Effects on blood lipids of a blood pressure–lowering diet: the Dietary Approaches to Stop Hypertension (DASH) Trial[1–3]

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ABSTRACT

Background: Effects of diet on blood lipids are best known in white men, and effects of type of carbohydrate on triacylglycerol concentrations are not well defined.

Objective: Our goal was to determine the effects of diet on plasma lipids, focusing on subgroups by sex, race, and baseline lipid concentrations.

Design: This was a randomized controlled outpatient feeding trial conducted in 4 field centers. The subjects were 436 participants of the Dietary Approaches to Stop Hypertension (DASH) Trial [mean age: 44.6 y; 60% African American; baseline total cholesterol: ≤6.7 mmol/L (≤260 mg/dL)]. The intervention consisted of 8 wk of a control diet, a diet increased in fruit and vegetables, or a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol (DASH diet), during which time subjects remained weight stable. The main outcome measures were fasting total cholesterol, LDL cholesterol, HDL cholesterol, and triacylglycerol.

Results: Relative to the control diet, the DASH diet resulted in lower total (−0.35 mmol/L, or −13.7 mg/dL), LDL- (−0.28 mmol/L, or −10.7 mg/dL), and HDL- (−0.09 mmol/L, or −3.7 mg/dL) cholesterol concentrations (all $P < 0.0001$), without significant effects on triacylglycerol. The net reductions in total and LDL cholesterol in men were greater than those in women by 0.27 mmol/L, or 10.3 mg/dL ($P = 0.052$), and by 0.29 mmol/L, or 11.2 mg/dL ($P < 0.02$), respectively. Changes in lipids did not differ significantly by race or baseline lipid concentrations, except for HDL, which decreased more in participants with higher baseline HDL-cholesterol concentrations than in those with lower baseline HDL-cholesterol concentrations. The fruit and vegetable diet produced few significant lipid changes.

Conclusions: The DASH diet is likely to reduce coronary heart disease risk. The possible opposing effect on coronary heart disease risk of HDL reduction needs further study. *Am J Clin Nutr* 2001;74:80–9.

KEY WORDS Diet, plasma total cholesterol, LDL cholesterol, HDL cholesterol, triacylglycerol, feeding study, Dietary Approaches to Stop Hypertension Trial, DASH

See corresponding editorial on page 1.

INTRODUCTION

Studies and meta-analyses have shown that replacement of saturated fats with carbohydrates, monounsaturated fats, or polyunsaturated fats reduces LDL cholesterol. Compared with carbohydrates, all types of fats raise HDL cholesterol (1, 2). In addition, carbohydrates raise triacylglycerol when substituted for any of the fats.

Despite extensive information, however, several important issues remain to be addressed. First, the effects of diet on blood lipids are known best in men. Several studies (3–6), but not all (7, 8), noted that blood lipids in women may be less responsive to diet than are blood lipids in men. Most studies had small numbers of women, and statistical comparisons of lipid responses between men and women were not always made. Second, there is even less information in African Americans because most studies enrolled whites or did not report results separately for different racial groups. Third, the effects of dietary carbohydrate on blood triacylglycerol may vary according to type of carbohydrate (9) as well as energy balance (10). It is well established that simple carbohydrates or mixtures of simple and complex carbohydrates raise triacylglycerol when substituted for fats (1).

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TABLE 1
Calculated nutrient content and food group servings of menus[1]

	Control diet	DASH diet	FV diet
Nutrient content (/d)[2]			
Protein (% of energy)	14	18	15
Total fat (% of energy)	37	27	37
Saturated	14	7	13
Monounsaturated	13	10	14
Polyunsaturated	7	8	7
Cholesterol (mg)	246	141	188
Carbohydrate (% of energy)	50	58	52
Fiber (g)	10.8	29.7	29.9
Soluble	3.7	9.4	8.5
Insoluble	6.7	20.0	21.3
Sucrose (g)	54.0	35.6	33.6
Keys score[3]	45.3	22.5	40.9
Potassium (mg)	1454	4589	4434
Calcium (mg)	379	1220	468
Magnesium (mg)	140	465	416
Food groups (servings/d)[4]			
Fruit and fruit juices	1.6	5.2	5.2
Vegetables	2.0	4.4	3.3
Grains			
Total	8.2	7.5	6.9
Whole	0	4.1	3.8
Low-fat dairy	0.1	2.0	0
Regular-fat dairy	0.4	0.7	0.3
Nuts, seeds, and legumes	0	0.7	0.6
Beef, pork, and ham	1.5	0.5	1.8
Poultry and fish	1.0	1.1	0.7
Fat, oils, and salad dressing	5.8	2.5	5.3
Snack foods and sweets	4.1	0.7	1.4

[1] DASH (Dietary Approaches to Stop Hypertension) diet, a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol; FV diet, a diet increased in fruit and vegetables.

[2] Protein; total, saturated, monounsaturated, and polyunsaturated fat; cholesterol; carbohydrate; potassium; calcium; and magnesium contents based on 8.8-MJ (2100-kcal) menus and calculated from Moore's Extended Nutrient database (version 1.0; Pennington Biomedical Research Foundation, Baton Rouge, LA). Total, soluble, and insoluble fiber and sucrose contents based on 8.8-MJ (2100-kcal) menus and calculated from the Nutrition Data System (version 2.8; University of Minnesota, Minneapolis).

[3] Calculated from individual intakes as estimated from study menus and daily diaries. Keys score (25) is $1.35 \times (2S - P) + 1.5\sqrt{C}$, where S is percentage of energy from saturated fat, P is percentage of energy from polyunsaturated fat, and C is mg dietary cholesterol per 4200 kJ.

[4] Based on 8.8-MJ (2100-kcal) menus.

What is not fully established is whether carbohydrate-rich foods that are rich in fiber, or that are digested slowly and produce a relatively mild increase in blood glucose and insulin, also raise triacylglycerol concentrations when substituted for dietary fat.

