Effect of Dietary Sodium Intake on Blood Lipids
Results From the DASH–Sodium Trial

David W. Harsha, Frank M. Sacks, Eva Obarzanek, Laura P. Svetkey, Pao-Hwa Lin,
George A. Bray, Mikel Aickin, Paul R. Conlin, Edgar R. Miller III, Lawrence J. Appel

Abstract—We evaluated the effect on serum lipids of sodium intake in 2 diets. Participants were randomly assigned to a

248 typical American control diet or the Dietary Approaches to Stop Hypertension (DASH) diet, each prepared with 3 levels
of sodium (targeted at 50, 100, and 150 mmol/d to 2100 kcal). The DASH diet is increased in fruits, vegetables, and
low-fat dairy products and is reduced in saturated and total fat. Within assigned diet, participants ate each sodium level
for 30 days. The order of sodium intake was random. Participants were 390 adults, age 22 years or older, with blood
pressure of 120 to 159 mm Hg systolic and 80 to 95 mm Hg diastolic. Serum lipids were measured at baseline and at
the end of each sodium period. Within each diet, sodium intake did not significantly affect serum total cholesterol, LDL
cholesterol, HDL cholesterol, or triglycerides. On the control diet, the ratio of total cholesterol-to-HDL cholesterol
increased by 2% from 4.53 on higher sodium to 4.63 on lower sodium intake (P=0.04). On the DASH diet, sodium
intake did not affect this ratio. There was no dose-response of sodium intake on serum lipids or the cholesterol ratio in
either diet. At each sodium level, total cholesterol, LDL cholesterol, and HDL cholesterol were lower on the DASH diet
versus the typical American diet. There were no significant interactions between the effects of sodium and the DASH
diet on serum lipids. In conclusion, changes in dietary sodium intake over the range of 50 to 150 mmol/d did not affect
blood lipid concentrations. (Hypertension. 2004;43[part 2]:393-398.)

Key Words: diet ■ sodium ■ lipids ■ cholesterol ■ blood pressure ■ hypertension

Studies on the health effects of sodium reduction have
largely focused on blood pressure, high levels of which
increase cardiovascular risk.1,2 The preponderance of evi-
dence has demonstrated that sodium reduction lowers mean
blood pressure levels.3 In addition, some evidence suggests
that high salt intake can also lead to higher cardiovascular
disease risk independent of its effect on blood pressure, such
as through increased left ventricular mass.4,5 However, some
studies have suggested that low sodium intake can have a
deleterious effect on cardiovascular disease risk because of
adverse effects on blood lipids.6–9 Most of these studies have
been conducted on small samples that ranged from 13 to
50,6,7,9 although one study had a larger sample size of 163.8
These studies generally compared extreme levels of sodium
(eg, 20 mmol versus 200 to 300 mmol) and were mostly of
short-duration (eg, 1 to 2 weeks). The mechanisms by which
salt intake could affect blood lipids are not clear.
The Dietary Approaches to Stop Hypertension (DASH)—
Sodium trial provided an opportunity to examine the effect of
dietary sodium on serum lipids at sodium levels typically
consumed and with sufficient power to detect small differences
because of large sample size. The DASH dietary pattern is rich
in fruits, vegetables, and low-fat dairy foods, emphasizes fish,
poultry, and whole grains, and is reduced in fats, red meat,
sweets, and sweetened beverages. We previously showed that
the DASH diet and sodium reduction substantially lowered
blood pressure in men and women with prehypertension (above
optimal blood pressure and high normal blood pressure) and
stage 1 hypertension compared with a control diet typical of
what many Americans consume.10–12 We also reported that the
DASH diet significantly lowered total cholesterol and LDL and
HDL cholesterol, without significantly increasing triglyceride
concentrations.13 The purpose of this report is to determine the
effects on serum lipids of 3 levels of dietary sodium in
participants eating either a diet typical of many Americans or the
DASH dietary pattern. Effects on serum lipids of the DASH diet
at 3 levels of sodium are also examined.

