generator and stratified by BMI and sex (both self-reported on screening questionnaires). Before revealing randomization assignment, weight was measured in light street clothes without shoes using a calibrated digital scale (SECA 869, Hamburg, Germany) accurate to 0.1 kg. Height was measured using a stadiometer (SECA 213) after participants had removed hats and shoes. All measures (with the exception of height and demographic characteristics) were assessed at baseline, 2 mo, and 6 mo. A university Institutional Review Board approved the study, and all the participants gave written informed consent. Participants received a \$20 incentive payment for completion of all 2-mo assessment activities, but did not receive any incentives for completion of 6-mo assessments.

Intervention diets

After all baseline measurements were assessed, participants met with their randomized group. All participants received a handout that provided details on their assigned diet, including food groups that can be included and ones that should be avoided, and details on low-fat cooking instructions and the glycemic index [14]. Two registered dietitians with graduate degrees and expertise in all the study diets led the classes. These research dietitians provided participants with the orientation presentation that detailed menu planning and reviewed recipes given to each group. All groups were provided with several foods to sample during the first class. Self-monitoring dietary or energy intake was not required by any of the groups and was not discussed at group meetings. Participants were free to eat whenever they wanted and at a frequency of their own choosing as long as it adhered to their diet assignment. All participants were encouraged to limit fast foods and processed foods in favor of more minimally processed foods to meet low-fat and low-glycemic index dietary recommendations. Participants could dine out and were instructed on how to make healthy choices at restaurants.

Table 1 provides an overview of the five intervention diets used in the New DIETs study as well as sample dinner menus. Because both low-glycemic index [15] and low-fat diets [10] are associated with weight loss, all participants were instructed to follow diets that favored low-glycemic index and low-fat foods. Participants were told they could include limited amounts of nuts and nut butters, avocados, seeds, and olives in their diets but were encouraged to focus on lower fat food options. There was no recommended restriction on energy intake for any of the five groups. All groups attended weekly 1-h meetings for 8 wk, with the exception of the omni group. The omni group allowed for the examination of consuming a usual diet (as all participants were following an omnivorous diet at baseline), while at the same time controlling for the selection made by all participants to participate in a weight loss study. The omni

group attended meetings at baseline, 1 mo, and 2 mo, and received their dietary information by e-mail, which included a weekly lesson plan covering the same topics addressed in the group sessions as well as an e-mail message providing an overview of the lesson information. Previous research studies have used this method of providing weekly e-mail lessons for a weight loss intervention [16, 17]. In summary, the omni group allowed for the examination of what would occur via minimal intervention with no recommendation to limit food groups (i.e., usual diet).

Although only vegan diets require supplementary vitamin B₁₂ [1], to control for supplement intake across groups, all participants were required to purchase and take a multivitamin or other form of vitamin B₁₂ daily. After the 2-mo main intervention was completed, all participants (including the omni group) were offered monthly meetings to assist with dietary maintenance. Participants were also provided with a private Facebook group for their diet group after the 2-mo mark to provide social support in between monthly meetings (joining was optional). After the 2-mo intensive intervention phase, participants were encouraged to continue following their assigned diet and meet with their diet group each month. Participants were told they could make alterations to the diet if they needed to but were encouraged to maintain their dietary changes. Participants received handouts and recipes related to the session topic for every meeting during the 6-mo study. Topic sessions for all the group meetings were informed by the Diabetes Prevention Program [18] and were grounded in social cognitive theory [19]. Each class included food samples or a cooking demonstration. All group sessions covered identical topics among the five groups with the only difference being the type of diet discussed. The first eight topic sessions for all groups were as follow:

1. Overview of assigned diet
2. Grocery shopping tips
3. Meal planning and dining out
4. Recipe modification
5. Grocery store tour
6. Problem solving: handling holidays and family pressures
7. Dealing with weight plateaus and the slippery slope
8. Ways to stay motivated.

Participants met with only their assigned diet group, which corresponded to a day of the week. Dietary adherence was measured as the absence of any proscribed foods from the dietary recalls (e.g., absence of meat, dairy, and eggs from vegan participants' food records). Participants in the omni group were considered adherent if their percent energy from fat was ≤40%. This method of assessing dietary adherence has been used in previous studies [3,20].

Statistical analyses

The study was powered to detect a significant difference in weight loss at 2 mo among the five groups with a significant trend in weight loss demonstrating a decrease in percent body weight incrementally going from the omni, semi-veg, pesco-veg, veg, through the vegan group. Assuming a mean incremental difference in change in body weight of 1% successively between each of the five groups (corresponding to an effect size of 0.57), a pooled SD of 2.5%, and significance at $\alpha = 0.05$, a sample size of 60 participants (12 per group) was estimated to provide 94% power for the linear trend among the five groups [21]. The sample size of 12 per group provided 80% power for differences of ≥2.85% for linear contrasts between two groups. Attrition was defined as a participant not completing the main outcome of body weight at either 2 mo (for 2-mo outcomes) or 6 mo (for 6-mo outcomes).

