RESEARCH
Research Brief

Changes in Food and Nutrient Intake and Diet Quality on a Low-Fat Vegan Diet Are Associated with Changes in Body Weight, Body Composition, and Insulin Sensitivity in Overweight Adults: A Randomized Clinical Trial

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ARTICLE INFORMATION

Article history:
Submitted 8 April 2021
Accepted 13 April 2022

Keywords:
Food groups
Diet quality
Plant-based
Vegan
Weight loss

https://doi.org/10.1016/j.jand.2022.04.008

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ABSTRACT

Background Consuming different food groups and nutrients can have differential effects on body weight, body composition, and insulin sensitivity.

Objective The aim was to identify how food group, nutrient intake, and diet quality change relative to usual-diet controls after 16 weeks on a low-fat vegan diet and what associations those changes have with changes in body weight, body composition, and measures of metabolic health.

Design Secondary analysis of a randomized clinical trial conducted between October 2016 and December 2018 in four replications.

Participants/setting Participants included in this analysis were 219 healthy, community-based adults in the Washington, DC, area, with a body mass index (BMI) between 28 and 40, who were randomly assigned to either follow a low-fat vegan diet or make no diet changes.

Intervention A low-fat, vegan diet deriving approximately 10% of energy from fat, with weekly classes including dietary instruction, group discussion, and education on the health effects of plant-based nutrition. Control group participants continued their usual diets.

Main outcome measures Changes in food group intake, macronutrient and micronutrient intake, and dietary quality as measured by Alternate Healthy Eating Index-2010 (AHEI-2010), analyzed from 3-day diet records, and associations with changes in body weight, body composition, and insulin sensitivity were assessed.

Statistical analyses performed A repeated-measure analysis of variance model that included the factors group, subject, and time was used to test the between-group differences throughout the 16-week study. Interaction between group and time was calculated for each variable. Within each diet group, paired comparison *t* tests were calculated to identify significant changes from baseline to 16 weeks. Spearman correlations were calculated for the relationship between changes in food group intake, nutrient intake, AHEI-2010 score, and changes in body weight, body composition, and insulin sensitivity. The relative contribution of food groups and nutrients to weight loss was evaluated using linear regression.

Results Fruit, vegetable, legume, meat alternative, and whole grain intake significantly increased in the vegan group. Intake of meat, fish, and poultry; dairy products; eggs; nuts and seeds; and added fats decreased. Decreased weight was most associated with increased intake of legumes ($r = -0.38$; $P < 0.0001$) and decreased intake of total meat, fish, and poultry ($r = +0.43$; $P < 0.0001$). Those consuming a low-fat vegan diet also increased their intake of carbohydrates, fiber, and several micronutrients and decreased fat intake. Reduced fat intake was associated with reduced body weight ($r = +0.15$; $P = 0.02$) and, after adjustment for changes in BMI and energy intake, with reduced fat mass ($r = +0.14$; $P = 0.04$). The intervention group's AHEI-2010 increased by 6.0 points on average, in contrast to no significant change in the control group (treatment effect, +7.2

[95% CI +3.7 to +10.7]; $P < 0.001$). Increase in AHEI-2010 correlated with reduction in body weight ($r = 0.14$; $P = 0.04$), fat mass ($r = -0.14$; $P = 0.03$), and insulin resistance as measured by the Homeostasis Model Assessment (HOMA-IR; $r = -0.17$; $P = 0.02$), after adjustment for changes in energy intake.

Conclusions When compared with participants' usual diets, intake of plant foods increased, and consumption of animal foods, nuts and seeds, and added fats decreased on a low-fat vegan diet. Increased legume intake was the best single food group predictor of weight loss. Diet quality as measured by AHEI-2010 improved on the low-fat vegan diet, which was associated with improvements in weight and metabolic outcomes. These data suggest that increasing low-fat plant foods and minimizing high-fat and animal foods is associated with decreased body weight and fat loss, and that a low-fat vegan diet can improve measures of diet quality and metabolic health.

J Acad Nutr Diet. 2022;122(10):1922-1939.

LOW-FAT VEGAN AND VEGETARIAN DIETS HAVE BEEN consistently shown to reduce body weight and increase insulin sensitivity in randomized trials up to 74 weeks long.[1-3] Such diets necessarily change the types and amounts of food groups consumed; reduce intakes of energy, fat, and protein; increase intakes of carbohydrate and fiber[4]; and modify the intake of many micronutrients, raising the question as to which of these changes is responsible for the observed metabolic effects.[5,6]

Meta-analyses of prospective studies analyzing food group intakes have found a lower risk of chronic disease and improved intermediate disease markers with decreased consumption of food groups such as red and processed meat and eggs, and increased intakes of fruits, vegetables, legumes, whole grains, and nuts.[7-10] A low-fat vegan diet is characterized by the elimination of animal products and minimization of oil, nuts, and seeds; thus, the diet is predominantly made up of fruits, vegetables, whole grains, and legumes.[11] A low-fat vegan diet would thus likely change food group intake in ways that may be protective.

Diet quality, estimated by the Alternative Healthy Eating Index (AHEI), has been shown to significantly improve on a low-fat vegan diet.[6] Higher AHEI scores have been associated with lower risk of chronic disease, including cardiovascular disease,[12] diabetes,[13] and total and cardiovascular mortality.[14]

The aim of this secondary analysis of data from a 16-week randomized clinical trial in overweight adults was to determine the effects of a low-fat vegan diet on food group intake, nutrient intake, and diet quality, and to identify potential associations with changes in body weight, body composition, and insulin sensitivity. It was hypothesized that consuming a low-fat vegan diet would increase food groups representing fiber-rich plant foods, decrease food groups representing animal products and refined foods, change nutrient intake, and improve diet quality as measured by AHEI-2010. It was also hypothesized that these changes would be associated with improvements in body weight, body composition, and insulin sensitivity.

RESEARCH SNAPSHOT

Research Question: How do food group intake, nutrient intake, and diet quality change relative to usual-diet controls after 16 weeks on a low-fat vegan diet, and what associations do these changes have with body weight, body composition, and measures of metabolic health?

Key Findings: Intake of fruits, vegetables, legumes, meat alternatives, and whole grains increased, while consumption of animal foods, nuts and seeds, and added fats decreased on a low-fat vegan diet. Intake of carbohydrates, fiber, and several micronutrients also increased, and diet quality improved, as measured by the Alternative Healthy Eating Index 2010 (AHEI-2010). Increases in fruit, legume, meat alternative, and whole grain intake and decreases in animal products, added oils, and animal fats were associated with weight loss. Increases in AHEI-2010 scores were associated with decreases in body weight, fat mass, and insulin resistance after adjustment for changes in energy intake.

METHODS

Study Design and Eligibility

Methods and the primary outcomes (body weight, insulin sensitivity, postprandial metabolism, and intramyocellular and hepatocellular lipid levels) have been described in detail previously.[15] The study was conducted between October 2016 and December 2018 in Washington, DC, in four replications using a single-center, randomized, open parallel design. Otherwise healthy individuals with a body mass index (BMI) between 28 and 40 were enrolled. Exclusion criteria were history of diabetes, smoking, or alcohol or drug abuse; expected pregnancy or lactation; and current use of a vegan diet. From 3,115 people screened over the phone, 244 completed the baseline assessment and were randomized. Of 244 participants who were randomized, 91% (n = 222) completed the entire study, and food record data were available at both baseline and 16 weeks for 90% (n = 219). Only those with food records available were included in this analysis (n = 219; 117 in the vegan group and 102 in the control group). Enrollment and study completion are shown in Figure 1. The study protocol was approved by the Chesapeake Institutional Review Board. All participants gave written informed consent. Trial Registration was ClinicalTrials.gov number NCT02939638.

Randomization and Study Groups

The participants were randomly assigned in a 1:1 ratio to an intervention group (n = 122) or a control group (n = 122).