Methods

Study Design

The DASH–Sodium Trial was a multicenter, randomized feeding
trial comparing the effect on blood pressure of 3 levels of sodium

Received September 30, 2003; first decision October 27, 2003; revision accepted December 4, 2003.
From Pennington Biomedical Research Center (D.W. H., G.A.B.), Baton Rouge, La; Endocrine–Hypertension Division and Channing Laboratory
(F.M.S.), Department of Medicine, Brigham and Women’s Hospital and Harvard Medical School and Nutrition Department, Harvard School of Public
Health, Boston, Mass; National Heart, Lung, and Blood Institute (E.O.), Bethesda, Md; Duke Hypertension Center and the Sarah W. Stedman Nutrition
and Metabolism Center (L.P.S., P.-H.L.), Duke University School of Medicine, Durham, NC; Kaiser Permanente Center for Health Research (M.A.),
Portland, Ore; and Welch Center for Prevention, Epidemiology, and Clinical Research (L.J.A., E.R.M.), Johns Hopkins University, Baltimore, Md.
Correspondence to Dr Lawrence J. Appel, Welch Center, Johns Hopkins University, Suite 2-600, 2024 East Monument St, Baltimore, MD 21205.
E-mail lappel@jhmi.edu

© 2004 American Heart Association, Inc.

Hypertension is available at http://www.hypertensionaha.org

DOI: 10.1161/01.HYP.0000113046.83819.a2

393
intake in 2 dietary patterns among adults with 120 to 159 mm Hg systolic and 80 to 95 mm Hg diastolic. A complete description of this study and its blood pressure results have been published. Briefly, 3 sodium levels were defined as “higher” (target of 150 mmol/d per 2100 kcal energy intake, reflecting typical US consumption), “intermediate” (target of 100 mmol/d per 2100 kcal, reflecting the upper limit of current US recommendations), and “lower” (target of 50 mmol/d per 2100 kcal, reflecting a level that might produce additional lowering of blood pressure). The daily sodium intake was commensurate with the total energy requirement of each participant, so that larger or very active people would receive more food and more sodium than smaller or less active people.

During a 2-week run-in period, eligible persons ate the control diet at the higher sodium level. Participants were then randomly assigned to eat 1 of 2 dietary patterns for 90 days using a parallel group design. Within the assigned diet, participants ate foods with higher, intermediate, and lower levels of sodium for 30 consecutive days each. The order of the sodium levels was random. Energy intake was adjusted for each participant when necessary to maintain body weight throughout the study. Four clinical centers, a coordinating center, and the National Heart, Lung, and Blood Institute collaborated on the trial. The clinical centers conducted the trial in 4 or 5 cohorts of participants.

The 2 dietary patterns were a control diet constructed to be typical of what many Americans eat and the DASH diet, which emphasizes fruits, vegetables, and low-fat dairy foods, includes whole grains, poultry, fish, and nuts, and is reduced in fats, red meat, sweets, and sugar-containing beverages. The nutrient composition of the diets was validated and monitored by chemical analysis. The control and the DASH dietary patterns were composed with the higher, intermediate, and lower sodium levels. Participants were provided all their food for the duration of the study.

The primary outcome was blood pressure measured at the end of each 30-day intervention feeding period. A prespecified secondary objective of the DASH–Sodium trial was to assess the impact of study interventions on total cholesterol, LDL cholesterol, HDL cholesterol, and triglyceride concentrations. The total cholesterol to HDL cholesterol ratio is also reported but was not prespecified in the protocol. The study was approved by the Institutional Review Board at each center, with written informed consent given by all participants.

### Participant Eligibility

Adults aged 22 years or older who had a blood pressure of 120 to 159 mm Hg systolic and 80 to 95 mm Hg diastolic averaged over 3 screening visits were eligible to participate. The trial targeted 50% enrollment of blacks and women. Exclusion criteria included a history of heart disease, renal insufficiency, poorly controlled hyperlipidemia (total cholesterol greater than 260 mg/dL), insulin-requiring or poorly controlled diabetes, special dietary requirements, intake of more than 14 alcoholic drinks per week, or use of antihypertensive drugs or other medications that would affect blood pressure or nutrient metabolism.

### Measurements

Blood samples were collected from participants after an approximate 12-hour fast at baseline and during the final week of each 30-day period of defined dietary sodium level. Baseline samples were collected during screening (ie, before the run-in period while the participant was on his/her usual diet). Blood samples were collected into serum separator tubes and centrifuged in a refrigerated centrifuge for 15 minutes at 1500g. The resulting serum was frozen at −20°C and shipped in batches to the Core Laboratory for Clinical Studies at Washington University School of Medicine, St. Louis, Mo. Specimens were analyzed by enzymatic kits on the Hitachi 917 analyzer for total triglycerides (Roche TGGB kit), total cholesterol (Miles-Technicon kit), and HDL cholesterol (Miles-Technicon cholesterol kit) after precipitation of apoB-containing lipoproteins with dextran sulfate. LDL cholesterol was estimated by the Friedewald equation for specimens with total triglyceride concentration below 400 mg/dL. The core laboratory is standardized for lipid measurements through the National Institutes of Health National Heart, Lung, Blood Institute–Centers for Disease Control Lipid Standardization Program.