For differences in baseline demographic characteristics, analysis of variance (ANOVA) was used with the Tukey's test for post hoc analyses of continuous variables and χ^2 test of independence was used for categorical variables. Change in percent weight loss among the five groups was analyzed at both 2 mo (after the intensive intervention) and at 6 mo (to assess weight loss maintenance) using one-way ANOVA. To test that weight loss would be incremental among the five groups (going from the vegan group losing the most to omnivores losing the least), an a priori linear contrast for trend was used at each time point. Additionally, three a priori linear contrasts among the specific groups were examined at each time point: vegan versus omni, vegan versus semi-veg, and vegan versus pesco-veg. Because weight loss differences between veg and vegan participants were expected to be smaller than the other groups, this study was not powered to detect weight loss differences between veg and vegan. Missing data for body weight was handled in two ways: 1) baseline observation carried forward for missing values at each time point (assuming no change) and 2) weight gain imputed at a rate of 0.3 kg/mo. This rate of weight gain has been shown to commonly occur during behavioral weight loss interventions [22,23] and has been used as the weight gain amount for other large, dietary weight loss trials [24,25]. Weight gain was extrapolated from time of attrition up through the 2- and 6-mo assessment

Table 1
Description of the five intervention diets and example meals

Dietary group	Definitions of diet patterns	Example day of meals
Vegan	Does not contain any animal products (meat, fish, poultry, eggs, or dairy) but emphasizes plant-based foods, such as fruits, vegetables, whole grains, and legumes/beans.	<p>Breakfast</p> <ul style="list-style-type: none"> • Oatmeal with cinnamon and soymilk topped with sliced strawberries <p>Lunch</p> <ul style="list-style-type: none"> • Hummus sandwich with lettuce, tomato, and mustard on pumpernickel bread • Baked tortilla chips • Baby carrots <p>Dinner</p> <ul style="list-style-type: none"> • Soft tacos made with whole wheat tortillas, black beans, roasted peppers, and salsa • Fruit salad
Vegetarian	Does not contain meat, fish, or poultry but does contain eggs and dairy, in addition to plant-based foods, such as fruits, vegetables, whole grains, and legumes/beans.	<p>Breakfast</p> <ul style="list-style-type: none"> • Oatmeal with cinnamon and 1% milk topped with sliced strawberries <p>Lunch</p> <ul style="list-style-type: none"> • Hummus sandwich with lettuce, tomato, reduced-fat feta, and mustard on pumpernickel bread • Baked tortilla chips • Baby carrots <p>Dinner</p> <ul style="list-style-type: none"> • Soft tacos made with whole wheat tortillas, black beans, roasted peppers, reduced-fat cheddar cheese, and salsa • Fruit salad
Pesco-vegetarian	Does not contain meat or poultry but does contain fish and shellfish, eggs, and dairy, in addition to plant-based foods, such as fruits, vegetables, whole grains, and legumes/beans.	<p>Breakfast</p> <ul style="list-style-type: none"> • Oatmeal with cinnamon and 1% milk topped with sliced strawberries <p>Lunch</p> <ul style="list-style-type: none"> • Hummus sandwich with lettuce, tomato, reduced-fat feta, and mustard on pumpernickel bread • Baked tortilla chips • Baby carrots <p>Dinner</p> <ul style="list-style-type: none"> • Soft tacos made with whole wheat tortillas, fish (mahi mahi), roasted peppers, reduced-fat cheddar cheese, and salsa • Fruit salad
Semi-vegetarian	Contains all foods, including meat, poultry, fish and shellfish, eggs, and dairy, in addition to plant-based foods, such as fruits, vegetables, whole grains, and legumes/beans. However, red meat is limited to once per week and poultry is limited to ≤ 5 times per week.	<p>Breakfast</p> <ul style="list-style-type: none"> • Oatmeal with cinnamon and 1% milk topped with sliced strawberries <p>Lunch</p> <ul style="list-style-type: none"> • Hummus sandwich with lettuce, tomato, reduced-fat feta, and mustard on pumpernickel bread • Baked tortilla chips • Baby carrots <p>Dinner</p> <ul style="list-style-type: none"> • Soft tacos made with whole wheat tortillas, chicken, roasted peppers, reduced-fat cheddar cheese, and salsa • Fruit salad
Omnivorous	Contains all food groups.	<p>Breakfast</p> <ul style="list-style-type: none"> • Oatmeal with cinnamon and 1% milk topped with sliced strawberries <p>Lunch</p> <ul style="list-style-type: none"> • Chicken breast sandwich with lettuce, tomato, reduced-fat feta, and mustard on pumpernickel bread • Baked tortilla chips • Baby carrots <p>Dinner</p> <ul style="list-style-type: none"> • Soft tacos made with whole wheat tortillas, flank steak, roasted peppers, reduced-fat cheddar cheese, and salsa • Fruit salad