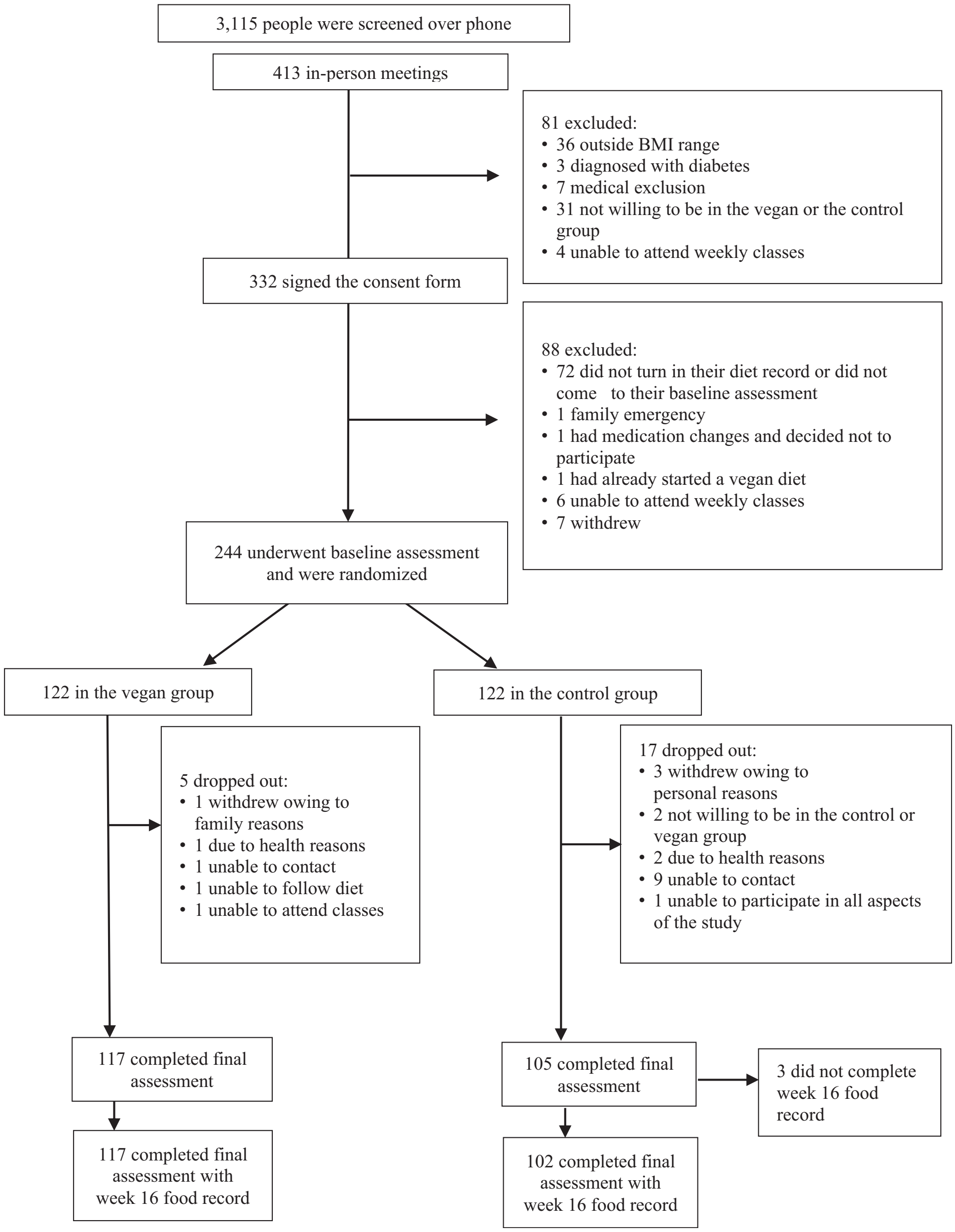

Figure 1. Flow diagram of enrollment of participants in a 16-week clinical trial of 244 overweight adults comparing a low-fat vegan diet with usual diet.

The intervention group was asked to follow a low-fat vegan diet, without energy restriction, consisting of vegetables, grains, legumes, and fruits and to avoid animal products and added fats. They received weekly 1-hour classes in the research center in Washington, DC, where the research staff (physicians, registered dietitians, and study coordinators) provided diet instruction, recipes, and group discussion. Attendance in the classes was recorded, and weekly weights were monitored but not considered in the data analysis. Daily fat intake was limited to 20 to 30 g. No meals were provided. Vitamin B_{12} was supplemented.

Control group participants were asked to maintain their current diets, which typically included animal products, and they received no classes. In both groups, alcoholic beverages were limited to one per day for women and two per day for men. Participants were examined at baseline and 16 weeks.

Dietary Intake, Physical Activity, and Anthropometrics

A 3-day dietary record (2 weekdays and 1 weekend day) was completed at baseline and at 16 weeks. The participants were asked to list all the foods and beverages consumed within the 3 days and estimate the amounts consumed. The diet records were reviewed by registered dietitians and research staff trained in Nutrition Data System for Research (NDSR) software. To reflect the marketplace throughout the study,

Reported food group	Subgroups included[a]
Fruit juice	FRU0100: Citrus juice FRU0200: Fruit juice excluding citrus juice
Whole fruit	FRU0300: Citrus fruit FRU0400: Fruit excluding citrus fruit
Avocado	FRU0500: Avocado and similar
Dark green vegetables	VEG0100: Dark green vegetables
Total nonstarchy vegetables (nonfried)	VEG0100: Dark green vegetables VEG0200: Deep yellow vegetables VEG0300: Tomato VEG0600: Other vegetables
Total starchy vegetables (nonfried)	VEG0400: White potatoes VEG0450: Other starchy vegetables (eg, cassava, corn, green peas, jicama)
Total fried vegetables	VEG0900: Fried vegetables VEG0800: Fried potatoes
Legumes	VEG0700: Legumes (cooked dried beans; excludes soy products)
Meat alternatives	MOF0700: Meat alternatives (includes veggie burgers, tofu, tempeh, TVP, soynuts)
Total legumes and meat alternatives	VEG0700: Legumes MOF0700: Meat alternatives
Whole grains[b]	Whole grains (ounce equivalents)
Refined grains[b]	Refined grains (ounce equivalents)
Nuts and seeds	MOF0500: Nuts and seeds MOF0600: Nut and seed butters
Eggs	MOF0300: Eggs
Total high-fat dairy (≥2% fat by weight)	DMF0100: Milk—whole (3.5%) DMR0100: Milk—reduced fat (2%) DCF0100: Cheese—full fat DCR0100: Cheese—reduced fat (natural and processed (8%—16%), part skim mozzarella, 2% cottage) FCF0100: Cream (light [20%], regular whipping [31%], heavy whipping [37%], regular sour cream) FCR0100: Cream—reduced fat (half and half [10%—12%], sour half and half, reduced fat sour cream) DYF0100: Yogurt—sweetened whole milk (3%—4% fat) DYF0200: Yogurt—artificially sweetened whole milk
Total low-fat dairy (<2% fat by weight)	DML0100: Milk—low fat and fat free (1%, skim) DCL0100: Cheese—low fat and fat free FCL0100: Cream—low fat and fat free DYR0100: Yogurt—sweetened low fat (1%—2% fat) DYL0100: Yogurt—sweetened fat free (<1% fat) DYR0200: Yogurt—artificially sweetened low fat DYL0200: Yogurt—artificially sweetened fat free
Total meat	

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Figure 2. Subgroups contained within food groups reported in a 16-week clinical trial of 219 overweight adults comparing a low-fat vegan diet with usual diet.

Reported food group	Subgroups included[a]
	MOF0100: Organ meats MCF0100: Cold cuts and sausage (fresh and cured) MRF0100: Beef MRF0200: Veal MRF0300: Lamb MRF0400: Fresh pork MCF0200: Cured pork MCL0100: Lean cold cuts and sausage (fresh and cured, ≤10% fat) MRL0100: Lean beef (≤10% fat) MRL0200: Lean veal (≤10% fat) MRL0400: Lean fresh pork (≤10% fat) MCL0200: Lean cured pork (≤10% fat) MRL0300: Lean lamb (≤10% fat) MRF0500: Game
Total fish and shellfish	MFF0100: Fish—fresh and smoked MFL0100: Lean fish—fresh and smoked (<10% fat) MSL0100: Shellfish MFF0200: Fried fish—commercial entrée and fast food MSF0100: Fried shellfish—commercial entrée and fast food
Total poultry	MPF0100: Poultry MPL0100: Lean poultry (≤10% fat) MPF0200: Fried poultry
Total meat, fish, and poultry	Total meat Total fish Total poultry
Added sugars	Added sugars (grams, by total sugars)
Added oils	FOF0100: Oil (including sprays) FDF0100: Salad dressing—regular
Added animal fats	FAF0100: Butter and other animal fats—regular FAR0100: Butter and other animal fats—reduced fat

[a]Unless otherwise noted, food subgroups listed are defined by the Nutrition Coordinating Center (NCC) Food Group Serving Count System within the Nutrition Data System for Research (NDSR), version 2017, with serving sizes based on the 2000 Dietary Guidelines for Americans or Food and Drug Administration (FDA) Guidelines.[16]

[b]United States Department of Agriculture (USDA) Food Pattern equivalents, as described in (NCC) Food Group Serving Count System within the Nutrition Data System for Research (NDSR), version 2017.

Figure 2. *(continued)* Subgroups contained within food groups reported in a 16-week clinical trial of 219 overweight adults comparing a low-fat vegan diet with usual diet.

dietary intake data were collected using NDSR software versions 2016, 2017, and 2018, developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN.[16] Final calculations were completed at the end of each replication with the same NDSR version used for collection. For food items missing from the program, a data entry was created to match the macronutrient content and the source of the macronutrients in the given food. Selected individual food subgroups output by NDSR were combined for analysis, as described in Figure 2. Included were food groups linked to health outcomes, for example, as described in the 2015-2020 Dietary Guidelines for Americans (eg, vegetables, fruits, whole and refined grains, dairy, protein foods, and oils) or subgroups within these groups (eg, dark green vegetables, legumes, high-fat dairy, low-fat dairy),[17] as well as other food subgroups likely to change when consuming a low-fat vegan diet (eg, meat, fish, poultry, soy-based meat alternatives, starchy vegetables, fried vegetables). In NDSR, serving sizes are based on the 2000 Dietary Guidelines for Americans, except for those foods not included in the recommendations,

Table 1. Relative contribution of food groups to weight loss for food groups with significant correlations with changes in body weight in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet with usual diet[a]

Food group	Parameter estimate for a 1-kg weight loss	Parameter estimate for a 1-kg weight loss, adjusted for energy intake
Whole fruit	+3.3; $P = 0.02$	+3.3; $P = 0.02$
Legumes	+1.5; $P = 0.01$	+1.4; $P = 0.02$
Total meat, fish, and poultry	−2.6; $P < 0.001$	−2.7; $P < 0.001$
High-fat dairy	−2.2; $P = 0.02$	−2.4; $P = 0.04$
Added oils	−2.4; $P = 0.002$	−2.6; $P = 0.006$

[a]A multivariable model was used to determine the relative contribution of food groups to weight loss. Results are presented as a change in daily serving intake associated with a 1-kg decrease in body weight, for each food group included in the final multivariable regression model. Results are presented first unadjusted, and then adjusted for energy intake.