The Dietary Approaches to Stop Hypertension (DASH) Trial provided the opportunity to study each of these topics (11, 12). DASH was an outpatient controlled feeding study that tested the effects on blood pressure of 2 experimental dietary patterns compared with a control dietary pattern similar to what many Americans eat. Both diets differed from the control diet in the type of carbohydrates they contained. Relative to the control diet, each experimental diet contained less refined grains and sweets and more whole grains, fruit, and vegetables. The last 3 foods contain carbohydrates that have been proposed to have little effect on triacylglycerol (13). Because one-half of the 459 DASH participants were women and 60% were African American, the DASH data can be used to determine the effects of a reduced-fat, increased-carbohydrate diet on blood lipids under conditions of stable weight in these large but understudied segments of the US population. Because LDL and HDL cholesterol are independent risk factors for coronary heart disease (CHD) (14), and because triacylglycerol may be a risk factor for cardiovascular disease independent of HDL (15), this information is relevant for disease prevention programs.

SUBJECTS AND METHODS

Design

Four field centers, a coordinating center, and the National Heart, Lung, and Blood Institute collaborated on DASH. The rationale and design of the trial, as well as the main blood pressure results, were published previously (11, 12, 16). Briefly, after a 3-wk run-in period with the control diet, during which energy intakes required to maintain a stable weight were established, 459 participants were randomly assigned to consume 1 of 3 dietary patterns (described below) for an additional 8-wk intervention. The primary outcome was change in diastolic blood pressure from baseline to the end of the 8-wk intervention period. Changes in plasma lipids were important secondary outcomes and are the subject of this report.

Participants and methods

Participants were eligible for the trial if they were ≥22 y old and had mean diastolic blood pressure between 80 and 95 mm Hg and systolic blood pressure <160 mm Hg. Lipid exclusion criteria included fasting or nonfasting plasma total cholesterol >6.7 mmol/L (>260 mg/dL) or, on repeat testing, LDL cholesterol ≥4.1 mmol/L (160 mg/dL) or 3.4–4.1 mmol/L (130–159 mg/dL) with ≥2 other CHD risk factors. Other major exclusion criteria included poorly controlled diabetes mellitus, a cardiovascular event within the previous 6 mo, body mass index (in kg/m^2) >35, use of medications affecting blood pressure or nutrient metabolism, unwillingness to stop taking vitamin and mineral supplements or antacids containing magnesium or calcium, and an alcohol intake of >14 drinks/wk. Because of the disproportionate incidence of hypertension in minority populations, the study placed an emphasis on recruiting minority participants. Participants were recruited in 4–5 cohorts per center.

Dietary patterns

Shown in **Table 1** are the nutrient and food group content of the menus for the 3 dietary patterns used in the study, based on an energy intake of 9.9 MJ (2100 kcal). Actual mean (±SD) energy intakes of the participants during the 8-wk intervention were 11.1 ± 2.4 MJ (2649 ± 584 kcal), 11.0 ± 2.3 MJ (2624 ± 552 kcal), and 10.9 ± 2.3 MJ (2610 ± 550 kcal) for the control, fruit and vegetable (FV), and DASH dietary patterns, respectively.

The control dietary pattern reflected the consumption of macronutrients, fruit, vegetables, and dairy products typical of what many Americans eat. The FV dietary pattern was higher in fruit, vegetables, and whole grains and lower in sweets but had a macronutrient content similar to that of the control diet. The combination dietary pattern, termed the DASH diet, was also higher in fruit, vegetables, and whole grains and lower in sweets than the control diet. In addition, the DASH diet was higher in low-fat dairy foods and lower in red meat and fats. Compared with the control and FV diets, the DASH diet was lower in saturated fat, total fat, and cholesterol and higher in protein and calcium. The DASH and FV diets were both higher in fiber and lower in sucrose than the control diet. The menus were validated for nutrient content and consistency among the clinics by having meal composites chemically analyzed before the start of feeding and by monitoring the nutrient content during the study. A detailed description of the diets was published previously (12, 17, 18).

Study procedures

During the 3 wk of run-in and 8 wk of intervention feeding, the clinical centers provided participants with all of their meals and snacks according to a 7-d menu cycle. All clinics followed a common protocol to prepare the standardized menus in a research kitchen (19). Energy intakes were adjusted as needed to keep body weight constant. Participants attended the clinic each weekday to be weighed, to consume one meal on-site (lunch or dinner), and to pick up the balance of their meals and snacks. The participants picked up their weekend meals and snacks on Fridays. Participants were allowed to consume ≤3 nonalcoholic diet beverages (coffee, tea, and soft drinks) and ≤2 alcoholic beverages daily. Lists of permissible beverages were provided. Participants were requested not to change their habitual levels of physical activity for the duration of the study.

Measurements

All measurement staff were blinded to the diet assignments. Twelve-hour fasting blood samples were drawn toward the end of the run-in period and again at the end of the 8-wk intervention period. Blood was collected into tubes containing 0.1% EDTA and was centrifuged at 4°C and 500 × *g* for 10 min to separate the plasma. Frozen plasma was shipped to a central laboratory, the Oregon Health Sciences University Lipid-Atherosclerosis Laboratory, for analysis of total cholesterol, HDL cholesterol, and triacylglycerol. Lipoproteins were separated by preparative ultracentrifugation (100 000 × *g* and 4°C for 12 h) at a density of 1006 g/L and were precipitated with use of standardized techniques (20, 21). Enzymatic colorimetric methods (20) were used to determine the amounts of total cholesterol, HDL cholesterol, and triacylglycerol in plasma by using an automated analyzer (model 704; Hitachi, Indianapolis). No participant had a triacylglycerol concentration >4.5 mmol/L (400 mg/dL). All lipid determinations were standardized with samples of known composition obtained from the Centers for Disease Control and Prevention–National Heart, Lung, and Blood Institute Lipid Standardization Program (22). The interassay CVs of the control plasma samples were 2.5% for total cholesterol and 3.5% for triacylglycerol. The ratios of total to HDL cholesterol (TC:HDL) and of LDL to HDL cholesterol (LDL:HDL) were calculated.