Energy and nutrient intake of participants were calculated from the assigned menus according to participants’ energy levels, from unit foods, and from logs that provided information on alcohol intake using Moore’s Extended Nutrition (MENu) database (version 3.1, 1997; Pennington Biomedical Research Foundation, Baton Rouge, La).

Dietary adherence was assessed by review of daily diaries, observation of on-site meal consumption, and measurement of 24-hour urinary excretion of sodium, potassium, phosphorus, and urea nitrogen. Participants and dietary staff were blinded to outcome data; personnel involved in collection of outcome data were blinded to diet assignment. Details of other measurements made during the trial are published elsewhere.

### Statistical Analysis

We used generalized estimating equations (GEE) to model lipid levels as a function of diet and sodium level while adjusting for cohort and clinical center. Baseline lipid levels were included as part of the design matrix, so that estimates of the DASH diet effect are net of baseline differences between participants in the DASH and control diet arms. The sodium contrasts are made within subjects and thus automatically incorporate baseline levels.

Linearity of the effects of sodium within the control diet or the DASH diet was assessed by comparing the change in lipids from the higher level to the intermediate level of sodium with the change from the intermediate level to the lower level of sodium; a significant test indicated deviation from linearity, that is, the change in lipids from the higher to the intermediate levels of sodium was not equivalent to the change from the intermediate to the lower levels of sodium. Interaction terms of sodium level by diet assignment were included to test whether lipid changes from the 3 sodium levels were different between the 2 diets. The analytic model included effects for 4 clinical centers and 5 feeding cohorts, and therefore the diet and sodium main effects and interactions, were all adjusted for potential site effects and time trends. A one-period carry-over effect was also included in the model for completeness, but it had no impact on the estimates of the diet and sodium estimated effects. The GEE model allows for intercorrelation among outcome measures on the same individual, as occurs in this crossover design, and is the same analytic model we used to analyze the effects of diet and sodium on blood pressure. Conventional 2-sided probability values are reported here for diet effects within sodium levels and for the sodium levels separately within the DASH and control diets. No adjustments were made for multiple comparisons.

The trial’s sample size provided 85% power at a 2-sided significance level of 0.05 to detect differences between the higher and lower sodium levels of 0.14 mmol/L for total cholesterol, 0.12 mmol/L for LDL cholesterol, 0.04 mmol/L for HDL cholesterol, 0.12 mmol/L for triglycerides, and 0.15 for total/HDL cholesterol ratio. These reflect differences in cholesterol of 3% to 4%, in triglycerides of 12%, and in the ratio of 3%.

### Results

Four-hundred twelve individuals were randomized in the DASH–Sodium trial. Baseline and follow-up measurements for total cholesterol and HDL cholesterol were obtained in 390 of them, and LDL cholesterol and triglycerides in 379, reflecting the number of participants who gave fasting blood. Baseline characteristics were similar between those in the control and DASH diet groups (Table 1). The average age of the participants was 48 to 49 years, 54% in the control group were women compared with 59% in the DASH group, and blacks accounted for 57% of participants in both treatment groups. The achieved sodium levels (based on 24-hour
The ratio of total cholesterol-to-HDL cholesterol was slightly but significantly higher during lower than higher and during lower than intermediate sodium intake with the control diet, ie, 4.63 for lower, 4.53 for intermediate, and 4.53 for higher (P=0.04 for lower versus higher) (Figure 1e). Among urinary excretion data) were 142, 107, and 65 mmol/d at the higher, intermediate, and lower sodium levels, respectively, for the DASH and control participants combined.

The calculated energy and nutrient intakes of the participants on the 2 diets are shown in Table 2. Except for sodium, intakes were similar at all 3 levels of sodium, so the average is shown.

Mean baseline lipid levels were virtually identical for participants in the 2 diet arms (Table 1). There was no significant effect of dietary sodium on total cholesterol with either the control or the DASH diet (Figure 1a). The DASH diet lowered total cholesterol similarly and significantly, by 0.4 to 0.5 mmol/L, at every level of sodium intake (each P<0.0001). As with total cholesterol, there was no significant effect of sodium level on LDL cholesterol (Figure 1b). At each sodium level, the DASH diet lowered LDL cholesterol similarly and significantly, by 0.3 to 0.4 mmol/L (each P<0.0001). Sodium level did not significantly affect HDL cholesterol with either the control or the DASH diet. However, the DASH diet lowered HDL cholesterol by 0.08 to 0.10 mmol/L at the 3 sodium levels (each P<0.0001).