Table 2. Relative contribution of food groups and macronutrients to weight loss for food groups and macronutrients with significant correlations with changes in body weight in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet with usual diet[a]

Food group	Parameter estimate for a 1-kg weight loss
Total meat, fish, and poultry	−3.0; $P = 0.005$
High-fat dairy	−2.8; $P = 0.09$
Added oils	−3.9; $P = 0.08$
Total fat (g/day)	−30.8; $P = 0.006$
Total fiber (g/day)	+13.9; $P < 0.001$
Total cholesterol (mg/day)	+290.7; $P = 0.12$

[a]A multivariable model was used to determine the relative contribution of food groups and macronutrients to weight loss. The results are presented as a change in daily serving intake (or in otherwise specified units) associated with a 1-kg decrease in body weight, for each variable included in the final multivariable regression model.

for which Food and Drug Administration serving sizes have been used. Whole and refined grain ounce-equivalents are defined per the USDA Food Patterns Equivalents Database.

AHEI-2010, the most recent update of the AHEI, was used to evaluate diet quality in this vegan diet intervention, because, unlike the Healthy Eating Index, AHEI separately categorizes and scores plant-based protein-rich foods (eg, beans, tofu, nuts) and does not penalize exclusion of dairy.[14] AHEI may also predict type 2 diabetes as well as or better than the Healthy Eating Index,[18] suggesting AHEI may be more relevant to insulin resistance, one of the outcomes of interest.

AHEI-2010 scores were calculated for each participant in the following categories: vegetables (servings/day), fruit (servings/day), whole grains (servings/day), sugar-sweetened beverages and fruit juice (servings/day), nuts and legumes (servings/day), red or processed meat (servings/day), trans fat (percentage of energy), and sodium (mg/day). Each of these categories received a score ranging from 0 to 10.[14] Alcohol use was not included in the analysis, because both groups were instructed to limit alcohol intake.

All study participants were asked not to alter their exercise habits and to continue their preexisting medication regimens for the duration of the study, except as modified by their personal physicians. Medication and supplement use was evaluated at baseline and week 16, and the participants were asked to report any changes that occurred during the study. Physical activity was assessed by the International Physical Activity Questionnaire.[19]

Outcomes

All measurements were performed at baseline and 16 weeks on an outpatient basis after a 10- to 12-hour overnight water-only fast. Height and weight were measured using a stadiometer and a periodically calibrated scale accurate to 0.1 kg in light clothing without shoes. Body composition was assessed using a dual-energy X-ray absorptiometry scan (GE Healthcare, Chicago, IL).

Plasma concentrations of glucose, immunoreactive insulin, and C-peptide were assessed at 0, 30, 60, 120, and 180 minutes after stimulation with a liquid breakfast (Boost Plus, Nestle, Vevey, Switzerland; 720 kcal, 34% of energy from fat, 16% protein, 50% carbohydrate). Serum glucose was analyzed using the Hexokinase UV endpoint method (Roche, Basel, Switzerland). Plasma immunoreactive insulin and C-peptide concentrations were determined using insulin and C-peptide electro-chemiluminescence immunoassay kits (Roche, Basel, Switzerland). PREDIcted M (PREDIM) index was calculated as a measure of dynamic postprandial insulin sensitivity and has been previously validated against clamp-derived measures of insulin sensitivity.[20] The Homeostasis Model Assessment (HOMA-IR) index was used to assess insulin resistance while fasting.[21]

Statistical Analysis

The analysis included all participants with available data for both baseline and 16 weeks for each outcome analyzed (n = 219). Data were assessed for approximate normality. A repeated-measure analysis of variance model that included the factors group, subject, and time was used to test the between-group differences throughout the 16-week study. Interaction between group and time was calculated for each variable. The treatment effect size is the difference in outcomes, from baseline to week 16, between the vegan and control groups. Within each diet group, paired comparison *t* tests were calculated to test whether the change from baseline to 16 weeks was significantly different from 0. Spearman correlations were calculated for the relationship between changes in food group intake, nutrient intake, AHEI-2010 score, and changes in body weight, body composition, and insulin

Table 3. Baseline characteristics of 219 overweight adults who completed the final assessment with week 16 food records in a 16-week clinical trial comparing a low-fat vegan diet to usual diet

Characteristic	Vegan group (n = 117)	Control group (n = 102)	*P* Value[a]
Age, y (mean ± SD)	52.6 (±12.8)	56.5 (±9.7)	0.01
Sex, n (%)			0.70
Female	100 (85.5)	89 (87.3)	
Male	17 (14.5)	13 (12.7)	
Race, n (%)			0.07
White	55 (47.0)	52 (51.0)	
Black	57 (48.7)	42 (41.2)	
Asian, Pacific Islander	1 (0.9)	6 (5.9)	
American Indian, Eskimo, Aleut	2 (1.7)	0 (0.0)	
Did not disclose	2 (1.7)	2 (2.0)	
Ethnicity, n (%)			0.31
Non-Hispanic	92 (78.6)	87 (85.3)	
Hispanic	8 (6.8)	4 (3.9)	
Did not disclose	17 (14.5)	11 (10.8)	
Marital status, n (%)			0.84
Not married	62 (53.0)	50 (49.0)	
Married	54 (46.2)	46 (45.1)	
N/A	1 (0.9)	6 (5.9)	
Education, n (%)			0.15
High school or less	7 (6.0)	8 (7.8)	
Some college	18 (15.4)	20 (19.6)	
College degree	20 (17.1)	23 (22.5)	
Graduate degree or more	71 (60.7)	51 (50.0)	
Unknown	1 (0.9)	0 (0.0)	
Occupation, n (%)			0.19
Service occupation	26 (22.2)	12 (11.8)	
Technical, sales, administrative	32 (27.4)	27 (26.5)	
Professional or managerial	33 (28.2)	34 (33.3)	
Retired	14 (12.0)	20 (19.6)	
Other	12 (10.3)	9 (8.8)	
Medications, n (%)			
Lipid-lowering therapy	22 (18.8)	17 (16.7)	0.68
Antihypertensive therapy	31 (26.5)	27 (26.5)	1.0
Thyroid medications	15 (12.8)	12 (11.8)	0.81

[a]*P*-values refer to *t* tests for continuous variables and χ^2 or Fisher's exact test for categorical variables. The *P*-value calculated for ethnicity distribution is for the comparison between Hispanic and non-Hispanic categories (and all other comparisons also exclude "did not disclose" data points).

sensitivity. For the food group analysis, Bonferroni correction for multiple comparisons was used for four outcomes in 24 food groups, first unadjusted, then adjusted for changes in BMI and energy intake, at $P = 0.05/(4 \times 24 \times 2) = 0.0003$. The relative contribution of food groups and nutrients to weight loss was evaluated using linear regression. Stepwise model selection, entering the most strongly predictive candidate factor with a *P*-value < 0.15 for entry into the current model, was used to construct multivariable models shown in Tables 1 and 2. Change in energy intake was forced into models denoted as energy-intake adjusted.

Table 4. Changes in food group intake, nutrient intake, and AHEI-2010 with body weight and composition, and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a]

	Control Group		Vegan Group			
	Baseline	**Week 16**	**Baseline**	**Week 16**	**Treatment Effect[b]**	***P* value**
Anthropometrics						
Body weight (kg)	92.7 (90.0-95.4)	92.2 (89.5-95.0)	93.6 (91.1-96.1)	87.2 (84.9-89.6)***	−5.9 (−6.8 to −5.0)	<0.001
BMI[c]	33.7 (32.9-34.4)	33.5 (32.7-34.2)	33.3 (32.6-34.0)	31.1 (30.4-31.8)***	−2.0 (−2.4 to −1.7)	<0.001
Fat mass (kg)	41.1 (39.2-43.0)	41.1 (39.2-43.1)	40.5 (38.8-42.2)	36.5 (34.8-38.2)***	−4.1 (−4.7 to −3.5)	<0.001
VAT[d] volume (cm^3)	1,538.9 (1,360.5-1,717.4)	1,549.8 (1,367.8-1,731.8)	1,439.8 (1,271.1-1,608.6)	1,212.4 (1,067.8-1,356.9)***	−238.3 (−316.7 to −159.9)	<0.001
Insulin Resistance						
HOMA[e] (dimensionless)	2.7 (2.3-3.1)	3.2 (2.4-4.0)	3.2 (2.7-3.6)	2.4 (1.9-2.8)**	−1.2 (−2.2 to −0.3)	0.008
PREDIM[f]	4.39 (4.07-4.71)	4.20 (3.86-4.53)	4.05 (3.79-4.31)	4.74 (4.43-5.04)***	+0.87 (+0.55 to +1.20)	<0.001
Physical Activity						
Physical activity (MET min/week[g])	2,851.0 (2,213.1-3,488.9)	2,218.9 (1,651.3-2,786.5)	2,915.6 (1,916.2-3,914.9)	2,271.6 (1,738.9-2,804.3)	−11.9 (−1,075.6 to +1,051.9)	0.983
Food Group Intake[h,i] (servings/day)	**Baseline**	**Week 16**	**Baseline**	**Week 16**	**Treatment Effect**	***P* value**
Fruit juice	0.3 (0.2-0.4)	0.2 (0.1-0.3)	0.2 (0.1-0.3)	0.3 (0.2-0.4)	+0.1 (−0.1 to +0.3)	0.265
Whole fruit	1.4 (1.2-1.6)	1.6 (1.2-2.0)	1.5 (1.2-1.8)	2.5 (2.2-2.8)***	+0.7 (+0.2 to +1.3)	0.008
Avocado	0.1 (0.1-0.2)	0.1 (0.1-0.1)	0.1 (0.1-0.1)	0.0 (0.0-0.0)***	−0.1 (−0.1 to 0.0)	0.049
Dark green vegetables	1.1 (0.8-1.4)	1.1 (0.9-1.3)	1.0 (0.8-1.2)	1.2 (1.0-1.4)	+0.1 (−0.3 to +0.5)	0.530
Total nonstarchy vegetables—nonfried	3.4 (2.9-3.8)	3.5 (3.1-3.8)	3.3 (2.9-3.6)	4.4 (4.0-4.9)***	+1.1 (+0.4 to +1.8)	0.003
Total starchy vegetables—nonfried	0.3 (0.2-0.4)	0.3 (0.2-0.4)	0.3 (0.2-0.4)	0.6 (0.4-0.7)**	+0.3 (+0.1 to +0.5)	0.005
Total fried vegetables	0.1 (0.1-0.2)	0.1 (0.1-0.2)	0.2 (0.1-0.3)	0.1 (0.0-0.1)*	−0.1 (−0.3 to 0.0)	0.017
Legumes	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	1.1 (0.9-1.3)***	+0.8 (+0.5 to +1.0)	<0.001
Meat alternatives	0.4 (0.2-0.6)	0.4 (0.2-0.6)	0.4 (0.2-0.5)	1.3 (1.0-1.6)***	+1.0 (+0.6 to +1.4)	<0.001
Total legumes and meat alternatives	0.8 (0.6-1.1)	0.7 (0.5-1.0)	0.7 (0.5-1.0)	2.4 (2.0-2.7)	+1.7 (+1.3 to +2.2)	<0.001
Whole grains (oz eq)	2.0 (1.7-2.3)	1.6 (1.3-1.9)*	1.8 (1.6-2.1)	2.9 (2.6-3.3)***	+1.5 (+1.0 to +2.0)	<0.001
Refined grains (oz eq)	3.8 (3.3-4.2)	3.5 (3.1-4.0)	4.4 (3.9-4.9)	3.6 (3.1-4.0)**	−0.6 (−1.4 to +0.2)	0.160
Nuts and seeds	1.0 (0.7-1.3)	0.9 (0.6-1.1)	0.9 (0.6-1.2)	0.2 (0.1-0.3)***	−0.6 (−1.1 to −0.2)	0.006