During the screening, height and weight were measured while the participants wore light indoor clothing and no shoes. Body mass index was calculated as kg/m^2. Participants completed a food-frequency questionnaire (23, 24) to provide information on their usual food intake over the year before their entry into the trial; from this, we calculated a Keys score (25), which reflects the atherogenicity of the diet (26). Participants also provided information during the screening on their smoking habits, alcohol intake, and medication use. Physical activity information was obtained from a 7-d activity recall (27) completed during the screening and at the end of the intervention period. During the entire 11 wk of feeding, participants were instructed to keep a daily diary that was reviewed by study staff to keep track of the allowed beverages and diet deviations as well as consumption of standardized muffins and cookies (unit foods) that were provided as needed to maintain body weight (12, 28).

Moore's Extended Nutrient (MENu) database (version 1.0, 1994; Pennington Biomedical Research Foundation, Baton Rouge, LA) was used to calculate the energy, macronutrient, cholesterol, and mineral contents of the menus. The Nutrition Data System (NDS) database (version 2.8, 1995; University of Minnesota, Minneapolis) was used to calculate total dietary fiber, water soluble and insoluble fiber, and sucrose. Energy and nutrient intakes of individuals were obtained on the basis of the calculated nutrient content of the assigned diet's energy level and on the number of unit foods consumed. The energy value of alcoholic beverages was included.

Statistical methods

We used one-way analysis of variance and chi-square tests to determine the significance of any baseline differences between diet groups and between population subgroups defined by sex and race. Although we had no real hypothesis of interest regarding baseline differences between diet groups, these tests provide the reader with a quantitative measure of the homogeneity of the samples.

The primary outcome measures for this report were the changes in lipids from run-in to the end of the intervention. We used standard linear regression techniques to model these changes, adjusted for cohort, as a function of treatment. The differences in changes produced by the FV and DASH diets in comparison with the control diet were tested for significance by calculating the appropriate contrasts from the regression models. That is, the changes were expressed "net of control."

Because triacylglycerol concentrations were highly skewed, we used nonparametric statistics to summarize the baseline concentrations. The distribution of change in triacylglycerol appeared symmetrical, so we did not transform these change data in the regression analyses.

The primary analyses used linear regression models that tested differences in lipid changes between diets, adjusted only for cohort effects, and that did not include subgroup indicators. Subgroup-specific estimates of treatment effects were simultaneously examined by using models that included main effects of treatment, cohort, race (African Americans and non-African Americans), sex, and baseline lipid concentrations (dichotomized as above or below a cutoff, as defined below, for total, LDL, and HDL cholesterol and triacylglycerol) and interactions of treatment with race, sex, and baseline lipid concentration. (Only the specific baseline lipid concentration corresponding to the outcome variable was used in any given model.) These models thus allowed us to estimate treatment effects within any one subgroup variable (eg, effects in men and women) and to test whether these effects differed (eg, men compared with women) after adjustment for the effects of the other 2 subgroup variables.

Baseline total and LDL-cholesterol cutoffs indicating a high risk of CHD were chosen (14): a baseline total cholesterol concentration ≥5.2 mmol/L (≥200 mg/dL), comprising 41% of the study sample, and a baseline LDL-cholesterol concentration ≥3.4 mmol/L (≥130 mg/dL), comprising 42% of the study sample. Only 13% had HDL cholesterol <0.9 mmol/L (<35 mg/dL)

TABLE 2
Baseline characteristics of participants in the Dietary Approaches to Stop Hypertension (DASH) Trial, according to diet group[1]

	Control diet (n = 145)	DASH diet (n = 145)	FV diet (n = 146)	Overall (n = 436)
Age (y)	44.6 ± 11.3[2]	44.3 ± 10.1	45.1 ± 10.8	44.6 ± 10.7
Women (%)	46.2	51.7	48.6	48.9
African American (%)	59.3	61.4	58.9	59.9
Smoke (%)	7.6	9.0	14.4	10.3
Drink alcohol (%)	64.1	53.1	52.7	56.7
BMI (kg/m^2)	28.0 ± 3.8	28.5 ± 4.0	28.1 ± 4.0	28.2 ± 3.9
Physical activity score				
(kJ·kg^{-1}·d^{-1})	157 ± 27.6	157 ± 28.0	157 ± 27.6	157 ± 27.6
(kcal·kg^{-1}·d^{-1})	37.6 ± 6.6	37.5 ± 6.7	37.6 ± 6.6	37.6 ± 6.6
Currently receiving cholesterol medication (%)	0.7	0.7	0.7	0.7
Women currently receiving estrogen replacement therapy (%)[3]	15.2	13.3	14.1	14.2

[1] DASH diet, a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol; FV diet, a diet increased in fruit and vegetables. There were no significant differences at baseline between the 3 diet groups (one-way ANOVA or chi-square test).
[2] $\bar{x}$ ± SD.
[3] n = 67 in the control diet group (hormone use data available for 66 women), 75 in the DASH diet group, and 71 in the FV diet group.

and 7.1% had triacylglycerol ≥2.3 mmol/L (≥200 mg/dL), so cutoffs for HDL and triacylglycerol were based on study sample medians [1.2 mmol/L (45 mg/dL) for HDL and 1.2 mmol/L (94 mg/dL) for triacylglycerol].

We used the equations of Keys et al (29) and of Mensink and Katan (1) to calculate predicted changes in lipid concentrations on the basis of calculated changes in macronutrient and cholesterol intakes of the participants and compared these with observed changes. To compare differences between observed and predicted lipid values net of control, we subtracted from each of the 2 experimental groups the mean observed change in the control group. All statistical analyses were conducted with SAS (version 6.12; SAS Institute Inc, Cary, NC).

RESULTS

Baseline characteristics

This report is based on 436 participants (95% of the randomly assigned participants) who provided fasting blood samples both at baseline and at the end of the intervention. The participants' mean age was 44.6 y and ≈60% were African American, 6% were other minorities, and 34% were white. Baseline characteristics of these participants did not differ significantly across the 3 diet groups (**Table 2**). The participants were overweight and inactive (30). At baseline, only 3 persons, 1 in each diet group, were taking cholesterol-lowering medication and 30 women, 10 in each diet group, were taking estrogen replacement therapy.