Serum triglycerides were slightly higher by 0.06 mmol/L during lower compared with higher sodium intake with the control diet (P=0.07) (Figure 1d). With the DASH diet, triglycerides showed no pattern across sodium levels. The DASH diet did not significantly affect triglyceride concentrations.

The ratio of total cholesterol-to-HDL cholesterol was slightly but significantly higher during lower than higher and during lower than intermediate sodium intake with the control diet, ie, 4.63 for lower, 4.53 for intermediate, and 4.53 for higher (P=0.04 for lower versus higher) (Figure 1e). Among

<table>
<thead>
<tr>
<th>TABLE 1. Characteristics of DASH–Sodium Trial Participants (mean and SD, or %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Age, y</td>
</tr>
<tr>
<td>Women, %</td>
</tr>
<tr>
<td>Black</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
</tr>
<tr>
<td>Drink alcohol, %</td>
</tr>
<tr>
<td>Alcohol intake, drinks per day (in drinkers)</td>
</tr>
<tr>
<td>Median physical activity score, kcal/kg per day (25th and 75th percentile)</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
</tr>
<tr>
<td>Hypertensive (BP≥140/90), %</td>
</tr>
<tr>
<td>Use of lipid-lowering medication, %</td>
</tr>
<tr>
<td>Use of hormone replacement therapy, % of women</td>
</tr>
<tr>
<td>Serum lipids, mmol/L</td>
</tr>
<tr>
<td>Total cholesterol</td>
</tr>
<tr>
<td>LDL cholesterol</td>
</tr>
<tr>
<td>HDL cholesterol</td>
</tr>
<tr>
<td>Median triglycerides (25th and 75th percentile)</td>
</tr>
<tr>
<td>Total cholesterol/HDL cholesterol</td>
</tr>
<tr>
<td>Urinary sodium, mmol/d</td>
</tr>
<tr>
<td>Screening</td>
</tr>
<tr>
<td>High sodium period</td>
</tr>
<tr>
<td>Intermediate sodium period</td>
</tr>
<tr>
<td>Lower sodium period</td>
</tr>
</tbody>
</table>

Mean baseline lipid levels were virtually identical for participants in the 2 diet arms (Table 1). There was no significant effect of dietary sodium on total cholesterol with either the control or the DASH diet (Figure 1a). The DASH diet lowered total cholesterol similarly and significantly, by 0.4 to 0.5 mmol/L, at every level of sodium intake (each P<0.0001). As with total cholesterol, there was no significant effect of sodium level on LDL cholesterol (Figure 1b). At each sodium level, the DASH diet lowered LDL cholesterol similarly and significantly, by 0.3 to 0.4 mmol/L (each P<0.0001). Sodium level did not significantly affect HDL cholesterol with either the control or the DASH diet. However, the DASH diet lowered HDL cholesterol by 0.08 to 0.10 mmol/L at the 3 sodium levels (each P<0.0001).

Serum triglycerides were slightly higher by 0.06 mmol/L during lower compared with higher sodium intake with the control diet (P=0.07) (Figure 1d). With the DASH diet, triglycerides showed no pattern across sodium levels. The DASH diet did not significantly affect triglyceride concentrations.

<table>
<thead>
<tr>
<th>TABLE 2. Daily Energy and Nutrient Intake of DASH–Sodium Trial Participants During the Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Energy, MJ</td>
</tr>
<tr>
<td>Energy, kcal</td>
</tr>
<tr>
<td>Total fat, % of energy</td>
</tr>
<tr>
<td>Saturated fat, % of energy</td>
</tr>
<tr>
<td>Polyunsaturated fat, % of energy</td>
</tr>
<tr>
<td>Monounsaturated fat, % of energy</td>
</tr>
<tr>
<td>Cholesterol, mg/d</td>
</tr>
<tr>
<td>Carbohydrate, % of energy</td>
</tr>
<tr>
<td>Fiber, g/d</td>
</tr>
<tr>
<td>Potassium, mg/d</td>
</tr>
<tr>
<td>Calcium, mg/d</td>
</tr>
<tr>
<td>Magnesium, mg/d</td>
</tr>
<tr>
<td>Sodium, mg/d (higher sodium)</td>
</tr>
<tr>
<td>Sodium, mg/d (intermediate sodium)</td>
</tr>
<tr>
<td>Sodium, mg/d (lower sodium)</td>
</tr>
</tbody>
</table>