(*continued on next page*)

Table 4. Changes in food group intake, nutrient intake, and AHEI-2010 with body weight and composition, and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a] (*continued*)

	Control Group		Vegan Group			
	Baseline	Week 16	Baseline	Week 16	Treatment Effect[b]	*P* value
Nut and seed butters	0.3 (0.2-0.5)	0.2 (0.2-0.3)	0.2 (0.1-0.2)	0.1 (0.1-0.2)	+0.1 (−0.1 to +0.2)	0.608
Eggs	0.6 (0.4-0.7)	0.5 (0.4-0.7)	0.6 (0.4-0.7)	0.0 (0.0-0.0)***	−0.5 (−0.7 to −0.3)	<0.001
Total high-fat dairy	1.0 (0.8-1.2)	0.8 (0.6-1.0)	1.2 (0.9-1.4)	0.0 (0.0-0.0)***	−0.9 (−1.3 to −0.6)	<0.001
Total low-fat dairy	0.2 (0.1-0.2)	0.2 (0.1-0.3)*	0.2 (0.1-0.4)	0.0 (0.0-0.0)***	−0.3 (−0.4 to −0.2)	<0.001
Total meat (oz)	1.2 (0.9-1.5)	1.3 (1.0-1.6)	1.0 (0.8-1.2)	0.0 (0.0-0.0)***	−1.1 (−1.5 to −0.7)	<0.001
Total fish and shellfish (oz)	0.8 (0.6-1.0)	0.9 (0.6-1.2)	0.9 (0.6-1.1)	0.0 (0.0-0.1)***	−1.0 (−1.4 to −0.6)	<0.001
Total poultry (oz)	1.4 (1.1-1.7)	1.3 (1.0-1.6)	1.6 (1.3-1.9)	0.0 (0.0-0.0)***	−1.5 (−2.0 to −1.0)	<0.001
Total meat, fish, and poultry (oz)	3.4 (3.0-3.8)	3.5 (3.0-4.0)	3.5 (3.0-3.9)	0.1 (0.0-0.1)***	−3.5 (−4.2 to −2.9)	<0.001
Added sugars (g)	40.9 (34.2-47.6)	38.0 (31.5-44.4)	42.9 (36.3-49.5)	29.4 (25.3-33.4)***	−10.6 (−19.5 to −1.6)	0.021
Added oils	1.9 (1.6-2.2)	2.1 (1.8-2.4)	2.1 (1.8-2.4)	1.0 (0.8-1.2)***	−1.4 (−1.9 to −0.8)	<0.001
Added animal fats	0.7 (0.4-1.0)	0.8 (0.4-1.2)	0.7 (0.4-0.9)	0.0 (0.0-0.1)***	−0.7 (−1.1 to −0.3)	0.002
Macronutrient Intake						
Energy (kcal)	1,790 (1,666-1,914)	1,656 (1,546-1,766)*	1,834 (1,729-1,940)	1,343 (1,259-1,427)***	−357 (−522 to −192)	*P* < 0.001
Total fat (g)	76 (69-83)	70 (63-76)	75 (70-80)	26 (24-28)***	−43 (−51 to −35)	*P* < 0.001
Total carbohydrate (g)	208 (193-222)	193 (179-207)*	220 (206-235)	244 (227-260)*	+38 (+14 to +62)	*P* = 0.002
Total protein (g)	70 (65-75)	68 (63-73)	71 (67-76)	45 (42-49)***	−24 (−31 to −17)	*P* < 0.001
Animal protein (g)	40 (36-44)	39 (35-44)	41 (37-44)	2 (1-3)***	−38 (−45 to −32)	*P* < 0.001
Vegetable protein (g)	30 (28-32)	29 (26-31)	31 (28-33)	44 (40-47)***	+14 (+10 to +18)	*P* < 0.001
Alcohol (g)	6 (4-9)	4 (3-6)*	5 (3-7)	3 (2-4)**	−1 (−3 to +2)	*P* = 0.64
Cholesterol (mg)	247 (214-280)	233 (198-267)	239 (212-265)	6 (4-7)***	−219 (−265 to −173)	*P* < 0.001
Total SFA[j] (g)	23 (20-25)	21 (18-23)	24 (21-26)	5 (5-6)***	−16 (−20 to −13)	*P* < 0.001
Total MUFA[k] (g)	28 (25-31)	25 (23-28)*	27 (25-29)	8 (8-9)***	−16 (−19 to −13)	*P* < 0.001
Total PUFA[l] (g)	19 (17-21)	18 (16-20)	18 (17-20)	10 (9-10)***	−8 (−10 to −5)	*P* < 0.001
Total fiber (g)	24 (22-26)	23 (21-25)	24 (22-26)	35 (32-37)***	+11 (+8 to +15)	*P* < 0.001
Soluble fiber (g)	6 (6-7)	7 (6-7)*	7 (6-7)	9 (8-10)***	+2 (0 to +3)	*P* = 0.004
Insoluble fiber (g)	18 (16-19)	16 (15-18)	17 (16-19)	26 (24-27)***	+10 (+7 to +12)	*P* < 0.001

(*continued on next page*)

Table 4. Changes in food group intake, nutrient intake, and AHEI-2010 with body weight and composition, and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a] (*continued*)