A food-frequency questionnaire was completed reliably during screening by 88% (n = 383) of the study sample for whom lipid data were available (**Table 3**). Participants reported consuming ≈9.2 MJ (2190 kcal) as their habitual energy intake, but required 11.0 MJ (2630 kcal) for weight maintenance during the study. The participants' usual intakes of total fat, saturated fat, and polyunsaturated fat as a percentage of energy were within one percentage point of the content of the control diet, and their usual intake of carbohydrate as a percentage of energy was 4 percentage points lower than the content of the control diet.

There were no significant differences between the 3 diet groups in baseline lipid concentrations and lipid ratios (**Table 4**). African Americans had a significantly lower TC:HDL and significantly lower triacylglycerol concentrations at baseline than did non-African Americans (**Table 5**). Additionally, women had significantly lower concentrations of LDL cholesterol and triacylglycerol, a lower TC:HDL and LDL:HDL, and higher concentrations of HDL cholesterol at baseline than did men (Table 5).

Lipid changes with the DASH diet

Relative to the control diet, the DASH diet resulted in significantly lower mean (95% CI) total [−0.35 (−0.49, −0.22) mmol/L, or −13.7 (−18.8, −8.6) mg/dL], LDL [−0.28 (−0.40, −0.16) mmol/L, or −10.7 (−15.4, −6.0) mg/dL], and HDL [−0.09 (−0.13, −0.06) mmol/L, or −3.7 (−5.1, −2.2) mg/dL] cholesterol (**Figure 1**). These changes represented net reductions of 7.3%, 9.0%, and 7.5% in mean concentrations of total, LDL, and HDL cholesterol, respectively. No significant changes were observed for triacylglycerol [0.04 (−0.06, 0.13) mmol/L, or 3.2 (−5.1, 11.6) mg/dL], TC:HDL [−0.03 (−0.19, 0.13)], or LDL:HDL [−0.08 (−0.22, 0.06)].

The same patterns, ie, significant reductions in total, LDL, and HDL cholesterol, but no significant changes in TC:HDL, LDL:HDL (except a significant decrease in the LDL:HDL in men), or triacylglycerol, occurred in subgroups defined by race,

TABLE 3
Usual nutrient intakes of the participants before the study[1]

Nutrient	Usual intake
Protein (% of energy)	15 ± 2.7
Total fat (% of energy)	38 ± 7.6
Saturated	13 ± 2.9
Monounsaturated	14 ± 3.2
Polyunsaturated	8 ± 2.5
Cholesterol (mg)	335 ± 202
Carbohydrate (% of energy)	46 ± 8.0
Total dietary fiber (g)	14.8 ± 7.6
Keys score[2]	43.3 ± 9.9
Potassium (mg)	3089 ± 1252
Calcium (mg)	839 ± 433
Magnesium (mg)	397 ± 247

[1] $\bar{x}$ ± SD; n = 383. Usual dietary intake was assessed by food-frequency questionnaire during the screening.
[2] Calculated as described in Table 1.

TABLE 4
Lipid concentrations of participants in the Dietary Approaches to Stop Hypertension (DASH) Trial at baseline, by diet group[1]

	Control diet (*n* = 145)	DASH diet (*n* = 145)	FV diet (*n* = 146)
TC			
(mmol/L)	4.95 ± 0.87[2]	4.86 ± 0.88	5.04 ± 0.93
(mg/dL)	191.4 ± 33.8	187.9 ± 33.9	194.8 ± 36.1
LDL			
(mmol/L)	3.15 ± 0.82	3.06 ± 0.78	3.22 ± 0.84
(mg/dL)	121.7 ± 31.6	118.5 ± 30.2	124.4 ± 32.3
HDL			
(mmol/L)	1.25 ± 0.36	1.26 ± 0.40	1.24 ± 0.36
(mg/dL)	48.2 ± 14.0	48.6 ± 15.6	47.9 ± 13.9
TC:HDL	4.26 ± 1.30	4.15 ± 1.23	4.38 ± 1.48
LDL:HDL	2.74 ± 1.03	2.67 ± 1.04	2.85 ± 1.20
Triacylglycerol			
(mmol/L)	1.06 (0.77, 1.48)[3]	1.05 (0.79, 1.35)	1.10 (0.81, 1.56)
(mg/dL)	94 (68, 131)	93 (70, 120)	97.5 (72, 138)

[1] DASH diet, a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol; FV diet, a diet increased in fruit and vegetables. There were no significant differences at baseline between the 3 diet groups (one-way ANOVA). TC, total cholesterol.
[2] $\bar{x} \pm$ SD.
[3] Median; 25th and 75th percentiles in parentheses.

sex, and baseline lipid concentrations (**Table 6**). However, the reductions in total and LDL cholesterol and the changes in the TC:HDL and LDL:HDL differed significantly between men and women, with reductions in values being larger in men than in women. Adjusted for cohort, race, and baseline concentrations, men had 0.27-mmol/L (10.3 mg/dL) and 0.29-mmol/L (11.2 mg/dL) greater net reductions in total and LDL cholesterol, respectively, and greater net reductions in TC:HDL and LDL:HDL than did women. Changes in total cholesterol, LDL cholesterol, HDL cholesterol, cholesterol ratios, and triacylglycerol did not differ significantly by race. Changes in total cholesterol, LDL cholesterol, and triacylglycerol also did not differ significantly by baseline lipid concentrations. However, adjusted for cohort, race, and sex, reductions in HDL were greater by 0.11 mmol/L (4.1 mg/dL) in those whose baseline HDL concentrations were ≥1.2 mmol/L (≥45 mg/dL) than in those whose baseline concentrations were <1.2 mmol/L (<45 mg/dL). This significant interaction with baseline HDL concentrations persisted after we omitted several outlying observations. Shown in **Figure 2** are the scatter plots of the changes in LDL and HDL in relation to their respective baseline concentrations.

