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Effects of the DASH Diet and Sodium Intake on Bloating: Results From the DASH–Sodium Trial

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Abstract

INTRODUCTION: Bloating is one of the most common gastrointestinal complaints. Evidence has linked fiber and sodium to bloating; however, randomized trials examining these diet components are lacking. Here, we used a randomized trial to examine the effects of the high-fiber DASH diet and dietary sodium intake on abdominal bloating. We hypothesized that both the high-fiber DASH diet and higher sodium intake would increase bloating.

METHODS: The DASH–Sodium trial (1998–1999) randomized healthy adults to a high-fiber (32 g/d) DASH or low-fiber (11 g/d) Western diet (control). On their assigned diet, participants ate 3 sodium levels (50, 100, and 150 mmol/d at 2100 kcal) in 30-day periods in random order, with 5-day breaks between each period. The participants reported the presence of bloating at baseline and after each feeding period. Statistical analyses included log-binomial models to evaluate the risk of bloating.

RESULTS: Of 412 participants (mean age 48 years; 57% women; 57% black), 36.7% reported bloating at baseline. Regardless of the diet, high sodium intake increased the risk of bloating (risk ratio = 1.27; 95% confidence interval: 1.06–1.52; $P = 0.01$). The high-fiber DASH diet also increased the risk of bloating over all sodium levels (risk ratio = 1.41; 95% confidence interval: 1.22–1.64; $P < 0.001$). The effect of high-fiber DASH on bloating was greater in men than in women (P for interaction = 0.001).

DISCUSSION: Higher dietary sodium increased bloating, as did the high-fiber DASH diet. Although healthful high-fiber diets may increase bloating, these effects may be partially mitigated

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by decreasing dietary sodium intake. Future research is needed to explore mechanisms by which sodium intake and diet can influence bloating.

INTRODUCTION

Bloating is one of the most commonly reported symptoms of gastrointestinal (GI) discomfort (1-4), reported by over 30% of adults in a recent survey of U.S. adults (5) and by over 90% of adults with irritable bowel syndrome (6-11). Although the causes of bloating are likely myriad, diet is often implicated.

A high-fiber diet has been shown in small studies to increase gas production and retention (12), which may keep adults from choosing this healthful dietary pattern. Identification of nonhealthful nutrients that cause bloating is needed to inform dietary advice for the relief of GI gas retention without compromising health.

Sodium is among the most ubiquitously consumed nutrients in a typical U.S. diet. In addition to causing elevated blood pressure (BP), among other health problems, high sodium intake has been linked to GI bloating (13-18). The most convincing evidence supporting this notion derives from a double-blind crossover trial, in which oral administration of oral sodium bicarbonate increased bloating (18). Whether the symptoms result from the sodium or the bicarbonate is unclear. In addition, whether bloating would occur in the setting of a low-fiber typical American diet or a high-fiber healthful diet has not been demonstrated.

In this context, we analyzed data from the DASH–Sodium randomized controlled trial to examine the effects of dietary sodium and the high-fiber DASH diet vs a low-fiber control diet on the risk of bloating. We hypothesized that higher sodium, and the high-fiber DASH diet, would increase abdominal bloating.

METHODS

Trial overview

The DASH-Sodium trial was a multicenter trial, completed in November 1999 and sponsored by the National Heart, Lung, and Blood Institute. This trial tested the effects of 3 sodium intake levels in 2 separate diets (32 g high-fiber DASH diet and 11 g low-fiber control diet) in adults with high BP. Based on 2,100 kcal consumption, these sodium levels were low (goal of 50 mmol/d), intermediate (goal of 100 mmol/d), and high (goal of 150 mmol/d). Participants who were smaller or less active received less sodium and food than those who were larger or more active to account for total energy requirements. The DASH diet had low total fat, saturated fat, and cholesterol and was rich in low-fat dairy products, fruits, and vegetables. There were also more whole grains, nuts, fish, and poultry, and less sugary items and red meat in the DASH diet than the typical Western diet (see Table, Supplementary Digital Content 1, <http://links.lww.com/AJG/A189> for a detailed description of both diets). The IRB at Johns Hopkins University School of Medicine approved secondary analyses of the DASH-Na trial.