periods. Both methods of imputation for missing data yielded similar results; therefore only analyses that used a weight gain of 0.3 kg/mo imputed for missing data are presented. Missing dietary and physical activity data were analyzed by carrying forward baseline observations, assuming no change in dietary intake or physical activity. All analyses were conducted using SPSS 21.0 for Windows software (SPSS Inc., Chicago, IL, USA) with a $P = 0.05$ to indicate statistically significant differences.

Results

Participants were screened in February 2013 and the trial was completed by August 2013. Of 219 participants who were screened, 63 (29%) were randomly assigned to a diet. At the 2-mo assessment time point, 57 (90%) of those assigned to a diet

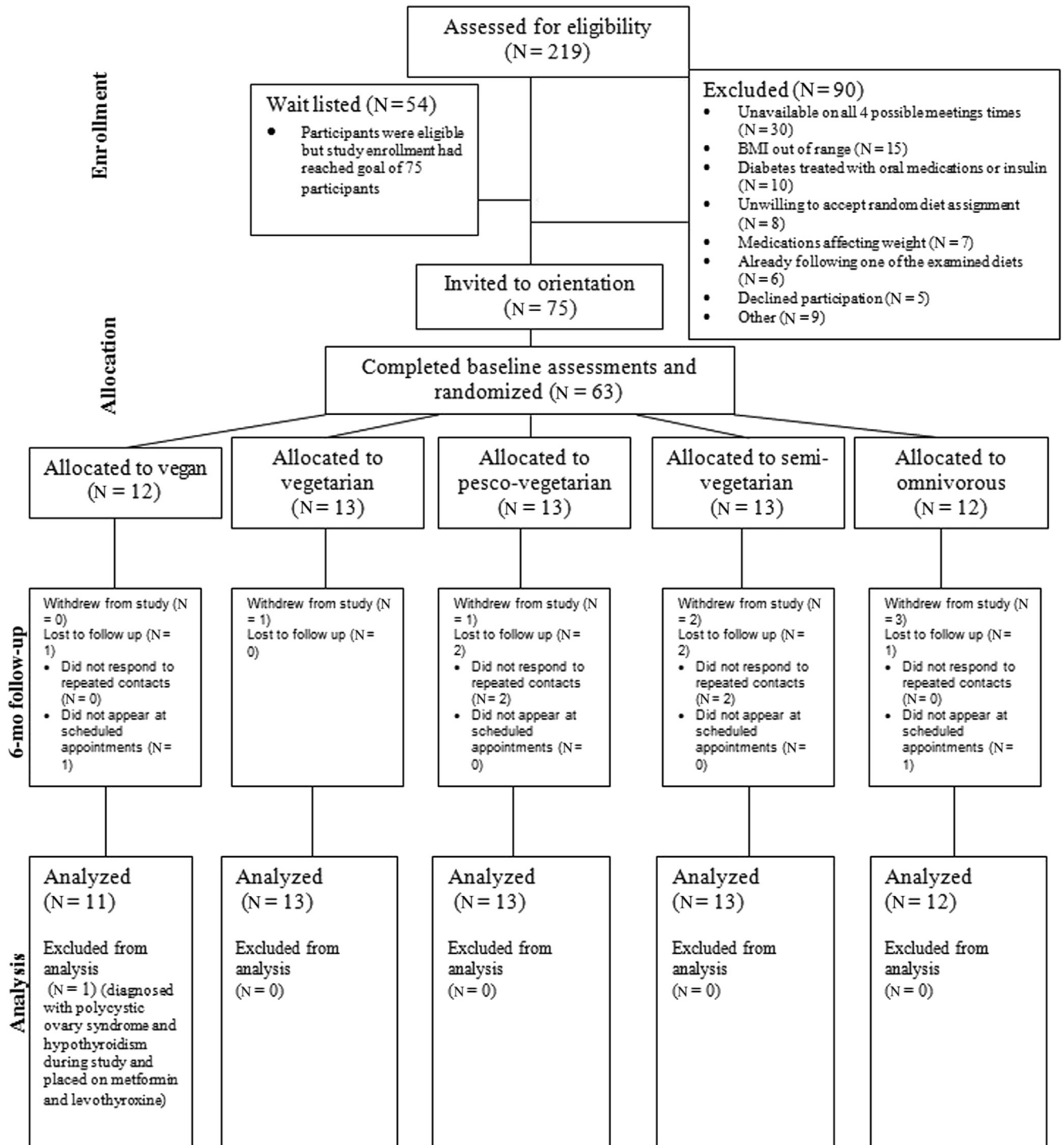


Fig. 1. CONSORT diagram showing the flow of participants through each stage of the New DIET's 6-mo weight loss trial. BMI, body mass index; New DIET, New Dietary Interventions to Enhance the Treatments.