Lipid changes with the FV diet

Compared with those consuming the control diet, no significant reductions were observed in total [−0.10 (−0.23, 0.04) mmol/L, or −3.75 (−8.9, 1.4) mg/dL], LDL [−0.05 (−0.17, 0.07) mmol/L, or −1.9 (−6.6, 2.7) mg/dL], or HDL [−0.005 (−0.04, 0.030) mmol/L, or −0.2 (−1.6, 1.2) mg/dL] cholesterol in participants consuming the FV diet (Figure 1). Mean triacylglycerol concentrations tended to be reduced by −0.09 (−0.19, 0.002) mmol/L [−8.2 (−16.5, 0.2) mg/dL]. Changes in the TC:HDL of –0.14 (−0.29, 0.02) and in the LDL:HDL of –0.10 (−0.23, 0.04) also were not significant.

Compared with their counterparts consuming the control diet, men consuming the FV diet had a significantly reduced LDL:HDL, both men and non-African Americans consuming the FV diet had a significantly reduced TC:HDL, and participants with higher baseline triacylglycerol concentrations had significantly reduced triacylglycerol concentrations (Table 6). Although there were no other significant changes in

TABLE 5
Lipid concentrations of participant subgroups at baseline[1]

	Race		Sex		Baseline lipids[2]	
	African American (*n* = 261)	Non-African American (*n* = 175)	Women (*n* = 213)	Men (*n* = 223)	Lower	Higher
TC						
(mmol/L)	4.90 ± 0.91[3]	5.03 ± 0.87	4.97 ± 0.94	4.93 ± 0.85	4.35 ± 0.58	5.80 ± 0.49
(mg/dL)	189.4 ± 35.1	194.5 ± 33.8	192.2 ± 36.4	190.6 ± 33.0	168.3 ± 22.4	224.2 ± 18.9
LDL						
(mmol/L)	3.13 ± 0.83	3.16 ± 0.78	3.06 ± 0.83[4]	3.22 ± 0.79	2.59 ± 0.54	3.89 ± 0.43
(mg/dL)	121.0 ± 32.3	122.3 ± 30.2	118.3 ± 32.1	124.7 ± 30.5	100.3 ± 21.1	150.4 ± 16.6
HDL						
(mmol/L)	1.27 ± 0.38	1.21 ± 0.37	1.41 ± 0.40[5]	1.09 ± 0.26	0.96 ± 0.13	1.51 ± 0.33
(mg/dL)	49.3 ± 14.6	46.7 ± 14.2	54.6 ± 15.7	42.2 ± 10.0	37.2 ± 5.0	58.5 ± 12.8
TC:HDL	4.11 ± 1.25[6]	4.49 ± 1.43	3.73 ± 1.05[5]	4.77 ± 1.39	—	—
LDL:HDL	2.68 ± 1.08	2.86 ± 1.12	2.34 ± 0.90[5]	3.14 ± 1.12	—	—
Triacylglycerol						
(mmol/L)	0.97 (0.72, 1.26)[7,8]	1.26 (0.93, 1.72)	0.99 (0.72, 1.32)[5]	1.16 (0.87, 1.58)	0.77 (0.65, 0.91)	1.48 (1.19, 1.91)
(mg/dL)	86 (64, 112)	112 (82, 152)	88 (64, 117)	103 (77, 140)	68 (58, 81)	131 (105, 169)

[1] TC, total cholesterol.
[2] By definition, the distribution of baseline lipids differed for subgroups defined by lower and higher baseline lipid concentrations. Hence, no *P* values are provided for this subgroup. Lower is <5.2 mmol/L (<200 mg/dL) for TC (*n* = 256), <3.4 mmol/L (<130 mg/dL) for LDL (*n* = 251), <1.2 mmol/L (<45 mg/dL) for HDL (*n* = 210), and <1.06 mmol/L (<94 mg/dL) for triacylglycerol (*n* = 213). Higher is ≥5.2 mmol/L (≥200 mg/dL) for TC (*n* = 180), ≥3.4 mmol/L (≥130 mg/dL) for LDL (*n* = 185), ≥1.2 mmol/L (≥45 mg/dL) for HDL (*n* = 226), and ≥1.06 mmol/L (≥94 mg/dL) for triacylglycerol (*n* = 223).
[3] $\bar{x} \pm$ SD.
[4,5] Significantly different from men: [4] $P < 0.05$, [5] $P < 0.0001$.
[6,7] Significantly different from non-African Americans: [6] $P < 0.01$, [7] $P < 0.0001$.
[8] Median; 25th and 75th percentiles in parentheses.

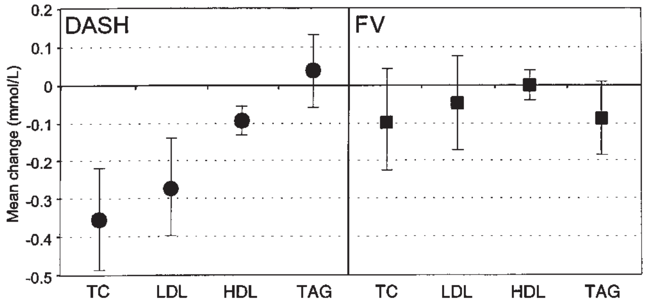

FIGURE 1. Mean change (and 95% CI) in lipids after a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol [DASH (Dietary Approaches to Stop Hypertension) diet] and after a diet increased in fruit and vegetables (FV diet), relative to the control diet. TC, total cholesterol; TAG, triacylglycerol. For the DASH diet, $P < 0.0001$ for TC, LDL cholesterol, and HDL cholesterol. For the FV diet, $P = 0.055$ for TAG.

lipids in subgroups of participants consuming the FV diet, the following trends (ranging from $P = 0.053$ to $P = 0.076$) were noted: a trend for reduced total cholesterol in men ($P = 0.053$) and trends for reduced triacylglycerol ($P = 0.076$) and reduced LDL:HDL ($P = 0.069$) in non-African Americans. None of the changes differed significantly between the subgroups (interaction terms NS).

Predicted versus observed lipid changes

For the DASH diet, the Keys equation generally predicted a greater total cholesterol reduction than was observed, whereas the Mensink and Katan equation predicted a smaller reduction than was observed (**Table 7**). The observed rise in triacylglycerol was less than predicted on the basis of the Mensink and Katan equation. The observed reductions in LDL and HDL cholesterol were not significantly different from the predictions of the Mensink and Katan equation.