Participants

Four clinical centers in the United States had randomized 412 participants (age 22 years) in the trial. For each participant, systolic BP was required to be between 120 and 159 mm Hg and diastolic BP to be between 80 and 95 mm Hg while not on hypertension medications. Exclusion criteria included diabetes mellitus, anemia, inflammatory bowel disease, pregnancy, renal insufficiency, history of cardiovascular event, use of insulin, poorly controlled dyslipidemia, and consumption of >14 alcoholic beverages per week. Written informed consent was obtained from all study participants.

Controlled feeding

Participants were provided with all meals and snacks during the run-in period and 3 intervention periods. During the run-in period, which lasted 2 weeks, participants followed the control diet with a high sodium level. Subsequently, participants were randomly assigned to either the control or DASH diet, using a parallel-arm design. Then, in a 3-period, crossover design, participants followed their assigned diet for 30 days at each of the 3 sodium levels (three 30-day periods). Each participant's calorie content was adjusted to maintain a constant weight throughout the trial.

Outcome measure: bloating

The participants completed a symptoms questionnaire at the end of the run-in period and at the end of each feeding period. On the questionnaire, they were asked whether they felt "bloating/uncomfortably full." There were 4 options that participants could pick: none (symptom did not occur), mild (symptom occurred but did not interfere with usual activities), moderate (occurrence of symptom somewhat interfered with usual activities), or severe (occurrence of symptom resulted in an inability to perform usual activities).

Other covariates

Data collection on other covariates occurred during screening (baseline) and during each feeding period. BP measurements were taken from the right arm of participants while in a seated position. Using height and weight measurements, body mass index (BMI) was derived. Urine collected over a 24-hour period was used to determine urine sodium levels.

Statistical analysis

We characterized the demographic and clinical factors of the study population using proportions and means (SD). We used histograms to illustrate the distribution of the severity score. To evaluate the effect of sodium intake on bloating, we made comparisons between intermediate vs low sodium, high vs intermediate sodium, and high vs low sodium overall and by the assigned diet (DASH vs control). To evaluate the effect of diet on bloating, we made comparisons between the DASH vs control diet overall and by strata of sodium level (low, intermediate, and high). To evaluate the combined diet-sodium effects, we compared high sodium in the control diet vs low sodium in the DASH diet. We modeled the risk of any bloating using log-binomial models with a log link, binomial family, and an exchangeable covariance structure.

To assess effect modification of baseline covariates on the association between sodium intake and bloating, as well as between diet and bloating, we stratified analyses by age (<60, 60 years), sex (men, women), race (white, black), obesity (BMI ≥ 30 , <30 kg/m²), and hypertension (BP $\geq 140/90$, <140/90 mm Hg). We chose these categories *a priori* based on the distribution of baseline data (age) and established clinical cut points (BMI or hypertension). We used interaction terms to test for differences across strata. We performed all analyses using Stata/SE 14.0 (Stata Corporation LP, College Station, TX). We considered a *P* value of < 0.05 as statistically significant. Missing data were rare (19 of 809 visits or <3%) and evenly distributed across treatments.

RESULTS

Of the 412 trial participants, 204 were assigned to the control diet and 208 to the DASH diet. The demographic and clinical characteristics were similar in both groups (Table 1).

In Figure 1, we show the percentage of bloating at the end of the diet period according to the sodium intake level and assigned diet. The highest occurrence of bloating was in the high sodium group for both the control diet (34.8%) and the DASH diet (48.1%). The lowest occurrence of bloating was in the low sodium group for both the control diet (25.5%) and the DASH diet (39.9%).

The occurrence and severity of bloating by sodium level and diet are displayed in Table 2. At the high level of sodium intake, more participants experienced severe bloating in the DASH diet than in the control diet (8 vs 4; 4.0% vs 2.1%). At the intermediate level of sodium, there was no difference in severe bloating by diet (5 participants [2.5%] on each diet). At the low sodium level, 9 participants (4.5%) on the DASH diet vs 4 participants (2.1%) on the control diet reported severe bloating.

Overall, high vs low sodium intake increased the risk of experiencing bloating (risk ratio [RR] = 1.27; 95% confidence interval [CI]: 1.06, 1.52; *P* = 0.010) (Table 3). Regardless of the sodium intake level, the DASH diet vs the control diet increased the risk of bloating (RR = 1.41; 95% CI: 1.22, 1.64; *P* < 0.001). Although there was no statistical evidence of a sodium-diet interaction on bloating (*P* for interaction = 0.55), we present the stratum-specific effects, according to strata of the other factor, in Table 3.