Table 2
Baseline demographic characteristics, body mass index, and dietary intake of study participants in New DIET weight loss studies

	Vegan	Vegetarian	Pesco-vegetarian	Semi-vegetarian	Omnivorous	P-value for difference among groups
n	12	13	13	13	12	
Mean age, y (\pm SD)	48.2 \pm 7.4	53.0 \pm 3.8	48.8 \pm 8.0	42.7 \pm 9.8*	51.0 \pm 8.6	0.02
Sex						0.97
Female (%)	8 (67)	10 (77)	9 (69)	10 (77)	9 (75)	
Male	4	3	4	3	3	
Race (%)						0.69
Black	3 (25)	3 (23)	3 (23)	2 (15)	1 (8)	
White	9 (75)	9 (69)	10 (77)	11 (85)	11 (92)	
Other	—	1 (8)	—	—	—	
Education (%)						0.20
High school or some college	—	—	1 (8)	—	3 (25)	
College graduate	8 (67)	6 (46)	6 (46)	8 (62)	5 (42)	
Advanced degree	4 (33)	7 (54)	6 (46)	5 (38)	4 (33)	
Marital status (%)						0.16
Married	9 (75)	7 (54)	8 (61)	5 (39)	10 (83)	
Other	3 (25)	6 (46)	5 (39)	8 (61)	2 (17)	
Mean BMI, kg/m ² (\pm SD)	32.5 \pm 5.2	35.1 \pm 5.0	35.8 \pm 5.2	35.1 \pm 5.3	36.3 \pm 5.5	0.49
Energy, kcal/d (\pm SD)	2460 \pm 239	2070 \pm 230	2028 \pm 230	2321 \pm 230	2125 \pm 239	0.65
Protein, % energy (\pm SD)	16.1 \pm 1.0	17.0 \pm 1.0	16.8 \pm 1.0	16.2 \pm 1.0	16.8 \pm 1.0	0.96
Fat, % energy (\pm SD)	40.2 \pm 1.7 [†]	40.0 \pm 1.7 [†]	33.2 \pm 1.7	36.8 \pm 1.7	38.1 \pm 1.7 [†]	0.045
Saturated fat, % energy (\pm SD)	13.9 \pm 0.8	12.4 \pm 0.7	10.8 \pm 0.7	12.4 \pm 0.7	12.3 \pm 0.8	0.09
Carbohydrate, % energy (\pm SD)	41.9 \pm 2.6	43.8 \pm 2.5	45.2 \pm 2.5	42.8 \pm 2.5	46.1 \pm 2.6	0.80
Fiber, g (\pm SD)	18.5 \pm 2.0	18.1 \pm 1.9	17.8 \pm 1.9	15.6 \pm 1.9	22.9 \pm 2.0	0.15
Cholesterol, mg (\pm SD)	290.5 \pm 44.2	361.3 \pm 42.1	318.2 \pm 42.2	289.1 \pm 42.1	297.0 \pm 43.8	0.73

BMI, body mass index; New DIET, New Dietary Interventions to Enhance the Treatments

* Significantly different from the vegetarian group ($P = 0.01$).

[†] Significantly different from the pesco-vegetarian group ($P < 0.01$).

completed the body weight assessment and questionnaires, and 56 (89%) completed 2 d of dietary recalls. At the 6-mo time point, 50 (79%) completed the study (i.e., provided a body weight measurement at 6 mo), 46 completed the questionnaires (73%), and 49 (78%) completed 2 d of dietary recalls (Fig. 1 presents a CONSORT diagram).

There were no differences in baseline demographic characteristics or BMI among the five groups with the exception of age and percent energy from dietary fat (Table 2). Attrition did not significantly differ by diet group. One participant in the vegan group was diagnosed with insulin-resistant polycystic ovary syndrome and hypothyroidism during the first month of the study and began treatment with levothyroxine and metformin. Because both of these conditions and/or medications were

reasons for exclusion from the study (as a result of their potential effect on body weight), this participant was excluded from weight loss analyses, but was included in physical activity and dietary outcomes.