For the FV diet, the observed changes in total, LDL, and HDL cholesterol did not differ significantly from the small changes predicted by the Keys and the Mensink and Katan equations (Table 7). However, the observed change in triacylglycerol was less than predicted.

Alcohol and physical activity

Mean changes in alcohol consumption and physical activity were small and did not differ significantly among the 3 diet groups (data not shown).

DISCUSSION

The DASH diet lowered total and LDL cholesterol, was associated with a decrease in HDL cholesterol, and had no adverse effects on triacylglycerol in the absence of changes in weight and physical activity. These trends were generally observed in all subgroups. In particular, we observed that reductions in total cholesterol, LDL cholesterol, TC:HDL, and LDL:HDL were greater in men than in women; lipid responses did not differ significantly between African Americans and non-African Americans; higher baseline HDL was associated with greater reductions in HDL; and triacylglycerol was not significantly increased overall or in any subgroup despite a predicted rise in triacylglycerol with increased carbohydrate intake.

Previous controlled feeding studies tended to have insufficient numbers of men and women to make comparisons with adequate power to detect a differential sex response of lipids to diet. In 2 controlled feeding studies that specifically tested for sex differences, no significant differences in lipid response were detected between 57 women and 46 men (7) or between 33 women and 30 men (8). In contrast, Schaefer et al (6) pooled the results of 5 controlled feeding studies having a total of 48 women and 72 men to compare their lipid response to a National Cholesterol Education Program Step II diet and found that, similar to the present study, men had greater mean net reductions in total cholesterol (by –0.24 mmol/L, or −9 mg/dL; $P < 0.03$) and in LDL cholesterol (by –0.17 mmol/L, or −6.6 mg/dL; $P = 0.058$) than did women. Unlike in the present study, however, Schaefer et al (6) reported a trend for a 0.05-mmol/L (1.9 mg/dL) greater reduction in HDL in men than in women ($P = 0.09$). The results of the present study, which used a single protocol with 223 men and 213 women and controlled for race and baseline lipid concentrations, suggest that women exhibit a smaller response in total and LDL cholesterol, but not in HDL cholesterol or triacylglycerol, to reduced-fat diets than do men of similar age and body mass index and under conditions of stable weight.

Connett and Stamler (31) reported that 416 black men in the special intervention group of the Multiple Risk Factor Intervention Trial study had total cholesterol, LDL-cholesterol, and triacylglycerol responses to the intervention similar to those of 5338 white men. Similarly, Ginsberg et al (7), examining 26 black participants, and Howard et al (8), examining 34 black participants, reported no significant differences in lipid response to diet between black and nonblack participants in their controlled feeding studies. The present study, with 261 African Americans, found no significant differences between African Americans and non-African Americans.

We found no significant differential reduction in plasma total cholesterol, LDL cholesterol, or triacylglycerol according to baseline concentrations of these measures. As shown in Figure 2, trends in LDL change were similar after both the control and DASH diets, indicating regression to the mean or some other nonspecific effect, rather than a specific diet effect. This finding suggests that appropriate statistical comparisons with the control group should be made before drawing conclusions regarding effects of baseline concentrations. In contrast, HDL cholesterol was reduced more by the DASH diet in individuals with higher baseline HDL-cholesterol concentrations than in those with lower baseline concentrations. Thus, the DASH diet has a smaller effect on HDL cholesterol in those whose low HDL-cholesterol concentrations might place them at increased CHD risk.

The Keys equation appeared to overpredict the degree of total cholesterol reduction from the DASH diet, perhaps because it was based primarily on studies of hyperlipidemic men (29). In the present study, persons with high total cholesterol were excluded and men had a greater total cholesterol response to the DASH diet than did women. Because the FV diet did not alter dietary fat, changes in total or LDL cholesterol were not expected and were not significantly different from those predicted. However, data from several studies indicated that increasing dietary soluble fiber reduces blood cholesterol concentrations independent of dietary fat intake (32–35). The present study suggests that changes in total and LDL cholesterol are minimal without concomitant reductions in fat intake when dietary fiber is increased by 20 g/d, with no particular emphasis on soluble or insoluble

TABLE 6
Mean (and 95% CI) change in lipids from the run-in to the end of the intervention, net of control, by race, sex, and baseline lipid concentration[1]