The effects of high vs low sodium intake and diet on bloating were also investigated through a stratified analysis by age, sex, race, BMI, and hypertension, but no interactions were found (Figure 2).

In another stratified analysis by age, sex, race, BMI, and hypertension, the effects of the DASH diet vs the control diet averaging over all sodium levels were analyzed (Figure 3). The one significant diet interaction found was sex. Men experienced over 2 times the risk of bloating on the DASH vs the control diet (RR = 2.04; 95% CI: 1.53, 2.73), whereas bloating in women was not significantly affected by the diet (RR = 1.16; 95% CI: 0.98, 1.37; *P* for interaction = 0.001).

DISCUSSION

In the DASH-Sodium trial, higher sodium intake and the high-fiber DASH diet increased bloating in additive fashion. The effects of sodium on bloating were consistent by diet (DASH vs control), and the effects for diet were similar across levels of sodium intake. The risk of bloating was similar for those consuming the low-fiber control diet at the high sodium level vs the high-fiber DASH diet at the low sodium level. The effect of the DASH diet on bloating was greater in men than in women.

Our findings on dietary sodium and bloating are largely consistent with another trial, which found that oral administration of sodium bicarbonate increased bloating in participants (18), and they are consistent with the biological effects of sodium on the gut. Higher sodium intake can promote water retention and suppress digestive efficiency, which can lead to bloating (19-22). In addition, rodent studies have shown that dietary sodium can change the composition of the gut microbiota, which could also increase bloating (23). Recent research has found that in both rodents and humans, a high-salt diet is associated with diminished abundance of *Lactobacillus* spp. in the gut (24). In a recent trial, Riezzo et al. (25) demonstrated that administration of *Lactobacillus* spp. in patients led to a significant improvement in intestinal symptoms, including bloating, constipation, and abdominal discomfort. Thus, it is plausible that the composition of the gut microbiome can mediate the effect of sodium on bloating, which is also supported by a recent review article by Li et al. (26).

Our finding of a high-fiber DASH diet causing more bloating than the low-fiber control diet is consistent with smaller studies showing that dietary fiber content influences gas production and retention (8,12,27-30). One trial involving 5 participants examined the effects of fiber on gas production and found that increased dietary fiber led to increased gas production (27). In a trial with 12 participants where gastric emptying was measured through real-time ultrasound, Bergmann et al. (28) found that increased dietary fiber led to delayed gastric emptying. As part of a separate trial, physiologic gas was jejunally infused into 10 healthy volunteers, and it was found that a high-fiber diet hindered intestinal transit by reducing bolus propulsion to the rectum (12). Finally, in a trial consisting of 63 participants, Ho et al. (30) found that consuming a high-fiber diet resulted in significantly more bloating than consuming a low- or no-fiber diet. High-fiber diets increase gas production through the fermentation of fiber by gut bacteria and promote gas retention by impeding intestinal gas transit (12,27,31).

On the DASH vs the control diet, men experienced more bloating than women. There is growing research that the gut microbiome differs by sex (32-37), which could lead to a difference in the processing and fermentation of dietary fiber in men vs women. In fact, one study found that women had a significantly lower abundance of Bacteroidetes in their gut microbiome than men (34). The *Bacteroides* genus (phylum: Bacteroidetes) has been found to be capable of metabolizing and fermenting many different types of fibers and glycans (38,39). Bacterial fermentation in the gut is known to lead to GI side effects such as bloating (40-43). Furthermore, another study found that dietary fiber supplementation in men increased the relative abundance of Bacteroidetes bacteria (44). Therefore, it is plausible that

consuming the high-fiber DASH diet vs the low-fiber control diet may have modified the gut microbiota differently by sex.

There are several limitations to our study. First, bloating was not the primary outcome of the DASH–Sodium trial, but rather a secondary outcome. The presence and severity of bloating symptoms experienced was based on a single question. The question asked participants the extent to which they felt “bloating/uncomfortably full,” which could result in variable interpretations for different individuals. Second, each feeding period for each sodium intake level lasted 4 weeks; although we expect effects to be applicable beyond 4 weeks, the design of this trial did not permit an assessment of long-term effects. Third, some of the bloating effects from the DASH diet may have been secondary to mass effects. That is, to be isocaloric, the total mass of food in those consuming the DASH diet may have been greater than in those consuming the control diet, contributing to the finding that those consuming the DASH diet experienced more bloating in the trial than those consuming the control diet. Fourth, because the trial had a crossover design, there is the possibility of a carryover effect from the previous period. However, we expect the carryover effects in our trial were negligible, if there were any, given the intervention periods lasted a maximum of 30 days with a 5-day washout period between interventions, which left about 30–35 days between the assessments of symptoms. In addition, the order of the intervention (low to high vs high to low sodium) yielded similar findings. Last, there was a relatively limited range of sodium intake because those in the high sodium group actually followed the average sodium intake in the United States, which could underestimate our results regarding the relationship of high sodium intake with abdominal bloating.