Weight loss

Figure 2 shows the weight loss among each group over the course of the 6-mo study. The trend for weight loss among the five groups was significant at both 2 mo ($P < 0.01$) and 6 mo ($P < 0.01$) with the greatest weight loss occurring in the vegan group ($-7.5\% \pm 4.5\%$), followed by the veg ($-6.3\% \pm 6.6\%$), pesco-veg ($-3.2\% \pm 3.4\%$), semi-veg ($-3.2\% \pm 3.8\%$), and omni ($-3.1\% \pm 3.6\%$) groups. Specifically, percent weight loss comparing the vegan group with the omni, semi-veg, and pesco-veg groups was examined. At 2 mo, weight loss in the vegan group ($-4.8\% \pm 2.1\%$) was not significantly different from pesco-veg ($-4.3\% \pm 1.8\%$; $P = 0.60$) or semi-veg ($-3.7\% \pm 2.4\%$; $P = 0.24$) but was different from the omni group ($-2.2\% \pm 2\%$; $P < 0.01$). At 6 mo, the weight loss in the vegan group ($-7.5\% \pm 4.5\%$) was significantly different from the omni ($-3.1\% \pm 3.6\%$; $P = 0.03$), semi-veg ($-3.2\% \pm 3.8\%$; $P = 0.03$), and pesco-veg ($-3.2\% \pm 3.4\%$; $P = 0.03$) groups. Self-reported intentional physical activity (kcal/d) was not significantly different among the five groups (means \pm SE), adjusting for baseline levels, at either 2 mo (vegan 99.3 ± 33.3 , veg 136.0 ± 31.9 , pesco-veg 107.7 ± 33.4 , semi-veg 169.0 ± 38.9 , and omni 178.8 ± 36.6 ; $F = 1.08$, $P = 0.38$) or 6 mo (vegan 227.9 ± 45 , veg 205.4 ± 46.3 , pesco-veg 158.8 ± 53.4 , semi-veg 83.0 ± 49.1 , and omni 194.3 ± 55.6 ; $F = 0.89$, $P = 0.48$); therefore, there was no need to adjust analyses of weight loss for physical activity.

Dietary intake

Table 3 shows changes in dietary intake at each time point. The trend for changes in energy intake was not significant at

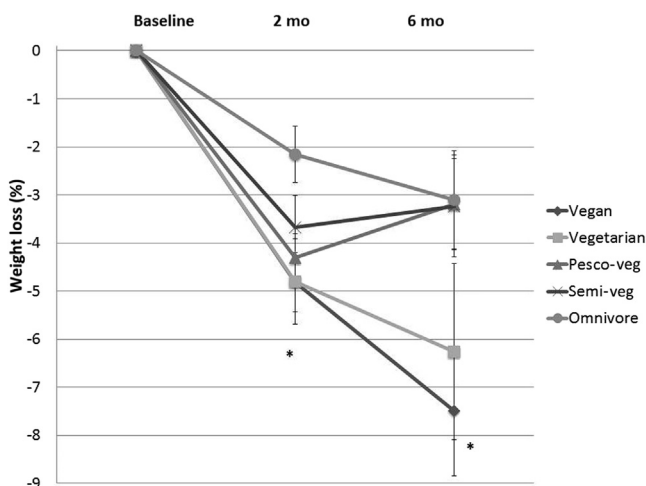


Fig. 2. Percent weight loss (\pm SE) during 6-mo New DIET's trial by diet group. New DIET, New Dietary Interventions to Enhance the Treatments. * P trend < 0.01 .

Table 3

Changes in macronutrients, fiber, and cholesterol intake and dietary adherence among five diet groups at 2 and 6 mo*