	Control Group		Vegan Group			
	Baseline	Week 16	Baseline	Week 16	Treatment Effect[b]	*P* value
Micronutrient Intake						
Antioxidant vitamins						
Total vitamin A activity (μg)	825 (711-939)	834 (748-921)	853 (766-939)	866 (756-977)	+4 (−173 to +181)	$P = 0.97$
Beta-carotene equiv. (μg)	6,165 (4,857-7,473)	6,570 (5,569-7,571)	6,102 (5,106-7,098)	8,748 (7,435-10,061)***	+2,241 (+263 to +4,220)	$P = 0.03$
Beta-carotene (μg)	5,703 (4,504-6,901)	6,021 (5,119-6,923)	5,639 (4,696-6,582)	8,026 (6,818-9,235)***	+2,070 (+238.6 to +3,901)	$P = 0.03$
Retinol (μg)	311 (274-349)	287 (252-322)	344 (301-388)	137 (107-167)***	−183 (−245 to −121)	$P < 0.001$
Vitamin C (mg)	90 (79-102)	99 (81-117)	92 (82-103)	133 (117-150)***	+33 (+8 to +57)	$P = 0.009$
Vitamin E (IU)	16 (14-18)	16 (14-18)	17 (15-18)	14 (13-16)*	−2 (−5 to 0)	$P = 0.09$
Vitamin K (μg)	217 (180-254)	222 (197-247)	252 (207-296)	276 (226-327)	+20 (−57 to +96)	$P = 0.62$
B vitamins						
Vitamin B6 (mg)	1.7 (1.5-1.8)	1.7 (1.5-1.8)	1.8 (1.7-1.9)	1.9 (1.6-2.3)	+0.1 (−0.2 to +0.5)	$P = 0.48$
Vitamin B12 (μg)	3.1 (2.6-3.6)	3.1 (2.8-3.5)	3.3 (3.0-3.7)	1.2 (0.9-1.6)***	−2.1 (−2.9 to −1.4)	$P < 0.001$
Total folate (μg)	390 (356-424)	377 (351-403)	402 (369-435)	484 (444-523)**	+94 (+36 to +153)	$P = 0.002$
Natural folate (μg)	295 (264-326)	282 (259-305)	281 (255-308)	375 (340-410)***	+107 (+60 to +155)	$P < 0.001$
Synthetic folate (μg)	95 (80-111)	95 (79-111)	121 (101-141)	109 (90-127)	−13 (−44 to +19)	$P = 0.43$
Niacin (mg)	19.0 (17.7-20.4)	18.8 (17.5-20.0)	20.0 (18.7-21.4)	16.1 (13.9-18.3)**	−3.7 (−6.5 to −0.9)	$P = 0.01$
Riboflavin (mg)	1.7 (1.6-1.8)	1.7 (1.6-1.8)	1.8 (1.6-1.9)	1.7 (1.3-2.0)	−0.1 (−0.5 to +0.2)	$P = 0.47$
Thiamin (mg)	1.5 (1.4-1.6)	1.5 (1.4-1.6)	1.6 (1.4-1.7)	2.2 (1.8-2.5)***	+0.6 (+0.2 to +1.0)	$P = 0.001$
Minerals and vitamin D						
Calcium (mg)	737 (673-800)	721 (656-787)	793 (720-867)	623 (577-669)***	−155 (−260 to −51)	$P = 0.004$
Magnesium (mg)	315 (291-339)	298 (276-320)	314 (292-336)	343 (321-365)*	+46 (+12 to +80)	$P = 0.008$
Phosphorus (mg)	1,123 (1,048-1,198)	1,085 (1,016-1,155)	1,143 (1,075-1,212)	875 (814-936)***	−231 (−340 to −122)	$P < 0.001$
Potassium (mg)	2,579 (2,399-2,759)	2,484 (2,342-2,626)	2,629 (2,475-2,784)	2,774 (2,592-2,956)	+240 (−21 to +500)	$P = 0.07$
Sodium (mg)	2,768 (2,563-2,972)	2,605 (2,394-2,815)	2,784 (2,593-2,975)	2,422 (2,229-2,614)**	−199 (−526 to +127)	$P = 0.23$
Vitamin D (μg)	3.4 (2.8-3.9)	4.3 (3.5-5.1)	5.0 (4.0-5.9)	1.4 (1.1-1.7)***	−4.5 (−5.9 to −3.1)	$P < 0.001$
Iron (mg)	13 (12-14)	12 (11-13)	14 (13-15)	15 (14-16)*	+2.3 (+0.7 to +4.0)	$P = 0.007$
Manganese (mg)	4.2 (3.9-4.6)	3.9 (3.5-4.3)	4.2 (3.9-4.6)	5.7 (5.3-6.1)***	+1.8 (+1.2 to +2.4)	$P < 0.001$
Selenium (mg)	98 (90-106)	94 (86-101)	99 (92-105)	64 (58-69)***	−31 (−42 to −19)	$P < 0.001$
Zinc (mg)	9.2 (8.4-10.1)	8.5 (7.9-9.2)	9.5 (8.7-10.2)	7.0 (6.5-7.5)***	−1.7 (−2.8 to −0.6)	$P = 0.003$

(*continued on next page*)

Table 4. Changes in food group intake, nutrient intake, and AHEI-2010 with body weight and composition, and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a] (*continued*)

	Control Group		Vegan Group			
	Baseline	**Week 16**	**Baseline**	**Week 16**	**Treatment Effect**[b]	***P* value**
Copper (mg)	1.38 (1.24-1.53)	1.32 (1.20-1.44)	1.43 (1.32-1.55)	1.59 (1.49-1.69)*	+0.22 (+0.04 to +0.40)	*P* = 0.01
Other						
Caffeine (mg)	121 (102-140)	122 (99-144)	116 (96-136)	98 (79-118)*	−19 (−43 to +6)	*P* = 0.13
Alternative Healthy Eating Index 2010 (AHEI-2010)[m]						
AHEI total score	62.9 (60.3-65.5)	61.7 (59.1-64.3)	62.3 (59.9-64.7)	68.3 (67.0-69.7)***	+7.2 (+3.7 to +10.7)	*P* < 0.001
AHEI fruits score	3.0 (2.5-3.4)	3.1 (2.5-3.6)	3.1 (2.6-3.6)	4.7 (4.2-5.2)***	+1.4 (+0.6 to +2.3)	*P* = 0.001
AHEI vegetables score	7.5 (7.0-8.1)	8.0 (7.5-8.5)	7.7 (7.2-8.3)	8.9 (8.5-9.2)***	+0.6 (−0.2 to +1.4)	*P* = 0.12
AHEI nuts and legumes score	6.9 (6.1-7.7)	6.5 (5.7-7.3)	6.5 (5.8-7.2)	9.1 (8.7-9.6)***	+3.0 (+1.9 to +4.2)	*P* < 0.001
AHEI red/processed meat score	6.9 (6.2-7.5)	6.7 (5.9-7.4)	7.2 (6.6-7.8)	10.0 (10.0-10.0)***	+3.0 (+2.1 to +3.9)	*P* < 0.001
AHEI trans fat score	8.7 (8.3-9.0)	8.8 (8.5-9.1)	8.7 (8.4-9.0)	9.9 (9.8-10.0)***	+1.0 (+0.5 to +1.6)	*P* < 0.001
AHEI long-chain fatty acids score	3.8 (3.1-4.5)	3.9 (3.2-4.6)	4.3 (3.6-5.0)	0.2 (0.02-0.4)***	−4.2 (−5.2 to −3.1)	*P* < 0.001
AHEI PUFA score	8.1 (7.7-8.5)	8.2 (7.8-8.6)	7.6 (7.2-8.0)	5.3 (4.7-5.8)***	−2.4 (−3.3 to −1.6)	*P* < 0.001
AHEI sugar-sweetened beverages and fruit juice score	6.6 (5.8-7.4)	6.9 (6.1-7.7)	6.5 (5.7-7.3)	7.2 (6.5-7.9)	+0.4 (−0.7 to +1.6)	*P* = 0.46
AHEI whole grains score	6.3 (5.7-7.0)	5.0 (4.3-5.7)**	5.6 (5.0-6.3)	7.9 (7.4-8.4)***	+3.6 (+2.5 to +4.7)	*P* < 0.001
AHEI sodium score	5.0 (4.4-5.6)	4.7 (4.1-5.3)	5.0 (4.4-5.6)	5.3 (4.7-5.9)	+0.7 (−0.3 to +1.7)	*P* = 0.18

[a]Data are means with 95% confidence intervals. Listed *P* values are for interaction between group and time assessed by repeated measures analysis of variance (ANOVA). **P* < 0.05, ***P* < 0.01, and ****P* < 0.001 for within-group changes from baseline assessed by paired comparison *t* tests.

[b]The treatment effect size is the difference in mean improvement in outcomes, from baseline to week 16, between the vegan and control group, calculated with a *t*-test.

[c]BMI = body mass index.

[d]VAT = visceral adipose tissue.

[e]HOMA = Homeostatic Model Assessment for Insulin Resistance.

[f]PREDIM = PREDIcted M.

[g]MET = metabolic equivalent.

[h]As measured by 3-day dietary record (2 weekdays and 1 weekend day) at baseline and at 16 weeks

[i]Food groups are defined in Figure 2, made up of individual or multiple relevant food subgroups from the 168 defined by the Nutrition Coordinating Center (NCC) Food Group Serving Count System within the Nutrition Data System for Research (NDSR), version 2017. Serving sizes are based on the 2000 Dietary Guidelines for Americans, except for those foods not included in the recommendations, for which Food and Drug Administration serving sizes have been used. Whole and refined grain ounce-equivalents are defined per the USDA Food Patterns Equivalents Database.[16]

[j]SFA = saturated fatty acid.

[k]MUFA = monounsaturated fatty acid.

[l]PUFA = polyunsaturated fatty acid.

[m]Alternative Healthy Eating Index 2010 (AHEI-2010) AHEI-2010 is used to assess dietary quality based on foods and nutrients linked to chronic disease risk. Higher scores are associated with lower chronic disease risk. AHEI-2010 scores were calculated for each participant in the AHEI categories listed in the table, as well as in total. Each category receives a score from 0 to 10. Total AHEI-2010 score is calculated by summarizing the category scores; total scores can thus range from 0-100.[14] Alcohol use was excluded from the AHEI-2010 scores reported here, because both groups were instructed to limit alcohol.