Our study also has several strengths. First, the study design allowed for a test of the effects of both diet (DASH and control) and sodium levels. Second, the trial was rigorously implemented with high levels of adherence and follow-up. Third, the study population enrolled a racially diverse, noninstitutionalized, cohort of middle-to-older aged men and women. Therefore, we believe these results to be applicable to the general, ambulatory population of U.S. adults.

Our findings have important clinical ramifications. Millions of U.S. adults visit health practitioners because of GI diseases, with bloating as one of the most common symptoms, reported by anywhere from approximately 15%–30% of the general population (3,40,45,46). Sodium intake in the United States is quite high (3,4,10) and is an unrecognized cause of bloating. Beyond the cardiovascular benefits of lowering sodium, our study demonstrates that lowering sodium intake can also improve GI bloating. This is meaningful for the general population and should be evaluated in subgroups with more pronounced and regular GI bloating.

Our results also show that although a high-fiber diet, such as the DASH diet, can increase the risk of bloating, decreasing sodium intake in such a diet may diminish some of these undesired effects. In fact, we showed that a high-fiber low-sodium diet does not cause significantly more bloating than a low-fiber high-sodium diet. This finding demonstrates that sodium reduction might improve compliance with a high-fiber diet, such as the DASH diet.

In conclusion, a high-fiber diet increased bloating symptoms, whereas sodium reduction lowered these effects. Sodium reduction represents an important dietary intervention to reduce bloating symptoms and could be used to enhance compliance with healthful high-fiber diets, such as the DASH diet. The mechanisms by which sodium intake and diet can influence bloating and related GI symptoms represent important areas for future research.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Study Highlights

WHAT IS KNOWN

- Bloating is one of the most common GI complaints.
- Dietary fiber and sodium have been hypothesized to increase bloating, but no rigorous randomized controlled trials have investigated these factors.

WHAT IS NEW HERE

- Higher sodium intake increased bloating in a dose-dependent manner, regardless of the diet.
- Even at the highest sodium level, participants consuming the control diet experienced less bloating than at baseline.
- One possible explanation is that the control diet at the highest sodium level still provided less sodium than participants' free-living diet before the feeding intervention.
- The high-fiber DASH diet also increased bloating compared with the control diet, with a greater effect in men than in women.