Outcome variable and group	Change in outcome measures		Comparisons among groups		
	Change from baseline to 2 mo	Change from baseline to 6 mo	P-value for linear contrasts	2 mo, P-values	6 mo, P-values
Energy intake (kcal/d)			Trend across 5 groups	0.65	0.09
Vegan	-786 ± 1043	-903 ± 1238			
Vegetarian	-134 ± 729	-223 ± 530			
Pesco-vegetarian	-401 ± 618	-327 ± 921	Vegan vs. pesco-veg	0.29	0.08
Semi-vegetarian	-481 ± 767	-397 ± 650	Vegan vs. semi-veg	0.32	0.12
Omnivorous	-455 ± 517	-194 ± 377	Vegan vs. omni	0.21	0.03
% Energy from protein			Trend across 5 groups	<0.001	0.02
Vegan	-2.4 ± 2.1	-1.3 ± 2.7			
Vegetarian	-3.6 ± 3.8	-2.8 ± 4.6			
Pesco-vegetarian	1.8 ± 5.6	-0.5 ± 5.8	Vegan vs. pesco-veg	0.02	0.65
Semi-vegetarian	1.4 ± 4.1	1.1 ± 4.1	Vegan vs. semi-veg	0.03	0.19
Omnivorous	2.6 ± 4.7	1.7 ± 4.3	Vegan vs. omni	<0.01	0.11
% Energy from fat			Trend across 5 groups	<0.01	<0.01
Vegan	-11.3 ± 8.6	-9.4 ± 10.1			
Vegetarian	-3.7 ± 10.6	-6.6 ± 6.1			
Pesco-vegetarian	-2.8 ± 7.3	-0.7 ± 4.5	Vegan vs. pesco-veg	0.02	0.01
Semi-vegetarian	-3.4 ± 8.3	-0.2 ± 9.4	Vegan vs. semi-veg	0.03	0.03
Omnivorous	1.4 ± 9.8	-0.6 ± 3.9	Vegan vs. omni	<0.01	0.02
% Energy from saturated fat			Trend across 5 groups	<0.001	0.01
Vegan	-8.2 ± 3.5	-5.3 ± 5.7			
Vegetarian	-1.5 ± 4.1	-2.4 ± 2.4			
Pesco-vegetarian	-1.9 ± 3.3	-1.4 ± 2.9	Vegan vs. pesco-veg	<0.001	0.05
Semi-vegetarian	-0.4 ± 6.1	-1.3 ± 2.0	Vegan vs. semi-veg	<0.001	0.04
Omnivorous	-0.5 ± 2.9	-0.7 ± 1.9	Vegan vs. omni	<0.001	<0.01
% Energy from carbohydrate			Trend across 5 groups	<0.001	<0.01
Vegan	14.0 ± 8.4	11.7 ± 13.7			
Vegetarian	5.2 ± 12.7	6.7 ± 11.4			
Pesco-vegetarian	3.1 ± 9.0	4.0 ± 9.9	Vegan vs. pesco-veg	<0.01	0.13
Semi-vegetarian	2.9 ± 9.8	0.3 ± 6.1	Vegan vs. semi-veg	<0.01	0.02
Omnivorous	-3.5 ± 11.8	-1.1 ± 5.6	Vegan vs. omni	<0.001	<0.01
Fiber (g)			Trend across 5 groups	<0.01	0.32
Vegan	12.1 ± 18.4	2.3 ± 15.5			
Vegetarian	9.3 ± 5.2	3.2 ± 8.4			
Pesco-vegetarian	3.9 ± 7.3	2.4 ± 10.8	Vegan vs. pesco-veg	0.17	0.99
Semi-vegetarian	0.6 ± 9.0	-1.1 ± 6.8	Vegan vs. semi-veg	0.07	0.50
Omnivorous	-4.3 ± 10.1	-1.0 ± 8.6	Vegan vs. omni	<0.01	0.52
Cholesterol (mg)			Trend across 5 groups	<0.01	0.001
Vegan	-311.3 ± 202.2	-240.5 ± 221.9			
Vegetarian	-146.1 ± 276.7	-172.8 ± 198.1			
Pesco-vegetarian	-62.8 ± 242.6	-60.8 ± 225.9	Vegan vs. pesco-veg	<0.01	0.02
Semi-vegetarian	-62.0 ± 162.3	-11.1 ± 131	Vegan vs. semi-veg	<0.01	<0.01
Omnivorous	-33.2 ± 186.2	-38.5 ± 117.7	Vegan vs. omni	<0.01	0.01
Number of participants meeting dietary adherence criteria (%)	2 mo	6 mo	χ^2 difference between groups:	2 mo	6 mo
Vegan	6 (50)	4 (33)		$\chi^2 = 5.2, P = 0.27$	$\chi^2 = 0.47, P = 0.98$
Vegetarian	10 (77)	5 (39)			
Pesco-vegetarian	7 (54)	5 (39)			
Semi-vegetarian	8 (62)	6 (46)			
Omnivorous	4 (33)	5 (42)			

* Results are means ± SD except for adherence criteria results.

either 2 or 6 mo. The only difference among the groups was between the omni and vegan groups at 6 mo with vegan participants decreasing their energy intake more than omni participants ($P = 0.02$). Vegan participants decreased their percent energy from protein more than did the pesco-veg, semi-veg, and omni groups at 2 mo but the between-group contrasts were not significant at 6 mo. Vegan participants also decreased their fat and saturated fat more than did the pesco-veg, semi-veg, and omni groups at both 2 and 6 mo. Opposite of the direction of fat intake, carbohydrate intake increased incrementally examining the groups from omni up through vegan at both 2 and 6 mo. Vegan participants had greater increases in carbohydrate intake compared with pesco-veg at 2 mo and compared with semi-veg and omni at both 2 and 6 mo. Vegan participants increased their fiber intake more than omni participants at 2 mo. Vegans had a

greater decrease in cholesterol intake compared with pesco-veg, semi-veg, and omni participants at both time points. Adherence to the dietary recommendations did not differ by diet group at either 2 or 6 mo (Table 3).