	Race[2]		Sex[3]		Baseline lipid[4]	
	African American	Non-African American	Women	Men	Lower	Higher
DASH diet						
TC						
(mmol/L)	−0.35 (−0.52, −0.19)	−0.39 (−0.60, −0.18)	−0.23 (−0.42, −0.04)[5]	−0.50 (−0.68, −0.31)[5]	−0.42 (−0.58, −0.26)	−0.29 (−0.50, −0.09)
(mg/dL)	−13.7 (−20.2, −7.2)	−15.0 (−23.1, −6.8)	−8.9 (−16.2, −1.6)[5]	−19.2 (−26.3, −12.2)[5]	−16.2 (−22.5, −9.9)	−11.4 (−19.4, −3.3)
LDL						
(mmol/L)	−0.29 (−0.44, −0.14)	−0.28 (−0.47, −0.09)	−0.14 (−0.31, 0.03)[6]	−0.43 (−0.60, −0.26)[6]	−0.34 (−0.50, −0.19)	−0.21 (−0.40, −0.02)
(mg/dL)	−11.2 (−17.1, −5.3)	−11.0 (−18.4, −3.6)	−5.4 (−12.1, 1.3)[6]	−16.5 (−23.0, −10.1)[6]	−13.3 (−19.2, −7.4)	−8.1 (−15.3, −0.9)
HDL						
(mmol/L)	−0.09 (−0.14, −0.05)	−0.10 (−0.16, −0.04)	−0.09 (−0.14, −0.03)	−0.10 (−0.16, −0.05)	−0.04 (−0.10, 0.01)[6]	−0.15 (−0.20, −0.10)[6]
(mg/dL)	−3.6 (−5.4, −1.8)	−3.9 (−6.2, −1.7)	−3.4 (−5.5, −1.3)	−4.0 (−6.0, −2.0)	−1.6 (−3.7, 0.5)[6]	−5.7 (−7.7, −3.7)[6]
TC:HDL	−0.05 (−0.25, 0.15)	0.00 (−0.25, 0.25)	0.14 (−0.08, 0.37)[6]	−0.20 (−0.41, 0.02)[6]		
LDL:HDL	−0.08 (−0.26, 0.09)	−0.07 (−0.29, 0.16)	0.08 (−0.12, 0.28)[6]	−0.23 (−0.42, −0.03)[6]		
TAG						
(mmol/L)	0.02 (−0.10, 0.14)	0.05 (−0.10, 0.21)	0.08 (−0.05, 0.22)	−0.02 (−0.15, 0.12)	0.04 (−0.09, 0.18)	0.02 (−0.11, 0.16)
(mg/dL)	1.7 (−9.2, 12.5)	4.7 (−8.8, 18.2)	7.5 (−4.7, 19.7)	−1.5 (−13.3, 10.3)	3.8 (−8.0, 15.6)	2.0 (−9.8, 13.8)
FV diet						
TC						
(mmol/L)	−0.02 (−0.19, 0.14)	−0.15 (−0.36, 0.05)	0.03 (−0.16, 0.22)	−0.18 (−0.36, 0.00)	−0.12 (−0.29, 0.05)	−0.01 (−0.21, 0.18)
(mg/dL)	−0.9 (−7.4, 5.6)	−5.9 (−13.9, 2.1)	1.2 (−6.1, 8.6)	−6.9 (−13.9, 0.1)	−4.6 (−11.3, 2.0)	−0.5 (−8.0, 7.0)
LDL						
(mmol/L)	0.00 (−0.15, 0.15)	−0.09 (−0.28, 0.10)	0.05 (−0.12, 0.23)	−0.12 (−0.29, 0.05)	−0.01 (−0.16, 0.15)	−0.08 (−0.25, 0.10)
(mg/dL)	0.0 (−5.9, 6.0)	−3.5 (−10.7, 3.8)	2.1 (−4.6, 8.8)	−4.7 (−11.1, 1.8)	−0.2 (−6.4, 6.0)	−3.0 (−9.7, 3.8)
HDL						
(mmol/L)	−0.02 (−0.07, 0.03)	0.01 (−0.04, 0.07)	0.01 (−0.04, 0.07)	−0.03 (−0.08, 0.02)	0.03 (−0.02, 0.08)	−0.04 (−0.09, 0.01)
(mg/dL)	−0.8 (−2.6, 1.0)	0.5 (−1.7, 2.7)	0.5 (−1.6, 2.6)	−1.0 (−3.0, 1.0)	1.1 (−1.0, 3.2)	−1.6 (−3.5, 0.4)
TC:HDL	−0.03 (−0.23, 0.17)	−0.28 (−0.53, −0.04)	−0.04 (−0.26, 0.19)	−0.23 (−0.44, −0.01)	—	—
LDL:HDL	−0.02 (−0.20, 0.16)	−0.20 (−0.42, 0.02)	0.02 (−0.19, 0.22)	−0.19 (−0.39, 0.00)	—	—
TAG						
(mmol/L)	−0.05 (−0.18, 0.07)	−0.14 (−0.29, 0.01)	−0.10 (−0.24, 0.04)	−0.07 (−0.20, 0.06)	−0.02 (−0.15, 0.12)	−0.15 (−0.29, −0.02)
(mg/dL)	−4.6 (−15.5, 6.3)	−12.3 (−25.7, 1.2)	−8.9 (−21.1, 3.3)	−6.5 (−18.1, 5.0)	−1.5 (−13.5, 10.6)	−13.6 (−25.3, −2.0)

[1] DASH (Dietary Approaches to Stop Hypertension) diet, a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol; FV diet, a diet increased in fruit and vegetables. TAG, triacylglycerol. Within-group changes are significant ($P < 0.05$) when 95% CIs do not overlap zero.

[2] Adjusted for sex and baseline lipids.

[3] Adjusted for race and baseline lipids.

[4] Adjusted for race and sex. Lower is <5.2 mmol/L (<200 mg/dL) for TC ($n = 256$), <3.4 mmol/L (<130 mg/dL) for LDL ($n = 251$), <1.2 mmol/L (<45 mg/dL) for HDL ($n = 210$), and <1.06 mmol/L (<94 mg/dL) for triacylglycerol ($n = 213$). Higher is ≥5.2 mmol/L (≥200 mg/dL) for TC ($n = 180$), ≥3.4 mmol/L (≥130 mg/dL) for LDL ($n = 185$), ≥1.2 mmol/L (≥45 mg/dL) for HDL ($n = 226$), and ≥1.06 mmol/L (≥94 mg/dL) for triacylglycerol ($n = 223$).

[5] Significant treatment (ie, diet group) × subgroup (sex) interaction, adjusted for cohort, race, and baseline lipids, $P = 0.052$.

[6] Significant treatment (ie, diet group) × subgroup (sex or baseline lipids) interaction, adjusted for cohort, race, sex, and baseline lipids (as appropriate), $P < 0.05$.

fiber.

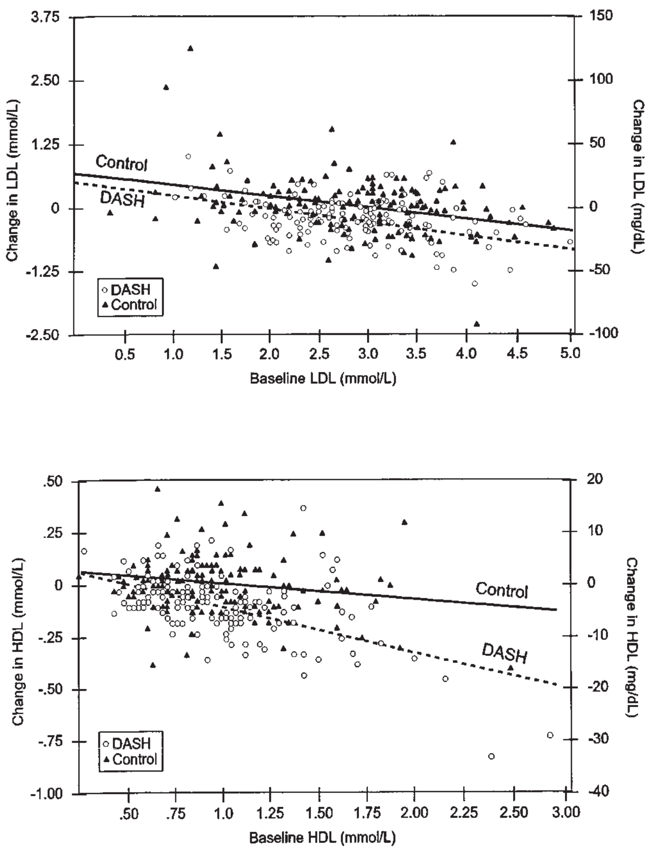

FIGURE 2. Changes in LDL and HDL cholesterol in relation to baseline concentrations for participants consuming a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol [DASH (Dietary Approaches to Stop Hypertension) diet] or a control diet. NS for LDL; $P = 0.02$ for HDL.