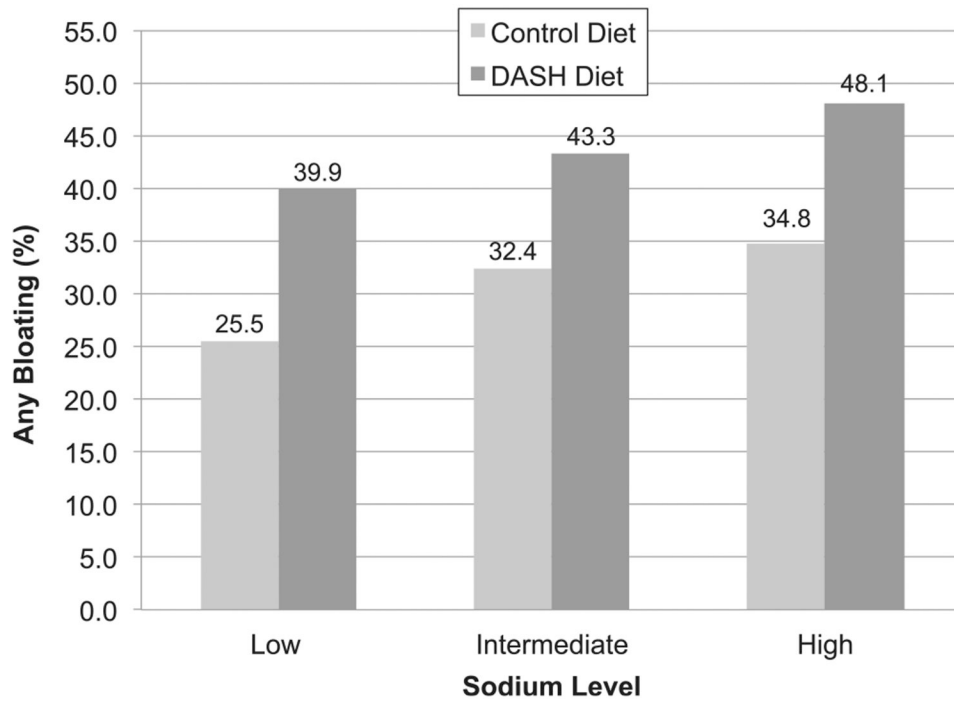


Figure 1.
Bloating by diet and sodium level.

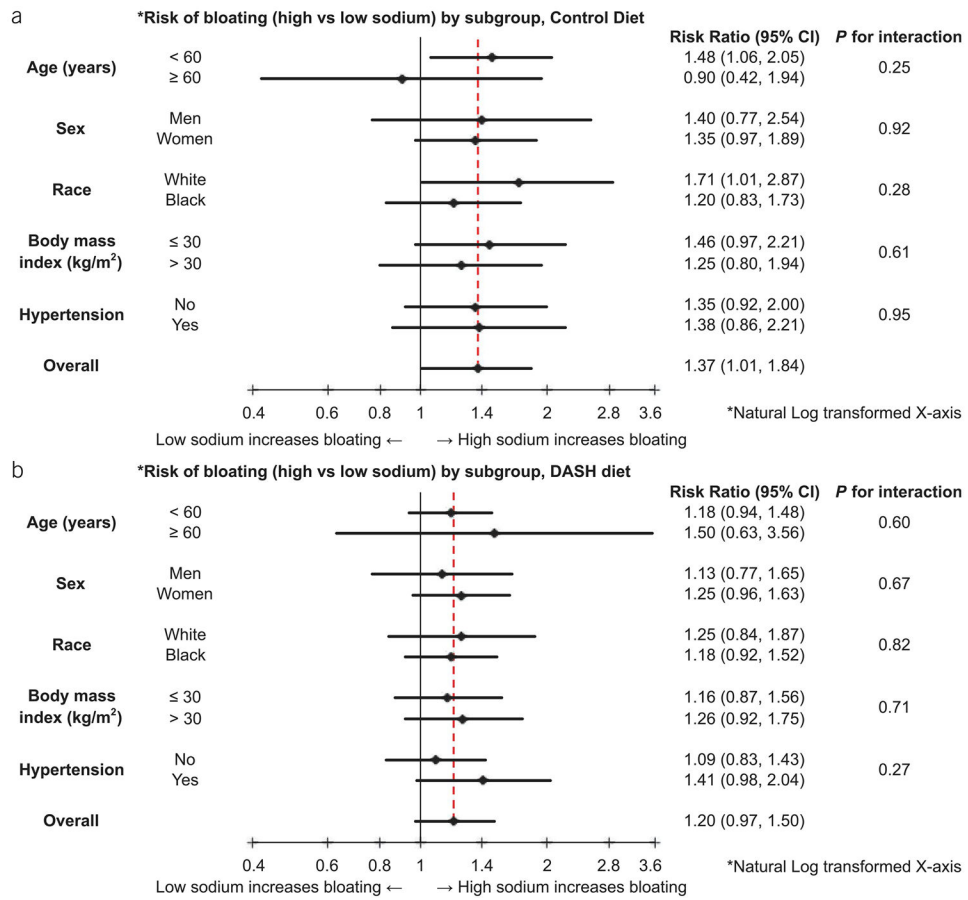


Figure 2. (a) Risk of bloating (high vs low sodium) by subgroup, in the control diet. (b) Risk of bloating (high vs low sodium) by subgroup, in the DASH diet. CI, confidence interval.