Table 5. Changes in food group intake and changes in anthropometric and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a,b]

Food Group[c]	⊿ Body weight (kg)	⊿ Fat mass (kg)	⊿ VAT[d] volume (cm^3)	⊿ HOMA[e] (dimensionless)
Fruit juice	$r = -0.02; P = 0.766$ $r = -0.04; P = 0.525$[f]	$r = -0.05; P = 0.461$ $r = -0.01; P = 0.858$[g]	$r = -0.03; P = 0.626$ $r = -0.01; P = 0.829$[g]	$r = 0.07; P = 0.330$ $r = 0.10; P = 0.160$[g]
Whole fruit	**$r = -0.25; P = 0.0002$** $r = -0.24; P = 0.0004$[f]	$r = -0.22; P = 0.0013$ $r = -0.03; P = 0.617$[g]	$r = -0.08; P = 0.226$ $r = 0.06; P = 0.349$[g]	$r = -0.08; P = 0.257$ $r = 0.00; P = 0.985$[g]
Avocado	$r = 0.06; P = 0.372$ $r = 0.05; P = 0.501$[f]	$r = 0.14; P = 0.044$ **$r = 0.26; P < 0.0001$**[g]	$r = 0.08; P = 0.226$ $r = 0.08; P = 0.258$[g]	$r = 0.01; P = 0.865$ $r = 0.01; P = 0.931$[g]
Dark green vegetables	$r = -0.10; P = 0.158$ $r = -0.08; P = 0.218$[f]	$r = -0.11; P = 0.123$ $r = -0.08; P = 0.255$[g]	$r = -0.07; P = 0.333$ $r = -0.02; P = 0.769$[g]	$r = -0.13; P = 0.085$ $r = -0.11; P = 0.128$[g]
Total nonstarchy vegetables—nonfried	$r = -0.17; P = 0.011$ $r = -0.18; P = 0.009$[f]	$r = -0.18; P = 0.007$ $r = -0.10; P = 0.136$[g]	$r = -0.12; P = 0.089$ $r = -0.04; P = 0.606$[g]	$r = -0.12; P = 0.101$ $r = -0.07; P = 0.374$[g]
Total starchy vegetables—nonfried	$r = -0.16; P = 0.022$ $r = -0.17; P = 0.013$[f]	$r = -0.13; P = 0.052$ $r = 0.02; P = 0.792$[g]	$r = -0.08; P = 0.270$ $r = 0.01; P = 0.859$[g]	$r = 0.02; P = 0.780$ $r = 0.08; P = 0.285$[g]
Total fried vegetables	$r = 0.13; P = 0.059$ $r = 0.09; P = 0.163$[f]	$r = 0.12; P = 0.071$ $r = 0.01; P = 0.902$[g]	$r = 0.08; P = 0.227$ $r = 0.00; P = 0.95$[g]	$r = 0.08; P = 0.294$ $r = 0.06; P = 0.449$[g]
Legumes	**$r = -0.38; P < 0.0001$** **$r = -0.39; P < 0.0001$**[f]	**$r = -0.39; P < 0.0001$** $r = -0.04; P = 0.531$[g]	**$r = -0.25; P = 0.0002$** $r = -0.01; P = 0.851$[g]	$r = -0.09; P = 0.215$ $r = 0.06; P = 0.445$[g]
Meat alternatives	**$r = -0.25; P = 0.0002$** $r = -0.22; P = 0.001$[f]	$r = -0.23; P = 0.0006$ $r = -0.06; P = 0.356$[g]	$r = -0.17; P = 0.011$ $r = -0.04; P = 0.566$[g]	$r = -0.08; P = 0.243$ $r = -0.01; P = 0.885$[g]
Total legumes & meat alternatives	**$r = -0.40; P < 0.0001$** **$r = -0.38; P = < 0.0001$**[f]	**$r = -0.39; P < 0.0001$** $r = -0.09; P = 0.204$[g]	**$r = -0.29; P < 0.0001$** $r = -0.07; P = 0.294$[g]	$r = -0.14; P = 0.056$ $r = -0.01; P = 0.93$[g]
Whole grains	**$r = -0.28; P < 0.0001$** **$r = -0.29; P = < 0.0001$**[f]	**$r = -0.25; P = 0.0002$** $r = -0.01; P = 0.921$[g]	$r = -0.13; P = 0.053$ $r = 0.03; P = 0.655$[g]	$r = -0.16; P = 0.029$ $r = -0.08; P = 0.297$[g]
Refined grains	$r = 0.14; P = 0.041$ $r = -0.03; P = 0.704$[f]	$r = 0.15; P = 0.028$ $r = 0.05; P = 0.507$[g]	$r = 0.12; P = 0.081$ $r = -0.02; P = 0.794$[g]	$r = 0.00; P = 0.986$ $r = -0.03; P = 0.649$[g]
Nuts and seeds	$r = 0.14; P = 0.039$ $r = 0.12; P = 0.080$[f]	$r = 0.15; P = 0.027$ $r = 0.11; P = 0.111$[g]	$r = 0.10; P = 0.149$ $r = 0.03; P = 0.641$[g]	$r = 0.11; P = 0.142$ $r = 0.07; P = 0.335$[g]
Nut and seed butters	$r = 0.00; P = 0.971$ $r = 0.02; P = 0.763$[f]	$r = -0.02; P = 0.825$ $r = -0.02; P = 0.796$[g]	$r = 0.09; P = 0.213$ $r = 0.12; P = 0.087$[g]	$r = 0.02; P = 0.798$ $r = 0.01; P = 0.84$[g]
Eggs	**$r = 0.28; P < 0.0001$** $r = 0.22; P = 0.001$[f]	$r = 0.24; P = 0.0003$ $r = 0.01; P = 0.898$[g]	$r = 0.23; P = 0.0005$ $r = 0.08; P = 0.24$[g]	$r = -0.06; P = 0.379$ $r = -0.15; P = 0.035$[g]
Total high-fat dairy	**$r = 0.31; P < 0.0001$** $r = 0.22; P = 0.0009$[f]	**$r = 0.29; P < 0.0001$** $r = 0.00; P = 0.951$[g]	$r = 0.18; P = 0.007$ $r = -0.05; P = 0.454$[g]	$r = 0.00; P = 0.950$ $r = -0.13; P = 0.079$[g]
Total low-fat dairy	$r = 0.20; P = 0.004$ $r = 0.17; P = 0.013$[f]	$r = 0.19; P = 0.006$ $r = 0.00; P = 0.985$[g]	$r = 0.13; P = 0.061$ $r = 0.00; P = 0.981$[g]	$r = 0.12; P = 0.096$ $r = 0.05; P = 0.524$[g]
Total meat	$r = 0.22; P = 0.0009$ $r = 0.16; P = 0.020$[f]	$r = 0.16; P = 0.016$ $r = -0.14; P = 0.039$[g]	$r = 0.14; P = 0.047$ $r = -0.04; P = 0.599$[g]	$r = 0.10; P = 0.153$ $r = 0.04; P = 0.58$[g]
Total fish and shellfish	$r = 0.24; P = 0.0004$ $r = 0.19; P = 0.005$[f]	$r = 0.23; P = 0.0006$ $r = 0.01; P = 0.922$[g]	$r = 0.11; P = 0.116$ $r = -0.07; P = 0.294$[g]	$r = 0.10; P = 0.160$ $r = 0.03; P = 0.665$[g]
Total poultry	**$r = 0.32; P < 0.0001$** **$r = 0.28; P < 0.0001$**[f]	$r = 0.25; P = 0.0003$ $r = -0.12; P = 0.071$[g]	$r = 0.17; P = 0.012$ $r = -0.04; P = 0.536$[g]	$r = 0.17; P = 0.021$ $r = 0.07; P = 0.32$[g]
Total meat, fish, and poultry	**$r = 0.43; P < 0.0001$** **$r = 0.36; P < 0.0001$**[f]	**$r = 0.38; P < 0.0001$** $r = -0.09; P = 0.204$[g]	$r = 0.23; P = 0.0006$ $r = -0.08; P = 0.229$[g]	$r = 0.21; P = 0.003$ $r = 0.09; P = 0.195$[g]
Added sugars	$r = 0.13; P = 0.053$ $r = -0.03; P = 0.675$[f]	$r = 0.10; P = 0.141$ $r = 0.03; P = 0.688$[g]	$r = 0.09; P = 0.184$ $r = -0.02; P = 0.765$[g]	$r = 0.08; P = 0.256$ $r = 0.08; P = 0.247$[g]

(*continued on next page*)

Table 5. Changes in food group intake and changes in anthropometric and metabolic outcomes in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet to usual diet[a,b] (*continued*)

Food Group[c]	Δ Body weight (kg)	Δ Fat mass (kg)	Δ VAT[d] volume (cm^3)	Δ HOMA[e] (dimensionless)
Added oils	**$r = 0.34$; $P < 0.0001$**	**$r = 0.30$; $P < 0.0001$**	$r = 0.25$; $P = 0.0003$	$r = -0.07$; $P = 0.367$
	$r = 0.26$; $P = 0.0001$[f]	$r = 0.02$; $P = 0.785$[g]	$r = 0.04$; $P = 0.577$[g]	$r = -0.20$; $P = 0.007$[g]
Added animal fats	**$r = 0.28$; $P < 0.0001$**	**$r = 0.27$; $P < 0.0001$**	$r = 0.20$; $P = 0.004$	$r = 0.15$; $P = 0.043$
	$r = 0.22$; $P = .001$[f]	$r = 0.04$; $P = 0.609$[g]	$r = 0.02$; $P = 0.808$[g]	$r = 0.07$; $P = 0.355$[g]

[a]Reported as Spearman correlations.
[b]Bonferroni correction for multiple comparisons was used for 4 outcomes in 24 food groups, first unadjusted, then adjusted for changes in energy intake (Δ body weight only) and in BMI and energy intake (remaining outcomes), at the $P = 0.05/(4 \times 24 \times 2) = 0.0003$.
[c]Food groups are defined in Figure 2, using food subgroups defined by the Nutrition Coordinating Center (NCC) Food Group Serving Count System within the Nutrition Data System for Research (NDSR), version 2017, with serving sizes based on the 2000 Dietary Guidelines for Americans or Food and Drug Administration (FDA) Guidelines, with the exception of whole and refined grain ounce-equivalents, which NDSR defines per the USDA Food Patterns Equivalents Database.[16]
[d]VAT = Visceral adipose tissue
[e]HOMA = Homeostatic model assessment for insulin resistance
[f]Correlation coefficient after adjusting for changes in energy
[g]Correlation coefficient after adjusting for changes in energy and BMI

RESULTS

Participant Characteristics

Baseline characteristics of participants who completed the study and provided both baseline and 16-week food records (n = 219) are shown in Table 3. Most participants were female, and participants randomized to the vegan group were younger than control group participants (52.6 ± 12.8 years vs 56.5 ± 9.7 years; $P = 0.01$).