Mean (SD). Values calculated from nutrient database.
individuals eating the DASH diet, there was no significant sodium effect on the ratio. There was a trend toward a lower ratio for the DASH diet with lower sodium intake compared with the control diet with lower sodium ($P = 0.09$) but not with intermediate or higher sodium intake. The ratio was similar for the DASH diet with lower sodium and the control diet with higher sodium (4.49 and 4.53, respectively). Tests for deviation from linearity were non-significant for serum lipids and the ratio of total cholesterol-to-HDL cholesterol. Tests for interactions between sodium level and diet were not significant, indicating that the effects of sodium level on serum lipids and the total cholesterol-to-HDL cholesterol ratio did not differ between the control and DASH diets.

**Discussion**

Overall, the DASH–Sodium trial showed no significant effects of sodium intake on serum cholesterol, LDL cholesterol, HDL cholesterol or triglycerides over a 77 mmol/d range of urinary sodium reflecting achieved intakes of ap-
Sodium trial, it is doubtful that the increased total cholesterol-to-HDL cholesterol ratio in the control diet is clinically relevant, especially in light of the non-significant changes in either total cholesterol or HDL cholesterol from sodium reduction. Furthermore, because the total cholesterol-to-HDL cholesterol ratio was not a protocol-specified outcome variable, there is also the possibility of a type 1 (false-positive) error.

The results from the present study showed that the DASH diet, compared with the control diet, significantly decreased serum lipoprotein concentrations without increasing triglyceride concentrations at all 3 levels of sodium. Sodium level did not influence the effects of the DASH diet on serum lipoproteins. Total cholesterol decreased by 0.4 to 0.5 mmol/L, LDL cholesterol by 0.3 to 0.4 mmol/L, and HDL cholesterol by 0.1 mmol/L. These decreases were similar to those found in the earlier DASH trial (0.35 mmol/L for total cholesterol, 0.28 mmol/L for LDL cholesterol, and 0.09 mmol/L for HDL cholesterol),15 which was conducted at a sodium level similar to the higher sodium level in the present DASH–Sodium trial (136 versus 142 mmol/L sodium, respectively). The earlier DASH trial observed a small, non-significant increase in triglycerides (0.04 mmol/L), whereas the present DASH–Sodium trial observed small non-significant changes in triglycerides of 0.06, −0.02, and 0.03 mmol/L from the DASH diet compared with the control diet at higher, intermediate, and lower sodium levels. Hence, the DASH diet, which is high in fiber and complex carbohydrates, might prevent the increase in triglycerides that otherwise occurs with diets rich in carbohydrates.13

The reductions in total cholesterol and LDL cholesterol observed with the DASH diet compared with the control diet in both the DASH and DASH–Sodium trials are beneficial. Using the DASH data,13 we previously calculated that the decrease in total cholesterol, even with the decrease in HDL cholesterol, coupled with the substantial decrease in blood pressure that accompanied the DASH diet, would result in a decrease in 10-year coronary heart disease risk of approximately 12% for those eating the DASH diet, in contrast to a 1% increase for those on the control diet. The lipid results from the DASH–Sodium trial are likely to yield similar, if not greater, predicted risk reduction given that lipid changes were slightly better and blood pressure was reduced the most with the combination of the DASH diet with lower sodium compared with the control diet with higher sodium. Nevertheless, it is important for epidemiologic studies to help determine the clinical relevance of reduced HDL cholesterol concentrations when accompanied by decreased total cholesterol or LDL cholesterol concentrations.

**Perspectives**

Moderate sodium reduction has no adverse effects on blood lipids. Thus, sodium reduction would be expected to decrease overall cardiovascular risk when consuming a diet similar to what many Americans consume or when consuming the DASH diet because of the salutary effect on blood pressure from sodium reduction.
Acknowledgments

The investigators express their deep appreciation to trial participants for their impressive commitment to the trial. This work was supported by cooperative agreement and other awards from the National Heart, Lung, and Blood Institute, National Institutes of Health to Pennington Biomedical Research Institute (U01-HL57190), Brigham and Women’s Hospital (U01-HL 57173), Duke University (U01-HL57114), Johns Hopkins University (U01-HL57139, K08 HL03857–01), and Kaiser Permanente Center for Health Research (U01-HL57156), and from the General Clinical Research Center Program of the National Center for Research Resources, National Institutes of Health to Brigham and Women’s Hospital (MO1-RR02635) and Johns Hopkins University (MO1-RR00722).

References