Intriguing findings in this report were the –0.09-mmol/L (−8.2-mg/dL; $P = 0.055$) lowering of triacylglycerol produced by the FV diet when no significant change was expected, and the nonsignificant 0.04-mmol/L (3.2-mg/dL; $P = 0.45$) increase in triacylglycerol produced by the DASH diet, when a much greater rise of 0.21 mmol/L (18.9 mg/dL) was expected on the basis of the prediction equations. Some investigators suggested that triacylglycerol concentrations will not rise if the carbohydrates consumed are low in sucrose and high in fiber (5, 35, 36). However, other investigators observed increases in triacylglycerol despite the use of foods high in fiber and complex carbohydrates (37). It is also unclear whether low-fat, high-carbohydrate diets improve insulin resistance (38, 39). The sucrose content of the FV and DASH diets was about one-third less, and the soluble, insoluble, and total dietary fiber contents were 2.5–3.0 times higher, than in the control diet. However, the increase in carbohydrate with the DASH diet (58% compared with 50%) was only moderate. The present study was not designed to test the specific dietary components responsible for the observed response in lipids. However, these results raise the intriguing possibility that lower-fat diets based on plants and whole grains prevent the predicted rise in triacylglycerol (40).

As did the diets in other studies in which dietary fat intakes were lowered, the DASH diet lowered HDL cholesterol in addition to total and LDL cholesterol. This reduction occurred similarly in each race and sex and was more pronounced in those with higher baseline HDL-cholesterol concentrations. The observation that reduced-fat diets lower HDL has led to controversy over the advisability of lower-fat, higher-carbohydrate diets and whether CHD risk is reduced when HDL is lowered along with LDL (41, 42). Several studies showed that populations with low total cholesterol and low HDL cholesterol do not have increased CHD risk (43–45), and that plant-based diets similar to the DASH diet are associated with decreased CHD risk (35, 46, 47). It is also recognized that overweight persons who lose weight

TABLE 7
Predicted compared with observed mean changes in plasma lipids[1]

	DASH diet			FV diet		
Equation and reference	Observed	Predicted	Observed − predicted (95% CI)	Observed	Predicted	Observed − predicted (95% CI)
Keys equation (29)						
TC						
(mmol/L)	−0.37	−0.53	0.17 (0.08, 0.25)[2]	−0.08	−0.11	0.02 (−0.08, 0.13)
(mg/dL)	−14.2	−20.6	6.4 (3.2, 9.6)[2]	−3.1	−4.2	1.0 (−3.0, 4.9)
Mensink and Katan equations (1)						
TC						
(mmol/L)	−0.37	−0.28	−0.08 (−0.17, −0.002)[3]	−0.08	−0.04	−0.04 (−0.14, 0.06)
(mg/dL)	−14.2	−10.9	−3.3 (−6.4, −0.1)[3]	−3.1	−1.6	−1.6 (−5.5, 2.3)
LDL						
(mmol/L)	−0.29	−0.23	−0.05 (−0.13, 0.02)	−0.04	−0.04	−0.01 (−0.10, 0.08)
(mg/dL)	−11.0	−9.0	−2.1 (−5.1, 0.9)	−1.7	−1.5	−0.3 (−3.7, 3.2)
HDL						
(mmol/L)	−0.10	−0.10	0.004 (−0.02, 0.03)	−0.002	−0.004	0.002 (−0.03, 0.03)
(mg/dL)	−3.8	−4.0	0.2 (−1.0, 1.3)	−0.1	−0.2	0.1 (−1.1, 1.2)
Triacylglycerol						
(mmol/L)	0.04	0.21	−0.18 (−0.24, −0.11)[2]	−0.08	0.005	−0.08 (−0.15, −0.01)[3]
(mg/dL)	3.3	18.9	−15.5 (−21.6, −9.4)[2]	−6.8	0.4	−7.2 (−13.3, −1.0)[3]

[1] DASH (Dietary Approaches to Stop Hypertension) diet, a diet increased in fruit, vegetables, and low-fat dairy products and reduced in saturated fat, total fat, and cholesterol; FV diet, a diet increased in fruit and vegetables.

[2,3] Significantly different from 0: [2] $P < 0.0001$, [3] $P < 0.05$.

while consuming reduced-fat diets have favorable changes in all lipids, including HDL and triacylglycerol (26, 48).

The DASH diet substantially reduced systolic and diastolic blood pressure (12), caused favorable changes in total and LDL cholesterol, resulted in no changes in triacylglycerol, and reduced HDL cholesterol. Efforts have been made to estimate the overall effect of various risk factors on CHD risk (49, 50). Applying the Framingham risk equation to estimate 10-y CHD risk on the basis of baseline and postintervention values of systolic blood pressure and total cholesterol, 10-y risk was decreased by 12.1% in participants consuming the DASH diet compared with a 0.9% increase in risk in participants consuming the control diet ($P < 0.01$). The respective changes in 10-y risk when LDL values were used in place of total cholesterol were –12.2% and –2.2% ($P = 0.057$). Thus, on balance, the DASH diet affects CHD risk favorably. The possible opposing effect on CHD risk of HDL reduction needs further elaboration in population studies, particularly in women who have smaller reductions in total cholesterol and in experimental models of HDL metabolism and atherosclerosis.

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