Table 6. Magnitude of treatment effect for food groups with significant correlations with changes in body weight in 219 overweight adults in a 16-week clinical trial comparing a low-fat vegan diet with usual diet

Food group	Δ Daily servings per 1-kg weight loss	Δ Daily servings per 1-kg weight loss, adjusted for energy intake
Whole fruit	+2.0; $P < 0.001$	+2.0; $P < 0.001$
Legumes	+0.8; $P < 0.001$	+0.7; $P < 0.001$
Total meat, fish, and poultry	-1.7; $P < 0.001$	-1.9; $P < 0.001$
Meat alternatives	+2.1; $P = 0.009$	+2.2; $P = 0.01$
Legumes and meat alternatives	+1.5; $P < 0.001$	+1.4; $P < 0.001$
Whole grains	+2.2; $P = 0.002$	+2.0; $P < 0.001$
Eggs	-0.8; $P = 0.002$	-1.0; $P = 0.01$
High-fat dairy	-1.2; $P < 0.001$	-1.5; $P = 0.003$
Added oils	-1.5; $P < 0.001$	-1.8; $P < 0.001$
Added animal fats	-2.1; $P = 0.008$	-2.6; $P = 0.03$

Body Weight, Body Composition, Insulin Sensitivity, and Physical Activity

Data on physical activity, body composition, insulin sensitivity, food group intake, nutrient intake, and AHEI-2010 are shown in Table 4. No statistically significant change in physical activity was observed in either group. Associations between food group intake, body weight, body composition, and insulin sensitivity are shown in Table 5.

Body weight, fat mass, and visceral fat volume decreased in the vegan group, but not the control group. Treatment effects were −5.9 kg; 95% CI, −6.8 to −5.0 for body weight; −4.1 kg; 95% CI, −4.7 to −3.5 for fat mass; and −238.3 cm^3; 95% CI, −316.7 to −159.9 for visceral fat volume; $P < 0.001$ for all. Insulin resistance as measured by HOMA-IR decreased as a result of the vegan intervention (treatment effect, −1.2; 95% CI, −2.2 to −0.3; $P = 0.008$), and insulin sensitivity, measured by PREDIM, improved (treatment effect, +0.87; 95% CI, +0.55 to +1.20; $P < 0.001$).

FOOD GROUP INTAKE

Fruits and Vegetables

Whole fruit intake increased as a result of the vegan diet intervention (treatment effect, +0.7 servings/day; 95% CI, +0.2 to +1.3; $P = 0.008$). Increased intake of whole fruit was associated with a decrease in body weight ($r = -0.25$, $P = 0.0002$). Intake of total nonstarchy and starchy vegetables also increased (respective treatment effects, +1.1 servings/day; 95% CI, +0.4 to +1.8; $P = 0.003$ and +0.3 servings/day; 95% CI, +0.1 to +0.5; $P = 0.005$), but increased vegetable intake was not significantly associated with weight loss.

Legumes and Meat Alternatives

Compared with controls, the vegan group increased intake of legumes (treatment effect, +0.8 servings/day; 95% CI, +0.5 to +1.0; $P < 0.001$) and meat alternatives, including tofu, tempeh, and veggie burgers (treatment effect, +1.0 servings/day; 95% CI, +0.6 to +1.4; $P < 0.001$). Increased legume consumption was associated with decreased weight ($r = -0.38$; $P < 0.0001$), fat mass ($r = -0.39$; $P < 0.0001$), and visceral adipose tissue ($r = -0.25$; $P = 0.0002$). Consuming more meat alternatives was associated with a decrease in body weight ($r = -0.25$; $P = 0.0002$).

Grains, Nuts, and Seeds

Whole grain intake decreased in the control group but increased in the vegan group (treatment effect, +1.5 oz Eq/day; 95% CI, +1.0 to +2.0; $P < 0.001$). Increased consumption of whole grains was associated with decreased body weight ($r = -0.28$; $P < 0.0001$) and fat mass ($r = -0.25$; $P = 0.0002$). Refined grain intake decreased only in the vegan group, with no significant difference between vegan and control groups (treatment effect, −0.6 oz Eq/day; 95% CI, −1.4 to +0.2; $P = 0.160$). Intake of whole nuts and seeds decreased in the vegan group compared with controls (treatment effect, −0.6 servings/day; 95% CI, −1.1 to −0.2; $P = 0.006$).

Eggs and Dairy Products

Relative to controls, the vegan group decreased intake of eggs, high-fat dairy products, and low-fat dairy products (treatment effect for eggs, −0.5 servings/day; 95% CI, −0.7 to −0.3; $P < 0.001$; high-fat dairy, −0.9 servings/day; 95% CI, −1.3 to −0.6; $P < 0.001$, and low-fat dairy, −0.3 servings/day; 95% CI, −0.4 to −0.2). Decreased egg intake was correlated with decreased weight ($r = 0.28$; $P < 0.0001$), and decreased high-fat dairy intake was associated with decreased weight ($r = 0.31$; $P < 0.0001$) and fat mass ($r = 0.29$; $P < 0.0001$).

Meat, Fish, and Poultry

Intake of total meat, fish/shellfish, and poultry decreased in the vegan group relative to controls (treatment effect, −3.5 servings/day; 95% CI, −4.2 to −2.9; $P < 0.001$). Reductions in the combined intake of total meat, fish, and poultry were associated with weight loss ($r = 0.43$; $P < 0.0001$) and a decrease in fat mass ($r = 0.38$; $P < 0.0001$).

Added Fats

Intake of added oils and animal fats decreased significantly as a result of the vegan intervention (treatment effect, −1.4 servings/day; 95% CI, −1.9 to −0.8; $P = <0.001$ for added oils and −0.7 servings/day; 95% CI, −1.1 to −0.3; $P = 0.002$ for added animal fats). Decreases in intake of added animal fats were associated with decreases in weight ($r = 0.28$; $P < 0.0001$) and fat mass ($r = 0.27$; $P < 0.0001$). Decreased intake of added oils also correlated with decreases in weight ($r = 0.34$; $P < 0.0001$) and fat mass ($r = 0.30$; $P < 0.0001$).

Food Group Contributions to Weight Loss

Exploratory treatment effects for food groups associated with weight loss are listed in Table 6. The following were significantly associated with a 1-kg weight loss in 16 weeks: increasing whole fruit consumption by 2.0 servings/day, legumes by 0.8 servings/day, meat alternatives by 2.1 servings/day, combined legumes and meat alternatives by 1.5 servings/day, and whole grains by 2.2 servings/day, and, conversely, decreasing consumption of total meat, fish, and poultry by 1.7 servings/day, eggs by 0.8 servings/day, high-fat dairy by 1.2 servings/day, added oils by 1.5 servings/day, and added animal fats by 2.1 servings/day. The relative contribution of food groups to weight loss, evaluated in a multivariable regression model constructed in a stepwise fashion using all food groups in Table 6 as candidate predictors, is shown in Table 1. The relative contribution of both food groups and nutrients to weight loss is shown in the exploratory multivariable model in Table 2.

Energy and Nutrient Intake

Although both groups reported decreased energy intake, the vegan group consumed significantly less energy, fat, saturated fat, cholesterol, and protein than the control group ($P < 0.001$ for all), but more carbohydrates ($P = 0.002$) and fiber ($P < 0.001$). Decreases in fat intake correlated with decreases in body weight ($r = +0.50$; $P < 0.001$), fat mass ($r = +0.46$; $P < 0.001$), and visceral fat volume ($r = +0.36$; $P < 0.001$), whereas insulin sensitivity, as measured by PREDIM, tended to improve with decreased fat intake ($r = -0.23$; $P = 0.002$). The macronutrient distribution of the vegan group was approximately 70%, 15%, and 15% energy from carbohydrate, fat, and protein, respectively.

Compared with the control group, the vegan group had significantly greater mean intakes of beta-carotene, vitamin C, lycopene, folate, thiamin, magnesium, iron, manganese, copper, phytic acid, and isoflavones, and significantly lower intakes of retinol, vitamin B_{12}, niacin, calcium, phosphorus, vitamin D, selenium, choline, and zinc ($P < 0.05$ for all).

DIET QUALITY

The vegan group's AHEI-2010 increased by 6.0 points on average in contrast to no significant change in the control group (treatment effect +7.2 [95% CI +3.7 to +10.7]; $P < 0.001$). This increase was attributable to an increased (improved) score in the following categories: fruits, vegetables, nuts and legumes, red/processed meat, trans fat, and whole grains. In contrast, the score decreased for polyunsaturated fatty acids and long-chain fatty acids because of decreased fat intake in the vegan group. Increases in AHEI-2010 scores were associated with decreases in body weight ($r = -0.20$; $P = 0.003$), fat mass ($r = -0.14$; $P = 0.03$), and HOMA-IR ($r = -0.17$; $P = 0.02$). That is, as AHEI-2010 score increased, weight, fat mass, and insulin resistance decreased.

DISCUSSION

This secondary analysis examined how food group intake, nutrient intake, and diet quality changed after a 16-week, low-fat vegan diet intervention and determined whether those changes were associated with changes in body weight, body composition, and insulin sensitivity. Adopting a low-fat vegan diet resulted in substantial changes in food group and nutrient intake. It also resulted in improved diet quality, which was associated with weight loss, fat loss, and improved insulin sensitivity. Individual food groups correlated only with weight or fat loss; any associations with insulin sensitivity lost significance after Bonferroni correction. This secondary analysis thus helps illuminate which food groups and nutrients may have had the greatest contribution to the beneficial body composition outcomes seen in the primary trial[15] and could inform future interventional research.