Discussion

This randomized trial examined the effect of differing levels of plant-based diets on body weight and intake of macronutrients, fiber, and cholesterol. This is the first study to go beyond observational trials to intervention research by randomizing participants to adopt these five different plant-based eating styles. This randomized design allowed for a more rigorous control of factors that may affect body weight, such as exercise and education level, than can be used in observational designs.

Additionally, this study provides evidence that participants can learn to adopt each of these dietary patterns using a minimal amount of contact time.

The weight loss achieved in this study occurred without the need for dietary self-monitoring. Dietary self-monitoring is considered the cornerstone of behavioral treatment for weight loss [23]; however, dietary self-monitoring requires daily recording of all foods and drinks consumed, which can be burdensome [26], time-consuming, and tedious [27]. Adherence to self-monitoring can be low and may decrease over time [28], highlighting the need to study dietary strategies that do not require dietary self-monitoring for effective weight loss. The mean 6-mo weight loss among the vegan participants (mean of 7.5% decrease in body weight) was greater than what has been observed in previous behavioral weight loss interventions, which typically lead to an average of 5% weight loss using a diet-only approach (with no exercise) [29]. It is possible that greater initial weight loss was motivational for the vegan group as other studies have demonstrated that early initial weight loss is predictive of long-term weight loss success [30]. This initial weight loss success also could have provided a stronger motivation to maintain dietary changes in the vegan and vegetarian groups leading to continued weight loss between 2 and 6 mo that was not seen in the pesco-veg and semi-veg groups.

Prevention of weight regain and promotion of weight loss maintenance has been challenging, with studies showing only 20% of individuals who lose weight are able to maintain it [31]. Future research examining these plant-based eating styles should examine long-term maintenance of weight loss beyond the 6-mo time frame. Additionally, the omni group saw continued weight loss from 2 to 6 mo. Future research should examine if this low-fat, low-glycemic index diet approach that includes all foods is effective for long-term weight loss.

As hypothesized, there was a trend in weight loss among the five groups at both 2 and 6 mo with greater weight loss seen in the vegan group at 6 mo compared with the other three dietary patterns that included meat (pesco-veg, semi-veg, and omni). The more plant-based diets also led to more favorable changes in macronutrients, fiber, and cholesterol, particularly among the vegan diet group. The findings point to a potential use of plant-based eating styles in the prevention and treatment of obesity and related chronic diseases. The weight loss results of the present study going from greatest weight loss among the vegan group to the least in the omni group mirror the direction of other health-related outcomes observed in several large non-randomized prospective cohort studies, including metabolic syndrome [32], cancer incidence [33], type 2 diabetes [4], and all-cause mortality [34].

Differences in health and weight outcomes among these five diets seen in other studies and in the present study may be the result of the differing intake in nutrients. The nutrition findings of the present study mirror the findings of several epidemiologic studies, which have consistently shown higher dietary fiber [35–38] and lower saturated fat intakes [35,36,38,39] among vegans and/or vegetarians compared with omnivores. Randomized trials comparing adoption of a vegan diet to a standard therapeutic or usual diet also have found greater increases in fiber and decreases in saturated fat among vegan diet participants [6–8]. These differences in dietary intake may be one of the reasons why vegan and vegetarian diets have higher dietary quality compared with omnivorous diets [7,40]. Additionally, there were greater decreases in percent energy from protein in the vegan group compared with the groups consuming fish, poultry, or meat at 2 mo, but not at 6 mo. It is possible that this

decrease in protein may have resulted in a loss of lean mass. Research has demonstrated that vegan and vegetarian diets can meet adequate protein needs [1], but other dietary factors, such as calcium, may be lower in those following a vegan diet and may in turn impact body composition [41]. Future studies should examine changes in body composition during transition to different plant-based diets.

Use of plant-based dietary approaches for weight loss has public health appeal. There was no restriction on energy intake recommended to any of the groups in the study. Participants were free to eat until they were satisfied. Because traditional weight loss dietary approaches require dietary self-monitoring, which often is viewed as burdensome [26], time consuming, and tedious by participants [27], dietary approaches that do not require self-monitoring may be appealing for individuals who are resistant to dietary self-tracking. Additionally, rates of dietary adherence did not differ by group, demonstrating that no single diet emerged as easier for participants to follow.