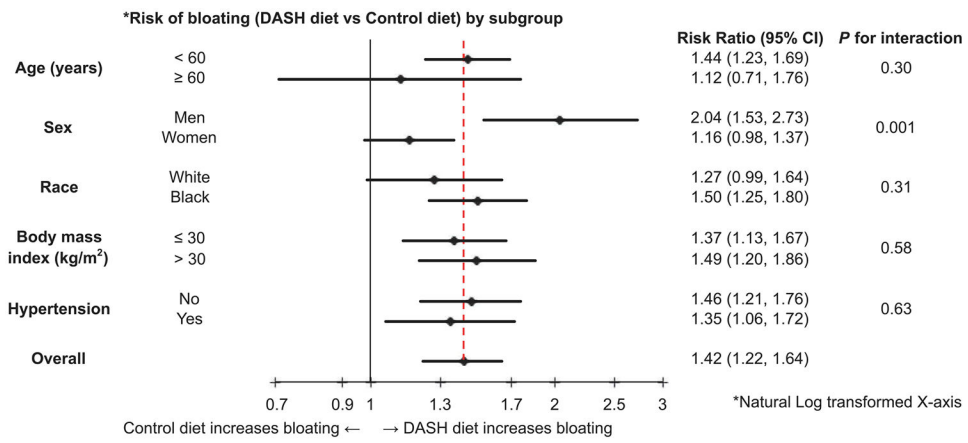


Figure 3. Risk of bloating (DASH diet vs control diet) by subgroup. CI, confidence interval.

Table 1.

Baseline characteristics overall and by diet

	Overall (N = 412)	Control diet (N = 204)	DASH diet (N = 208)
Age, yr (SD)	48.2 (10.0)	49.1 (10.4)	47.4 (9.6)
Women, %	56.8	54.4	59.1
Black, %	56.8	56.4	57.2
Hypertension ^a , %	40.8	40.7	40.9
Blood pressure, mm Hg			
Systolic (SD)	134.8 (9.5)	135.4 (9.4)	134.2 (9.6)
Diastolic (SD)	85.7 (4.5)	85.8 (4.1)	85.6 (4.8)
BMI, kg/m ² (SD)	29.2 (4.8)	29.5 (5.0)	28.8 (4.7)
BMI 30, %	38.8	40.2	37.5
Urinary sodium ^b , mmol/d (SD)	155.03 (75.4)	152.5 (71.8)	157.6 (78.9)
Any bloating, % ^c	36.7	39.2	34.1

BMI, body mass index.

^aDefined in the trial as a systolic blood pressure ≥ 140 mm Hg or diastolic blood pressure ≥ 90 mm Hg.

^bN = 408 (Control Diet, N = 204; DASH Diet, N = 204).

^cObtained at the end of run-in on the control diet, prerandomization.

Table 2.

Occurrence and severity of bloating by sodium diet and level, n (%)

	Mild	Moderate	Severe
Level of sodium			
Low			
Control (n = 194)	37 (19.1)	11 (5.7)	4 (2.1)
DASH (n = 200)	50 (25.0)	24 (12.0)	9 (4.5)
Intermediate			
Control (n = 197)	41 (20.8)	20 (10.2)	5 (2.5)
DASH (n = 200)	62 (31.0)	23 (11.5)	5 (2.5)
High			
Control (n = 195)	51 (26.2)	16 (8.2)	4 (2.1)
DASH (n = 201)	63 (31.3)	29 (14.4)	8 (4.0)

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Table 3.

The effects of sodium intake and diet on the occurrence of bloating

	Bloating	
	RR (95% CI)	P
Sodium effects		
Sodium effects overall ^a		
Intermediate vs low sodium	1.16 (0.96, 1.39)	0.127
High vs intermediate sodium	1.10 (0.93, 1.30)	0.286
High vs low sodium	1.27 (1.06, 1.52)	0.010
Sodium effects on the control diet ^a		
Intermediate vs low sodium	1.27 (0.93, 1.73)	0.128
High vs intermediate sodium	1.08 (0.82, 1.41)	0.600
High vs low sodium	1.37 (1.01, 1.84)	0.042
Sodium effects on the DASH diet ^a		
Intermediate vs low sodium	1.08 (0.86, 1.36)	0.487
High vs intermediate sodium	1.11 (0.90, 1.37)	0.326
High vs low sodium	1.20 (0.97, 1.50)	0.095
Diet effects (DASH vs control)		
Low sodium	1.57 (1.17, 2.09)	0.002
Medium sodium	1.34 (1.04, 1.72)	0.024
High sodium	1.38 (1.09, 1.75)	0.007
All sodium levels	1.41 (1.22, 1.64)	<0.001
Combined effects		
High sodium in the control diet vs low sodium in DASH diet	0.87 (0.68, 1.12)	0.287

CI, confidence interval; RR, risk ratio.

^aA test for a diet-sodium interaction was nonsignificant, $P=0.55$.