To the authors' knowledge, this is the first study to examine the relationship between changes in food group intake and weight and metabolic outcomes in the context of a low-fat vegan diet. Those in the vegan group significantly increased legume intake, and consuming more legumes was the best single-food-group predictor of weight and fat loss. A 2015 meta-analysis of randomized controlled trials found that eating one serving of pulses daily reduced body weight by 1.74 kg on diets designed for weight loss (negative energy balance) and 0.29 kg on diets designed for weight maintenance (neutral energy balance).[22] Legumes may support weight loss by increasing post-meal satiety,[23] possibly because of their high fiber[24] and protein content[25]; the soluble fiber in legumes also causes gel formation, slowing gastric emptying.[24] Beans also have been shown to trigger the release of appetite-reducing peptide YY and may influence gut microbiota in ways that promote satiety.[26] Legumes have been shown to improve glycemic control in previous research in type 2 diabetes[27,28]; the lack of correlation between legume intake and insulin sensitivity here may be attributable to the modest change in intake (treatment effect: +0.8 servings per day, or slightly less than 0.5 cups cooked beans) in a study population without diabetes. Increased intake of meat alternatives, a category containing predominantly soy products in the software used for dietary analysis, was also associated with decreased weight. Similar results were seen in a meta-analysis of 22 randomized controlled trials of 870 overweight participants showing that use of soy products reduced body weight, body fat percentage, and waist circumference.[29]

Decreases in body weight and fat mass associated with increased whole grain intake align with prior findings that diets high in whole grains are associated with favorable effects on weight status[30,31] and body composition.[32] No association was seen between refined grain intake and changes in body weight, in keeping with a 2019 meta-analysis of 43 prospective reports that found that high refined grain intake was not associated with weight gain, although high intakes (>90 g/day) were linked to a higher risk of overweight/obesity.[33]

The findings for whole fruit are essentially consistent with previous research linking whole fruit intake with weight loss[34] and decreases in body weight, waist circumference, and adiposity.[35] The lack of significant association observed between changes in nonstarchy vegetable intake and body composition or insulin sensitivity was unexpected, because prospective cohort data suggest an inverse relationship with body weight.[36,37] Although starchy vegetables such as potatoes have been linked in some prior studies to increased risk for diabetes,[37] starchy vegetables had no observed effect on body composition or insulin sensitivity in this study, perhaps because potatoes are commonly consumed fried,[37-39] and in this report nonfried starchy vegetables were analyzed independently.

Decreases in egg intake were associated with decreases in body weight, consistent with a previous study in which high egg intake was associated with an increased risk of weight gain by 54% compared with low egg consumption. Similarly, previous research has shown that each increase in egg intake of 50 g/day (approximately one egg) increased the risk of weight gain by 24%.[33] Similarly, decreased intake of high-fat dairy products was associated with reductions in body weight and fat mass, whereas low-fat dairy yielded no significant associations, consistent with a recent 12-week randomized clinical trial that showed weight gain when eating more than three servings/day of full-fat dairy and no significant change in body weight when consuming low-fat dairy. Interestingly, insulin sensitivity decreased with both full-fat and low-fat dairy in that 12-week trial.[40]

The association seen between reduced intake of total meat, fish, and poultry and reduced body weight and fat mass aligns with findings from the National Health and Nutrition Examination Survey, demonstrating that higher total meat consumption (which included red meat, poultry, fish and shellfish, and other meat products) was linked with higher BMI, waist circumference, obesity, and central obesity.[41] High consumption of poultry and red meat has been previously reported to increase the risk of weight gain,[42] and high red meat intake has been shown to increase the risk of obesity[43] and weight gain[33] as well as metabolic syndrome and abdominal obesity.[44,45] Results for fish have been mixed, with analysis of two studies showing decreased risk of abdominal obesity with fish intake, and other studies finding no effect on risk of weight gain or overweight/obesity.[33]

The lack of relationship between changes in the consumption of added sugars and changes in weight or metabolic outcomes in this study contrasts with the results of a 2012 meta-analysis of five randomized clinical trials, which found that decreasing intake of free sugars reduced body weight (−0.80 kg; $P < 0.001$).[46] The modest reduction in added sugar in the vegan group relative to control subjects (−10.6 g/d, or approximately −2.5 teaspoons) may partly explain the null findings. Decreasing dietary fat decreases the energy density of the diet, which has been linked to body weight reduction in both observational and clinical trials,[47,48] likely explaining the correlation between decreased added fat intake and weight loss.

As might be expected, nutrient intake changed substantially and in predictable ways. Those in the vegan group increased intakes of micronutrients commonly found in plant foods and decreased intakes of those found predominantly in animal foods. The mean intakes of both vegan and control groups met or exceeded the estimated average requirement (EAR)[49] for vitamin B6, folate, niacin, riboflavin, thiamin, vitamin C, and iron. As expected, the vegan group's mean intake of vitamin B12 from food did not meet the EAR, whereas the control group's did. Mean intakes of both groups fell short of the EAR for calcium and vitamin D. Regarding macronutrients, exploratory analyses conducted in this study suggest that substantially decreasing fat and increasing fiber promote weight loss, consistent with previous research.[50,51]

Diet quality findings from the current study align with previous studies. For example, a 22-week study in people with type 2 diabetes on a low-fat vegan diet showed significant increases in AHEI scores compared with a more conventional diabetes diet based on portion control. When data from both the low-fat vegan group and the portion-control group were pooled, AHEI was found to correlate with decreases in body weight and hemoglobin A1c.[6]

Study strengths include the 16-week, randomized parallel controlled trial design, which facilitated assessment of changes in food group intake and associations with body weight, body composition, and insulin sensitivity. The low attrition rate preserved statistical power and suggests the diet was sustainable. Despite the intervention diet being associated with improvements in insulin resistance and insulin sensitivity in this trial, after Bonferroni correction, no single food group correlated significantly with improvements in metabolic outcomes. Although this may be attributable to limitations of the study as described later, given that the low-fat vegan diet tested in the primary trial was associated with metabolic improvements,[15] these findings suggest that the additive effects of individual food groups support weight management and metabolic health.[52] The AHEI-2010 used in this study is a good measure of diet quality that has been previously correlated with the risk of chronic disease.[14]

The study also has limitations. Other than animal products and fats, the interventions in this trial did not regulate consumption of specific food groups, or total caloric or other intake. Therefore, the reported associations of food groups and nutrient intake must be interpreted with caution, even after adjustment for other factors. Participants' dietary intake was self-reported and thus subject to bias and imprecision.[53] Certain foods were missing from the NDSR database. Although data entries were created to match the macronutrient content and source of the missing foods, it was impossible to match micronutrients. Some commercial ingredients in these custom entries, such as yellow pea protein used in some meat substitutes, were not assignable to a specific food group, so were not included in food group serving counts. Participants were predominantly female, so repeating the study with increased male representation would be beneficial. Repeating this intervention and assessing post-intervention adherence and efficacy could provide useful longer-term data and insight into effectiveness outside the research setting. Study participants were willing to make a dietary change and therefore may not be representative of the whole population but are likely representative of individuals seeking clinical care. Finally, the use of a no-treatment control group allows for a possible influence of "attention placebo" in the intervention group, which could have affected their outcomes. Like all determinations of statistical significance, the Bonferroni correction is arbitrary and can create false negatives and thus should be interpreted with caution.

CONCLUSIONS

When compared with participants' usual diets, intake of fruits, vegetables, legumes, meat alternatives, and whole grains increased on a low-fat vegan diet, whereas consumption of animal foods, nuts and seeds, and added fats decreased. Increases in plant-based food groups tended to be associated with weight loss, with legumes being the single food group most associated with weight and fat loss. Decreases in added fats and animal-based food groups also tended to be associated with weight loss.

Diet quality as measured by AHEI-2010 improved on the low-fat vegan diet relative to no diet change and was associated with beneficial weight and metabolic changes. Overall, these data suggest that consuming more low-fat plant food and less high-fat and animal-derived food is associated with weight loss, and that a low-fat vegan diet intervention can improve diet quality and insulin sensitivity.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

L. Crosby, S. Levin, Z. Ali, D. N. Holtz, and H. Kahleova are employees of the Physicians Committee for Responsible Medicine, a nonprofit organization providing educational, research, and medical services related to nutrition. A. Green and M. Jardine are nutrition consultants for the Physicians Committee, and R. Holubkov is a biostatistical consultant for the Physicians Committee. M. Nguyen was an employee; P. Elliott, D. Goldstein, A. Freeman, and M. Bradshaw were clinical research interns; and E. Rembert was a clinical research consultant for the Physicians Committee when work on the paper commenced. L. Crosby declares that a trust for her benefit previously held stock in 3M, Abbot Labs, AbbVie, Johnson and Johnson, Mondelez, Nestle, and Walgreens; she is the author of a food and nutrition blog, *Veggie Quest;* and she is former publications editor and current chair of the Women's Health Dietetic Practice Group within the Academy of Nutrition and Dietetics.

FUNDING/SUPPORT

This work was funded by the Physicians Committee for Responsible Medicine.

AUTHOR CONTRIBUTIONS

L. Crosby and E. Rembert compiled the data. A. Green checked dietary data and ran nutrient analysis reports. R. Holubkov completed statistical analyses. L. Crosby, E. Rembert, N. D. Barnard, and H. Kahleova drafted the manuscript with contributions from S. Levin, Z. Ali, M. Jardine, M. Nguyen, P. Elliott, D. Goldstein, and A. Freeman, M. Bradshaw, and D. N. Holtz. All authors reviewed subsequent drafts of the manuscript.