In studies using traditional reduced-energy weight loss diets, adherence to and frequency of self-monitoring are highly correlated with weight loss [28]. Whereas adherence is important with traditional dietary approaches, the present study examines the effect of recommending different plant-based diets to free-living individuals and suggests that adherence to plant-based diets, such as vegan and vegetarian diets may not need to be complete. In a randomized trial examining 2-y weight loss comparing a vegan diet to the National Cholesterol Education Program Step 2 diet (a standard low-fat diet), dietary adherence at 2 y was marginal (60% adherent vegan, 55% adherent in Step 2) and not significantly different between the two diet groups, but the vegan group had a significantly greater weight loss than the Step 2 diet group [3]. Although adherence rates were low in all groups, the vegan group had more dietary adherence criteria to meet to count as adherent than the other groups. The 2 d of dietary recalls at each time point had to be free of eggs or foods containing eggs, dairy products or foods containing dairy products, meat, poultry, and fish to be considered adherent. For example, a participant in the vegan group could have had egg whites in a recipe, which wouldn't impact overall macronutrient intake to any large degree, but would still be considered nonadherent to the diet. Participants in the pesco-veg group, for example, could have had eggs or foods containing eggs, dairy products or foods containing dairy products, and fish on their dietary recalls and still be considered adherent.

There are several strengths to the present study. The study was delivered with modest contact with study participants in the four plant-based groups, who received eight weekly classes, followed by four additional classes and online support via Facebook groups over 4 mo (total of 12 one-hour class sessions in 6 mo). In behavioral weight loss treatment research, weight regain is common when contact time in a study is decreased [42, 43]. In the present study, weight loss continued to occur in the vegan and veg groups despite transitioning to monthly meetings. In addition to the modest contact, other aspects of the study also make the findings applicable outside the research setting, including participants preparing all their own foods or finding meals to eat at restaurants. The study also had a low attrition rate of 21%, particularly considering that no incentive was provided at 6 mo. Most behavioral weight loss studies have attrition rates greater than 30% [44,45]. Greater weight loss occurred in the vegan group despite equal diet adherence among the groups. The present study was also conducted in the southern United States where traditional southern food preferences might result in high obesity rates greater challenges to adoption of more plant-based eating styles than other regions [46].

There are also some limitations. Although weight change was an objectively measured outcome, diet and physical activity were both self-reported, and changes in body composition, including changes in lean mass, were not assessed. The dietary data were collected by two unannounced, 24-h recalls, which is considered to be an accurate way to measure overall dietary intake [47–49]. For energy expenditure, the Paffenbarger Physical Activity Questionnaire was used and has been shown to be both valid and reliable [50,51]. Other limitations include the short duration and a sample that was mostly white and educated. The sample had a higher percentage of men, however, than is typical for behavioral weight loss programs [52–55]. Additionally, neither participants nor study personnel were blinded to diet assignment. The study was not powered to detect differences in weight loss and dietary intake between the vegan and vegetarian groups. Future research with a larger sample size will be needed to examine differences between vegan and vegetarian. Finally, the present study had reduced contact time for the omni group, which met monthly during the initial 8 wk of the study, receiving their dietary information mainly by e-mail during that time. All groups received the same intensity of the intervention for the majority of the study (months 3–6), however, and even without the omni group included, weight loss among vegan participants was significantly greater than pesco-veg or semi-veg participants. This indicates that, even without inclusion of the omni group, there is evidence toward greater weight loss with the vegan diet compared with plant-based diets, which include some fish or meat.

Conclusions

This study provides evidence for greater short-term weight loss and improved macronutrient, fiber, and cholesterol intake among individuals randomly assigned to follow plant-based diets that do not include meat (vegan) compared with other plant-based approaches with limited meat (pesco-veg and semi-veg) or unrestricted meat intake (omni). Studies examining the effect of plant-based diets on long-term weight loss maintenance are needed. Diets excluding food groups have not been the norm in nutrition recommendations, with the predominant message from nutrition and health organizations being that modest dietary changes are more acceptable to participants and that “all foods fit” [56,57]. Stricter dietary recommendations, however, may yield greater dietary changes than more modest recommendations [58]. Additionally, dietary approaches that include all foods require strict adherence to dietary self-monitoring if weight loss is to occur [59]. Because complete adherence may not be necessary with plant-based dietary approaches, and vegan and vegetarian diets appear to be effective strategies for both weight loss and improving nutrition profiles, those creating dietary guidelines for disease prevention and treatment should consider these plant-based eating styles as a potential strategy for healthy eating recommendations.

Acknowledgments

The authors acknowledge the University of South Carolina's Office of Public Health Practice for assistance with survey design.

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